Genetic algorithm approach for solving multi-objective facility layout problem

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Although several schemes for solving the facility layout problems by genetic algorithms are available in the literature, none of them deal with multi-objective of the identical Facility Layout Problem (FLP) that resolve the problem of inconsistant scales and diferent measurment units. This paper is concerned with the application of the technique of Genetic Algorithm (GA) to solve the above-mentioned points. Computational results show that the proposed GA is an efficient approach for obtaining good quality solutions.

برغم وجود طرق عديدة لحل مشكلة تنظيم التسهيلات باستخدام الخوارزمات الوراثية ، لا يوجد منها ما يتعامل مع مشكلة تخطيط التسهيلات متعددة الأهداف متغلبا بذلك على تضارب المعايير و اختلاف الوحدات. في هذا البحث، تم تناول مشكلة تنظيم التسهيلات متعددة الأهداف باستخدام خوارزم وراثي مع الأخذ فى الأعتبار ما ذكر سالفا. و قد بينت النتائج أن الخوارزم الوراثي المقترح طريقة فعالة للحصول على حلول جيدة.

Keywords: Multi-objective, Facility layout problem, Genetic algorithm, Quadratic assignment problem

1. Introduction

The facility layout problem deals with finding the most effective physical arrangement of facilities, human resources, and any resources required to facilitate the production of goods and services. It has attracted the attention of many researchers because of its practicality and interdisciplinary importance. The production function of a manufacturing system is significantly affected by the layout of its manufacturing shop. While a well designed layout can considerably improve the efficiency of the shop, a poor one can lead to increased Work-In-Process (WIP), overloading the material handling system and contribute to inefficient set-ups, longer queues, etc. [1]. Material handling and layout related costs have been estimated to be about 20%-50% of the operating expenses in manufacturing [2]. Historically, two basic approaches have most commonly been used to generate desirable layouts: a qualitative one and a quantitative one.

Qualitative approaches used the closeness relationship to determine the layout based on the maximization function of the subjective ratings for system departments. The subjective closeness ratings are; A (absolutely necessary), E (essentially important), I (important), O (ordinary), U (un-important) and X (undesirable), to indicate the respective degrees of necessity that any two given departments be located close together. Layout designers may assign numerical values to these ratings. [3-6] have developed algorithms based on numeric values for qualitative criteria to obtain final layouts.

Quantitative approaches involve primarily the minimization of material handling costs between facilities. One of the commonly used model was the quadratic assignment problem (QAP) formulation for assigning n facilities to n mutually exclusive locations. Exact algorithms for solving the QAP include branch and bound technique which has been used by [7-10] and cutting plane technique which has been developed by [11-12]. The QAP formulation belongs to the class of NP-complete problems [13], and non of the solving methods can arrive at an optimal solution in a reasonable time for 15 or more facilities problem. Consequently, many heuristic algorithms have been developed for achieving a trade-off between computation time and the efficiency of the final solution [14] and our proposed approach is also a heuristic one.

Many researchers are seeking about the appropriateness of a single criterion objective to solve the facility layout problem through qualitative and quantitative approaches. The major drawbacks of these approaches lie in the fact that the search for the best layout is not very efficient and they do not consider the multi-objective nature of the problem [15]. In real life, the facility layout problem must consider quantitative and qualitative criteria and this falls into the category of the Multi-Objective Facility Layout Problem (MOFLP). In this aspect, and [16-23] all developed QAP formulations by specifying different objective weights to generate the best layout. Two inadequacies exist in these approaches where all factors are not represented on the same scale and measurement units used for objectives are incomparable.

[24] developed a heuristic approach to overcome the above-mentioned inadequacies by reasonably normalizing all objectives of the MOFLP, and handling qualitative and quantitative information in similar fashion. In the current paper, GA for solving the MOFLP using Chen and Sha's formulation is applied.

2. Past approaches

The QAP formulation of the MOFLP is shown in eqs. (1) to (4):

$$Min.: Q = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sum_{l=1}^{M}\sum_{k\neq l}^{M} A_{ijkL} X_{(i,l)} X_{(j,k)}, \tag{1}$$

subject to:

$$\sum_{v=1}^{M} X_{(u,v)} = 1 \qquad \forall\ u = 1,2,\ldots,N, \tag{2}$$

$$\sum_{u=1}^{N} X_{(u,v)} \leq 1 \qquad \forall\ v = 1,2,\ldots,M \ \ and \tag{3}$$

$$X_{(u,v)} = 0 \ \ or \ \ 1 \quad for\ all\ \ u,v \tag{4}$$

Where

$$X_{(u,v)} = \begin{Bmatrix} 1 & if\ facility\, u\, is\, asssigned\, to\, location\, v \\ \\ 0 & otherwise, \end{Bmatrix}$$

A_{ijkL} is the cost of locating facility i at location l and facility j at location k.

A_{ijkl} in eq. (1) is a cost variable representing the combination of quantitative and qualitative measures in MOFLP models. Eq. (2) ensures that each location contains only one facility. Eq. (3) ensures that each facility is assigned to only one location. [24] mentioned, divided these models presented in previous studies into four categories:

1. [16,17] defined the cost term as:

$$A_{ijkl} = F_C C_{ijkl} - W_R R_{ijkl}, \tag{5}$$

where C_{ijkl} is the total material handling cost, R_{ijkl} is the total closeness rating score, and F_C and W_R are weights assigned to the total material handling cost and to the total rating score.

2. [18] defined the cost term as:

$$A_{ijkl} = F_{ij}\ \mathrm{D}_{kl}\ R_{ij}, \tag{6}$$

where F_{ij} is the work flow between two facilities, D_{kl} is the distance between two locations and R_{ij} is the closeness rating desirability of the two facilities.

3. [20, 21] defined the cost term as:

$$A_{ijkl} = (F_{ij} + CR_{ij})D_{kL}, \tag{7}$$

where C is a constant weight that determines the importance of the closeness rating to the work flow.

4. [25] defined the cost term as:

$$A_{ijkl} = (W_1 F_{ij} + W_2 R_{ij})D_{kL}, \tag{8}$$

where W_1 and W_2 are weights assigned to the workflow and to the closeness rating.

The listed models are similar in nature, and vary only in stating the relationship between the cost term A_{ijkl} and the quantitative and qualitative measures. Although, as [24] mentioned, these models have been applied to the MOFLP, they all have the cited two inadequacies. For this reason, [23] suggested an approach that normalizes all factors, before combining them. The following eqs. (9,10) are used for normalizing process and as an objective function.

$$T_{ikm} = \frac{S_{ikm}}{\sum_{a=1}^{N}\sum_{b=1}^{N} S_{abm}} \, . \tag{9}$$

Where S_{ikm} is the relationship value between departments i and k for factor m, and T_{ikm} is the normalized relationship value between departments i and k for factor m.

$$Min.\, Q = \sum_{i}^{N}\sum_{k}^{N}\sum_{j}^{N}\sum_{l}^{N} a_m T_{ikm} D_{kl} X_{ik} X_{jl} \, , \tag{10}$$

where α_m = is the weight for factor m.

[23] proposed a methodology for normalizing all factors into comparable units on the same scale. However, the scaling problem remains unresolved. Note first that values for work flow may range from zero to a very large positive value, while closeness rating values may range from a negative value to a positive value. [24] proposed an approach that normalize all factor, before combining them as shown in eq. (11):

$$H_f = \frac{\sum_{i}^{N}\sum_{k}^{N}\sum_{j}^{N}\sum_{l}^{N} S_{ijf} X_{ik} X_{jl} - M_f}{V_f^{1/2}} \, , \tag{11}$$

where,

S_{ijf} is the objective value of locating facility i at location k and facility j at location l for objective f. (f = 1,2,..., t),

Mf is the mean value of the layout cost distribution for objective f,

Vf is the variance of the layout cost distribution for objective f, and

Hf is the normalize value for objective f.

Both of V_f, and M_f are proposed by [26, 27]. This approach is based on minimization of Total Flow Cost (TFC) and minimization of Total Numerical Rating (TNR). The values obtained are then multiplied by weights W_f representing the relative importance of each objective. The resulting objective function is shown in eq. (12):

$$Min.\, Q = \sum_{f}^{t} W_f H_f \, . \tag{12}$$

3. Genetic algorithm

3.1. Overview of GAs

Genetic algorithms attempt to mimic the biological evolution process for discovering good solutions. They are based on a direct analogy to Darwinian natural selection and mutations in biological reproduction and belong to a category of heuristics known as randomized heuristics that employ randomized choice operators in their search strategy and do not depend on complete a priori knowledge of the features of the domain. A genetic algorithm maintains a collection or population of solutions throughout the search. It initializes the population with a pool of potential solutions to the problem and seeks to produce better solutions by combining the better of the existing ones through the use of one or more genetic operators. Theoretical analyses suggest that genetic algorithms can quickly locate high performance regions in extremely large and complex search spaces.

3.2. Chromosome representation

Chromosome representation maps feasible solutions of the problem. The effectivness of the crossover operator depends greatly on the representation scheme used. The representation should be such that the crossover operator preserves high performing partial arrangements of strings, and minor changes in the chromosome translate into minor changes in the corrosponding solution. For the problem under consideration, the cell assignment representation is used to represent the facilities layout as shown in fig. 1.

3	4	7
1	8	2
9	6	5

Fig.1. Chromosome:3,4,7,1,8,2,9,6,5

3.3. Initial population

The initial population of chromosome is generated randomly. For not generating illegal chromosome, each process of generating random gene (facility) checks the previous genes (facilities) which is once pick and choose a gene which has not been chosen before in the chromosome. This procedure makes each gene shown just once in a chromosome. This initialization keeps proceeding untill the number of chromosome reaches the pre-set population size.

3.4. Selection method

The selection criteria are used to select the two parents to apply the crossover operator. The appropriateness of selection method for a GA depends upon the other GA operators chosen. In the literature, a typical selection method gives a higher priority to fitter individuals since this leads to a faster convergence of the GA. In this aspect, the tournment selection is applied in order to control convergence speed by the tournment size.

3.5. Crossover operator

The crossover operation is a simple yet powerful way of exchanging information and creating new solutions. The Partially Mached crossover (PMX) operator is applied to generate two offsprings. The PMX operator starts as follows, at first two cut points are chosen at random for the parents. Then the genes of the father string bounded by the cut points will be copied to the same positions of the first offspring, and the remaining genes of the offspring will be filled up by the mother string in the same order. In case of the offspring will be illegal because of possibilities of repeated genes, the repeated genes will be replaced by genes corresponding to the mapping of the father and mother spring bounded by the cut points. The second offspring is generated by the same manner but it use the mother genes inside the cut points, and the remaining genes are filled up by the father string in the same order. Fig. 2 shows the PMX method to generate feasible solutions.

3.6. Mutation operator

If the entire population has only one type of spring, then the crossover of two strings does not produce any new strings. To escape from this scenario, the mutation operator is used. The mutation operation is applied with a probability (Pm), to swap every allele (gene) and randomly selected allele. For example, chromsome 1,5,6,3,4,2 may be change to 1,3, 6,5,2,4.

3.7. Reproduction system

The generation-based system is used. That is, λ offsprings from μ parents are produced and the best μ chromosome of $(\lambda + \mu)$ are retained.

3.8. Evaluation function

The objective function used to evaluate the solutions. (i.e. eq. (12)).

				Cut points					
The father	2	4	5	3	8	9	6	1	7
The mother	3	9	8	6	5	4	2	7	1
First offspring	3	9	8	3	8	9	2	7	1
Second offspring	2	4	5	6	5	4	6	1	7
Legal 1st offspring	6	5	4	3	8	9	2	7	1
Legal 2nd offspring	2	3	8	6	5	4	9	7	1

Fig. 2. PMX crossover method.

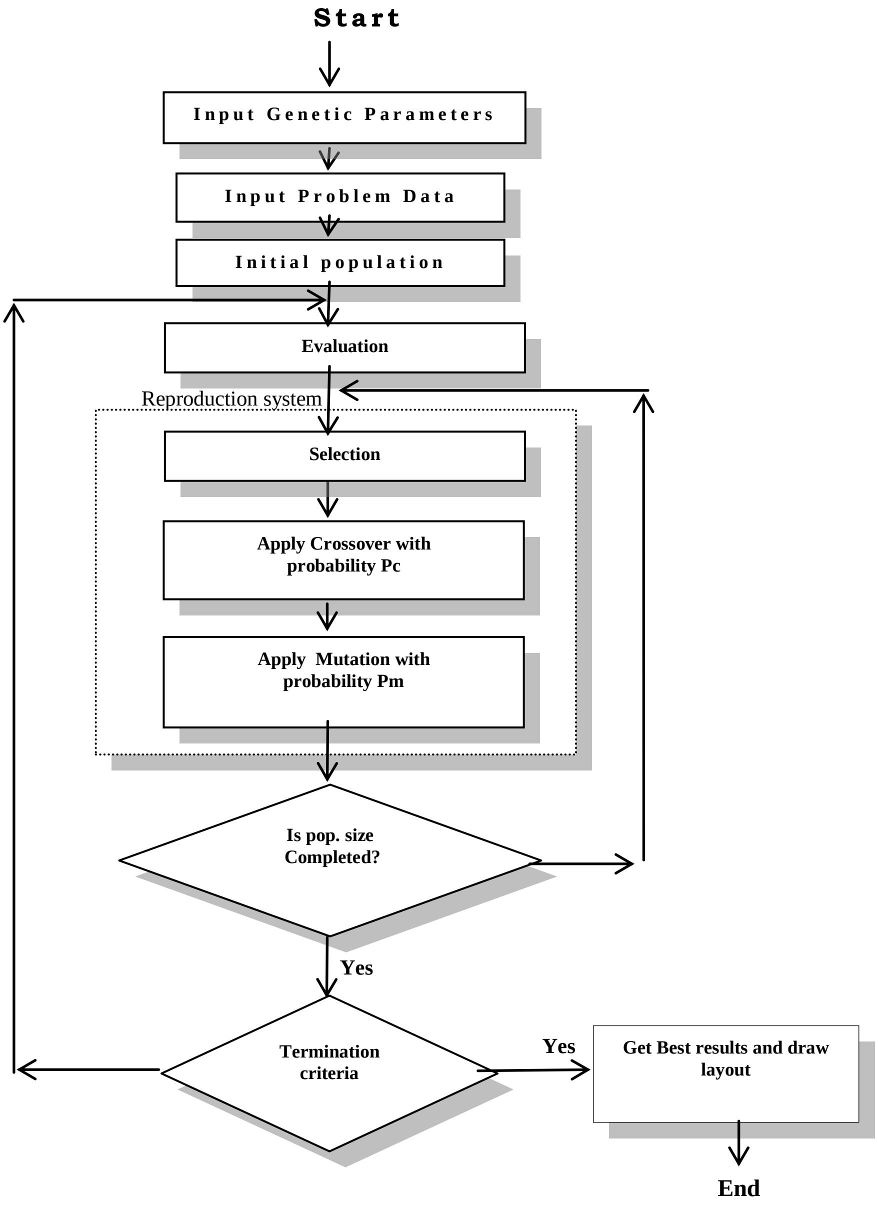

Fig. 3. Genetic algorithm search procedure for MOFLP.

3.9. Stop criteria

The GA is stopped when the number of iterations equal to the maximum iteration number (max.Iter) or when a certain fittness value has been achieved.

3.10. Flow chart for the proposed GA

Fig. 3 shows a genetic algorithm search procedure for MOFLP.

4. Performance evaluation

The proposed method is evaluated using two standard criteria. One is computation time, and the other is the quality of solution. In the current paper a comparison with procedure [24] using the four test problems in their paper is considered. Further comparisons are made with eight test problems [27] solving with other heuristic methods.

4.1. Comparison with Chen and Sha's procedure

[24] have shown the superiority of their procedure over previous algorithms presented by and [23, 16, 17, 18, 20]. Therefore, in the current work the comparison was made with the results obtained by [24] All layouts for each weight combination generated by the proposed approach were listed and scores were compared. These results are shown in tables 1 and 2. Table 1 summarize the results for the 8-department, 12-department and 15-department problems; and show that the proposed algorthim provide the same quality solution. In table 2, the results for 20-department problem are summarized and show that the proposed algorthim is capable of obtaining good-quality solutions.

4.2. Common test problems

In the aim of robustness of the effectiveness of the proposed algorithm, another important comparison was made with other published heuristic approaches to the eight commonly used test problems proposed in [27]. For single-objective problems, the solutions were obtained by setting the value of the qualitative weight equal to 0. Comparisons were made in terms of the quality of the solutions obtained and the computation time required. With respect to the solution quality, [14] took it as $(OV \times 100)/LB$, where OV is the objective value and LB is the lower bound as given by [27]. Thus, the lower the value of the solution quality measure, the better the solution. The proposed genetic algorithm is applied 10 times for each test problem. The comparison results are shown in tables 3 and 4. Table 3 gives a comparison of the quality for the best solutions obtained with these heuristic methods, and table 4 gives a comparison of the average solution quality obtained with these heuristic methods. As mentioned by [14], the computation time provided in table 4 cannot be directly used for comparison because the computation time for each of the algorithms depends on factors such as the programmer's efficiency, the computer system used, etc.

Table 1
Comparison of the best solution qualities for [24]

Wieghts		Problem size					
		8 facilities		12 facilities		15 facilities	
W1	*W2*	Scores for the *C+S*† layout	Scores for the proposed layout	Scores for the *C+S* layout	Scores for the proposed layout	Scores for the *C+S* layout	Scores for the proposed layout
1	0	-3.8730	-3.8730	-4.2233	-4.2233	-5.7751	-5.7751
0.9	0.1	-3.4312	-3.4312	-3.7797	-3.7797	-5.0971	-5.0971
0.8	0.2	-3.0038	-3.0038	-3.4235	-3.4235	-4.4392	-4.4392
0.7	0.3	-2.6113	-2.6113	-3.1550	-3.1550	-4.1012	-4.1012
0.6	0.4	-2.2188	-2.2188	-3.0986	-3.0986	-4.0121	-4.0121
0.5	0.5	-2.0705	-2.0705	-3.1647	-3.1647	-3.9556	-3.9556
0.4	0.6	-2.0199	-2.0199	-3.3025	-3.3025	-3.9674	-3.9674
0.3	0.7	-2.2302	-2.2302	-3.4403	-3.4403	-4.3027	-4.3027
0.2	0.8	-2.5735	-2.5735	-3.7008	-3.7008	-4.7276	-4.7276
0.1	0.9	-2.9899	-2.9899	-4.0271	-4.0271	-5.2320	-5.2320
0	1	-2.4063	-2.4063	-4.4277	-4.4277	-5.8092	-5.8092

†*C+S* is a symbol representing [24]
Note: Problem size n=8 (area limited to two rows and four columns).
Problem size n=12 (area limited to three rows and four columns).
Problem size n=15 (area limited to three rows and five columns).

Table 2
Comparison of the best solution qualities for the 20-department test problem in Chen and Sha [24]

Weights W1	Weights W2	Scores for C+S layout	Scores for the Proposed layout	Proposed layout					Improvement (%)
1	0	-5.6513	-5.7265	18	5	19	15	12	1.313193♀
				13	17	2	8	3	
				16	7	1	10	14	
				20	11	4	6	9	
0.9	0.1	-4.9734	-5.042	18	5	19	15	12	1.360571
				13	17	2	8	3	
				16	7	1	10	14	
				20	11	4	6	9	
0.8	0.2	-4.5214	-4.6264	8	11	4	6	20	2.269583
				16	7	1	10	18	
				17	2	14	19	5	
				13	9	3	15	12	
0.7	0.3	-4.3692	-4.4234	13	16	7	9	8	1.225302
				17	2	14	3	11	
				19	10	1	4	6	
				5	18	12	15	20	
0.6	0.4	-4.3766	-4.399	5	15	19	17	13	0.509207
				18	12	10	2	3	
				11	4	1	14	16	
				20	6	9	7	8	
0.5	0.5	-4.5022	-4.5843	8	16	3	13	17	1.790895
				6	7	9	2	15	
				11	1	10	14	19	
				20	4	12	18	5	
0.4	0.6	-4.8599	-4.8599	8	13	3	7	17	0
				6	16	9	2	15	
				11	12	14	10	19	
				20	4	18	1	5	
0.3	0.7	-5.2405	-5.3521	5	10	1	18	4	2.085163
				19	2	14	11	20	
				17	9	16	12	6	
				15	7	3	13	8	
0.2	0.8	-5.8506	-5.9017	5	10	1	18	4	0.865852
				19	2	14	11	20	
				17	9	16	12	6	
				15	7	3	13	8	
0.1	0.9	-6.4512	-6.4687	8	3	17	7	15	0.270533
				6	16	12	9	19	
				20	13	14	2	10	
				4	11	18	1	5	
0	1	-7.0729	-7.1091	8	3	17	7	15	0.509207
				6	16	12	9	19	
				20	13	14	2	10	
				4	11	18	1	5	
Average improvement									1.109

Note: Problem size n=20 (area limited to four rows and five columns).
♀Improvement=-5.7265-(-5.6513)/-5.7265=1.313193%.

Table 3

Comparison of the best solution qualities for the eight test problems in Nugent et al. [27]

Problem size (n)	H63	H63-66	CRAFT	Biased Sampling	Tsp	Flac	STEP	Proposed approach	Best known
5	100.0	100.0	100.0	100.0	100.0	100.0	104.0	100.0	100.0
6	104.5	104.5	104.5	104.5	104.9	104.9	112.2	104.5	104.5
7	114.9	110.4	110.4	110.4	110.5	110.4	110.4	110.4	110.4
8	119.8	117.6	117.6	117.6	117.6	117.6	122.0	117.6	117.6
12	123.9	125.1	118.9	118.9	118.9	118.9	118.9	118.9	118.9
15	125.8	120.7	121.7	120.0	122.1	122.1	123.6	120.0	120.0
20	136.5	130.1	130.6	128.6	127.9	128.5	129.9	126.7	126.7
30	145.0	141.2	140.7	138.2	137.9	137.6	139.2	137.6	136.8
Computer system	GE 265	GE265	GE265	GE265	ICL 470	IBM 4341	VAX 6000	PENTIM1 -233MMX	

Notes: Results for H63, H63-66, CRAFT, biased sampling were obtained from nugent et al. [27].

Results for STEP were obtained from[28].

For n<20, the best known results (n=5 : 8)are global optimal solutions obtained from nugent et al.[27] the best known results (n=12, 15) are obtained from [29] and the best known results (n=20, 30) were obtained from [12].

5. Conclusions

In this paper, a genetic algorithm to tackle and resolve the multi-objective facility layout problem is presented. It incorporates qualitative and quantitative objectives and resolves the problem of inconsistent scales and different measurement units. The proposed genetic approach seems simple, applicable and computationally efficient. It is optimistic that the proposed approach will be helpful in assisting layout planners select good-quality solutions to practical facility layout problems. In this paper only departments of equal area are considered. In future research, MOFLPs for unequal-area departments will be considered. The comparisons verified that the proposed procedure provides acceptable suboptimal solutions in reasonable amount of computing time, and the rendered solutions are better than those provided by other heuristic methods, or are at least as good.

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Table 4
Comparison of the average solution qualities for the eight test problems in Nugent et al. [27]

Problem size (n)	H63 Solution quality	H63 CPU time (sec)	H63-66 Solution quality	H63-66 CPU time (sec)	CRAFT Solution quality	CRAFT CPU time (sec)	Baised sampling Solution quality	Baised sampling CPU time (sec)	FATE Solution quality	FATE CPU time (sec)	Proposed method Soluti on quality	Proposed method CPU Time (sec) Mean	Proposed method CPU Time (sec) Std.	Best known solution quality
5	110.4	6	117.6	10	112.8	1	107.2	11	104.0	2.8	100.0	0	0	100.0
6	107.8	7	107.8	9	107.8	2	106.3	21	123.4	2.4	104.5	0.03	0.02	104.9
7	117.6	15	117.0	12	118.8	5	111.6	57	116.4	3.1	110.4	3.08	0.23	110.4
8	125.7	14	121.1	14	124.6	10	117.6	109	139.2	3.3	117.6	4.25	0.92	117.6
12	130.6	55	127.7	19	121.9	70	120.6	658	134.3	4.8	119.9	5.25	0.68	118.9
15	132.1	78	125.3	40	126.5	160	121.1	2192	138	6.1	121.4	25.1	7.34	120.0
20	138.1	168	132.6	75	132.1	528	129.4	6915	141.6	11.9	129.4	78.2	21.63	126.7
30	146.1	398	143.3	285	142.5	3150	139.6	4224	151.5	32.4	141.6	177.3	72.58	136.8
Com-puter sys.	GE265		GE265		GE265		GE265		ICL1903T		P1-233MMX			

Results for H63, H63-66, CRAFT and biased sampling were from nugent et al. [27]
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