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A Simulated Annealing Optimization Algorithm for Equal and Un-equal Area Construction Site Layout Problem

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A B S T R A C T

Construction Site Layout Planning (CSLP) is an important problem because of its impact on time, cost, productivity, and safety of the projects. In this paper, CSLP is formulated by the Quadratic Assignment Problem (QAP). At first, two case studies including equal and un-equal area facilities are solved by the simulated annealing optimization algorithm. Then, the obtained results are compared with the other papers. The comparisons show that the proposed Simulated Annealing (SA) is as efficient as ACO, PSO, CBO, ECBO, WOA, WOA-CBO, and ACO-PA which have been proposed by other papers for the same problems. As a result, the comparisons show that SA is as capable as other meta-heuristics of solving the combinatorial optimization problems like CSLP, while the hardware properties and computational times have been compared. Besides the comparisons, the design of experiments shows the relationship between each SA parameter and the computational time of the algorithm. Also, the history of convergence of the proposed SA indicates the high speed of reaching the optimal solution and the artificial intelligence of the proposed SA.

Keywords: Construction project, Construction site layout planning, Quadratic assignment problem, Simulated annealing.

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1. Introduction

Problems which are related to construction projects consist of engineering design, cost estimation, planning, scheduling, and monitoring and control. Among these problems, planning is one of the most important phases because of its effect on time, cost, productivity, and safety of the projects. Furthermore, one of the most considerable cases in the planning stage is the site/floor layout [1]. Site layout or Construction Site Layout Problem (CSLP) deals with the determination of the locations of site-level facilities while considering the constraints of the project [2].

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Locations of the facilities of CSLP can be modeled in two ways, discrete and continues. By discrete modeling, in which locations are represented as a single point or multiple points in a grid system, the computational complexity of the problem is getting lower. On the other hand, locations of continues modeling are not limited by distinct points, instead, they can be located in every place of the site. Also, in the discrete mode, if locations are considered predetermined and equal to the number of the facilities, the problem can be formulated by Quadratic Assignment Problem (QAP) - one of the hardest problems of operations research field - with assignment of one facility to each location exactly [3].

In the literature, CSLP had been investigated by many researchers over many years because of its important role in construction projects. By the review papers [4 and 5], the classification of CSLP, types of site space modeling, types of site layout objects, time dimension, types of objective functions, and optimization techniques were presented to solve the problem. Based on this mentioned classifications, the features of our paper problem is determined by sign × as it is given in Table 1. In Table 1, by predetermined location for site space, it means the locations considered for facilities are determined before and they are fixed. By dimensionless site objects, it means the dimensions of the facilities are considered one-dimension and as a geometry representation; they are just points. Static time means there is no change for material flows and the locations of the facilities are determined only one time. The goal of the objective function is about productivity because we consider the minimization of the material flow products distances between locations. Finally, the solution method of this paper is a meta-heuristics algorithm – simulated annealing.

Table 1. The features of the problem of our paper.

Site space			Site objects			Time dimension			Goals			Solution technique		
Predetermined	Grid system	Continuous	Dimensionless	Approximated	Actual	Static	Phased	Dynamic	Productivity	Safety	Security	Exact	Heuristics	Meta-heuristics
×			×			×			×					×

After determining the properties of the problem of the current paper, comparisons between this article and other papers of the various scientific databases are performed to distinguish the gap of studies, which had been done before (Table 2). In fact, in Table 2, the papers which are close to our modeling are shown. These papers are modeled by predetermined locations, dimensionless objects at the static time, and with the goal of productivity and solution of meta-heuristic algorithms.

Table 2. References of the various scientific databases related to CSLP.

Ref.	Site space	Site objects	Time	Goals	Optimization technique
[6]	Predetermined	Dimensionless	Static	Productivity	ANN
[3]	Predetermined	Dimensionless	Static	Productivity	GA
[7]	Predetermined	Dimensionless	Static	Productivity	GA
[8]	Predetermined	Dimensionless	Static	Productivity	GA
[9]	Predetermined	Dimensionless	Static	Productivity	GA
[10]	Predetermined	Dimensionless	Static	Productivity	GA
[11]	Predetermined	Dimensionless	Static	Productivity	PSO
[12]	Predetermined	Dimensionless	Static	Productivity	PSO
[13]	Predetermined	Dimensionless	Static	Productivity	ACO
[14]	Predetermined	Dimensionless	Static	Productivity	ACO-PA
[15]	Predetermined	Dimensionless	Static	Productivity	PSO-CBO-ECBO

As it is shown in Table 2, GA is one of the popular optimization techniques that are used in the literature of CSLP. Now, we can state our motivation of this paper by the performed comparative study. In fact, by solving the numerical examples presented in each of these papers by our proposed technique, not only optimization algorithms can be compared with each other, but also the efficiency of the proposed algorithm to solve the various examples of CSLP can be shown. Moreover, CSLP with the class of problems, which are shown in Table 1, have never been solved by Simulated Annealing (SA) optimization algorithm which is the optimization technique of this paper. In the other words, in this paper, we are going to evaluate the SA parameters statistically by Design of Experiments (DOE) in order to investigate the relationship among SA parameters and the computational time of CSLP and the quality solution of the problem.

The main purpose of this article is to show the efficiency of SA algorithm of a solution of the combinatorial optimization problems like CSLP problem which is modeled by QAP formulation. In the following, in Section 2, SA is introduced briefly. In Section 3, the methodology of problem-solving based on SA is proposed. Next, in Section 4, the sample examples are solved and the results obtained by the proposed algorithm are compared with others' findings. Finally, in the last section, conclusions have been mentioned.

2. Simulated Annealing Optimization Algorithm

SA was introduced first time by [16] in 1983, and its capability of dealing with the combinatorial optimization problems has been proven [17]. SA starts with a random or greedy solution, and then by calculating the objective function, it decides to accept the better solution or accept the worse solution by a probability. This probability is one the specific features of SA which allows the algorithm to search the more space of solutions in order not to trap in the local solution. Like the other meta-heuristics, the parameters of SA must be set to proper values [18].

3. Optimization of Construction Site Layout Problems using SA

3.1. Problem Definition

The construction site can be explained as the main building in which the goal of construction is to construct. This main building will be erected by using different facilities which will be located in the proper places around the main site. The determination of these locations of the facilities is the layout planning of the construction site. In other words, as a mathematical approach, CSLP can be formulated by QAP, which we want to detect the proper locations for the facilities. The case study with equal area facilities investigated in this paper is taken from [3], in which there are 11 facilities that have to be located in 11 predetermined locations in order to minimize the total travel distances among facilities. These 11 facilities are listed below:

- Site office.
- Falsework workshop.
- Labor residence.
- Storeroom 1.
- Storeroom 2.
- Carpentry workshop.
- Reinforcement steel workshop.
- Side gate.
- Electrical, water, and other utility control room.
- Concrete batch workshop.
- Main gate.

Total construction space, which has the predetermined locations and its plan, is outlined in Figure 1. Also, the assumptions of this case study can be listed below:

- All of the locations have the permission to accommodate each facility.
- Locations are predetermined, and distances between locations had been calculated before.
- The size of each facility is dimensionless.
- The time dimension is static.

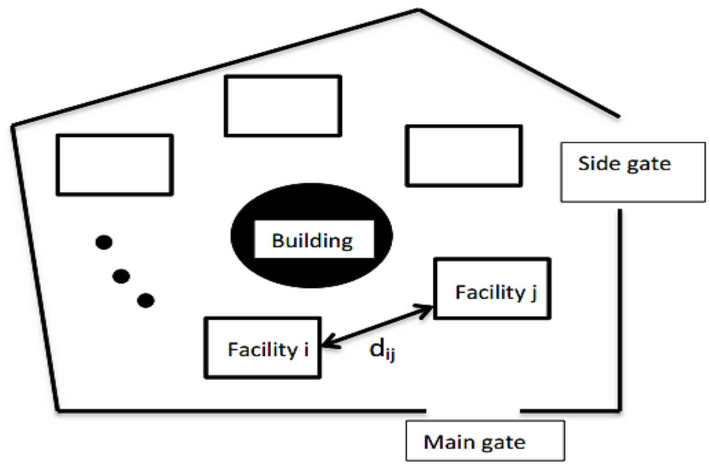

Figure 1. Construction site of the case study mentioned by [3].

Now the mathematical model for the CSLP is formulated as below:

$$Min\ z = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n}\sum_{k=1}^{n} x_{ik} * x_{jl} * f_{ij} * d_{kl} \tag{1}$$

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad \forall j = 1,2,\dots,n \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad \forall i = 1,2,\dots,n \tag{3}$$

$$x_{ij}\ \{0,1\} \qquad \forall i,j = 1,2,\dots,n \quad i \neq j \tag{4}$$

In this mathematical model, the objective function (1) is to minimize the total material flows among facilities products distances among locations. The notation x_{ij} is a binary variable (4), and it takes one if the facility i is allocated to location j. The notation f_{ij} indicates the frequency of the trips or flows between the facilities i and j per day. The notation d_{ij} indicates the distance between locations i and j, and if there are more than one available paths between 2 facilities, the shorter distance will be considered. Also, n is the number of facilities. It is noteworthy to say that in this model the number of locations should be equal to a number of facilities; otherwise, the “dummy” facilities with zero f and d will be added if the number of locations is more than the number of facilities. Moreover, constraints (2) and (3) control the assignment of only one facility to only one location.

3.2. Proposed SA

In this section, the optimization algorithm based on SA for CSLP is proposed. To solve the layout planning problem, the representation of solution space will be a permutation array in which 11 numbers are ordered in one arrow. For example, the first left number of the array will be an indicator of the first facility's location and so the other facilities' locations will be specified too. To clarify, one example of a representation of the solution space is shown in Table 3. Also, in Table 3, the solution space is just the second row, in which by changing the numbers of the locations, the solution space is searched along the feasible space. By this representation, which is indicated in Table 3, the process of searching solution space by the proposed algorithm will be fast. In this representation, the fixed facilities are considered easily by fixing the number of the fixed facility and are not permitted the other facilities to occupy those locations.

Table 3. Representation of the solution space of CSLP.

Facility	1	2	3	4	5	6	7	8	9	10	11
Location	3	5	1	8	7	2	11	10	6	4	9

In the following, the steps of the optimization algorithm based on SA are proposed.

Input. Cooling schedule

$s = s_0$ // the solution space is the permutation array of numbers 1 to 11

$t = 0$

$T_0 = T_{max}$

Repeat

$k = 0$

Repeat

Generate neighbor solution by changing the m pair locations randomly (for example for m =2)

1	2	3	4	5	6	7	8	9	10	11
3	5	9	1	2	7	8	4	11	10	6

1	2	3	4	5	6	7	8	9	10	11
3	5	4	1	6	7	8	9	11	10	2

$\Delta E = f(\acute{s}) - f(s)$

If $\Delta E \leq 0$ **then** $s = \acute{s}$

Else accept $\acute{s}$ with the probability $e^{-\Delta E / T_t}$

$k = k + 1$

Until (k <epoch length)

$T_{t+1} = \alpha * T_t$

$t = t + 1$

Until ($T_t > T_{min}$)

Output. Display the best solution.

In the above-mentioned pseudo-code, $f(s)$ is the objective function of the mathematical model, T_t is the temperature of the SA at each stage t. In addition, the definition of each parameter of SA is given in Table 4. It is noteworthy to say that the parameter m is considered in the experimental evaluation and its impact on the computational time and the quality of the solution is evaluated, so that if m is considered close to the size of the problem, the algorithm is only the stochastic searching process, and also if it is considered low, the algorithm cannot find the global solution or near to global solution.

Table 4. Parameters of SA and each definition.

Parameter	Notation	Definition
Maximum temperature	T_{max}	The initial temperature in which the cooling schedule starts with
Minimum temperature	T_{min}	The temperature at which the cooling process will be finished at
Epoch length	L	The maximum iteration permitted to run at each temperature
Cooling rate	α	Ratio of cooling

4. Results and Discussion

In this section, at first, two case studies of construction site examined by other researchers were described, and the DOE of the SA parameters was done. The statistical analysis considered the relationship of SA parameters with both the execution time and solution quality of the problem. Then, by the results obtained from DOE and the statistical analysis, the optimal values of the SA parameters were determined. Finally, by the optimal SA parameters, two case studies (equal and unequal area) werre solved by the proposed SA. In the last part, the performance of the proposed SA was compared with a totally stochastic algorithm which generates the random solutions without any improvement at each iteration in order to evaluate the artificial intelligence of the proposed SA.

4.1. A Solution of the Equal Area Construction Site Layout Problem (EA-CSLP)

In this section, EA-CSLP case study, which has been used by most of the researchers, was considered. This case study has been taken from [3]. The inputs of the case study are indicated in Figure 2 for the frequency of the trips and distances between locations; these inputs are equal for 2 case studies.

$$F=\begin{bmatrix} 0 & 5 & 2 & 2 & 1 & 1 & 4 & 1 & 2 & 9 & 1 \\ 5 & 0 & 2 & 5 & 1 & 2 & 7 & 8 & 2 & 3 & 8 \\ 2 & 2 & 0 & 7 & 4 & 4 & 9 & 4 & 5 & 6 & 5 \\ 2 & 5 & 7 & 0 & 8 & 7 & 8 & 1 & 8 & 5 & 1 \\ 1 & 1 & 4 & 8 & 0 & 3 & 4 & 1 & 3 & 3 & 6 \\ 1 & 2 & 4 & 7 & 3 & 0 & 5 & 8 & 4 & 7 & 5 \\ 4 & 7 & 9 & 8 & 4 & 5 & 0 & 7 & 6 & 3 & 2 \\ 1 & 8 & 4 & 1 & 1 & 8 & 7 & 0 & 9 & 4 & 8 \\ 2 & 2 & 5 & 8 & 3 & 4 & 6 & 9 & 0 & 5 & 3 \\ 9 & 3 & 6 & 5 & 3 & 7 & 3 & 4 & 5 & 0 & 5 \\ 1 & 8 & 5 & 1 & 6 & 5 & 2 & 8 & 3 & 5 & 0 \end{bmatrix} \quad D=\begin{bmatrix} 0 & 15 & 25 & 33 & 40 & 42 & 47 & 55 & 35 & 30 & 20 \\ 15 & 0 & 10 & 18 & 25 & 27 & 32 & 42 & 50 & 45 & 35 \\ 25 & 10 & 0 & 8 & 15 & 17 & 22 & 32 & 52 & 55 & 45 \\ 33 & 18 & 8 & 0 & 7 & 9 & 14 & 24 & 44 & 49 & 53 \\ 40 & 25 & 15 & 7 & 0 & 2 & 7 & 17 & 37 & 42 & 52 \\ 42 & 27 & 17 & 9 & 2 & 0 & 5 & 15 & 35 & 40 & 50 \\ 47 & 32 & 22 & 14 & 7 & 5 & 0 & 10 & 30 & 35 & 40 \\ 55 & 42 & 32 & 24 & 17 & 15 & 10 & 0 & 20 & 25 & 35 \\ 35 & 50 & 52 & 44 & 37 & 35 & 30 & 20 & 0 & 5 & 15 \\ 30 & 45 & 55 & 49 & 42 & 40 & 35 & 25 & 5 & 0 & 10 \\ 20 & 35 & 45 & 53 & 52 & 50 & 40 & 35 & 15 & 10 & 0 \end{bmatrix}$$

Figure 2. Trip frequencies between facilities (left hand) and the distance between locations (right hand).

The descriptions of EA-CSLP are implied below:

In this problem, all of the locations are capable of accommodating each facility (equal area) and also there are 2 fixed facilities; facilities 8 and 11 must be located in the locations 1 and 10, respectively. In the following, DOE is performed and its result for investigating the relationship between SA parameters and the computational time is shown in Table 5. For the experiments, T_{max} was valued by 1, 50, and 100; T_{min} was valued by 0.1, 0.05, and 0.0001; L was ranged by 5, 8, and 10; α was valued by 0.1, 0.05, and 0.0001 and finally m was ranged by 2, 3, and 4. DOE was done by the Response Surface Methodology (RSM) with 6 iterations for central points and totally 32 points in order to investigate the relation between each SA parameters and the computational time. Total experiments have been calculated by design expert software. In this experiment, the quality of the solutions was not evaluated, because by these values of the parameters, the optimal solution was obtained.

Table 5. Statistical analysis for investigating the relation between SA parameters and the computational time (EA-CSLP case study).

ANOVA for Response Surface 2FI model						
Source	Sum of Squares	df	Mean Square	FValue	p-value	Significant
Model	0/391511	15	0/026101	6/136877	0/000412	YES
A-T_{max}	0/073345	1	0/073345	17/24498	0/000749	YES
B-T_{min}	0/000697	1	0/000697	0/163855	0/690992	NO
C-L	0/019734	1	0/019734	4/639971	0/046825	YES
D-α	0/093889	1	0/093889	22/07544	0/000242	YES
E-m	0/037813	1	0/037813	8/890591	0/008809	YES
AB	8/1E-05	1	8/1E-05	0/019045	0/89196	NO
AC	0/02387	1	0/02387	5/612446	0/030753	YES
AD	0/061752	1	0/061752	14/51938	0/001539	YES
AE	0/013456	1	0/013456	3/163816	0/094291	NO
BC	0/006972	1	0/006972	1/639337	0/218668	NO
BD	0/000506	1	0/000506	0/119031	0/734581	NO
BE	0/024649	1	0/024649	5/795549	0/028497	YES
CD	0/017424	1	0/017424	4/096784	0/059994	NO
CE	3/03E-05	1	3/03E-05	0/007112	0/933836	NO
DE	0/017292	1	0/017292	4/065807	0/060867	NO
Residual	0/068049	16	0/004253			
Lack of Fit	0/053192	11	0/004836	1/627338	0/308371	not significant
Pure Error	0/014858	5	0/002972			
Cor Total	0/45956	31				

As it has been shown in Table 5, the parameters of T_{max}, L, α, and m are significant at the 0.05 level. So, we can conclude by the results of Table 5 that the computational time is affected by T_{max}, α, and m strongly. Also, the parameter T_{min} is distinguished as an insignificant factor, while its dual composition with the factor m is significant. The significance of the other dual compositions is shown and also the lack of fit of the model is insignificant, so the 2FI model fits correctly and the results are acceptable. After DOE, the optimal values of parameters of SA are obtained, as it is shown in Table 6. These optimal values minimize the computational time of EA-CSLP case study.

Table 6. Optimal values for minimization of the computational time of EA-CSLP case study.

Parameter	Optimal value by DOE
T_{max}	1
T_{min}	0.0001
L	10
α	0.99
M	4

In the following, the result of solution of EA-CSLP case study by the proposed algorithm with its optimal parameters is shown in Table 7, and also the comparison of the results with the other works is indicated. For EA-CSLP, the proposed algorithm gained the better objective function value than two first algorithms, and also the proposed SA was as efficient as ACO, PSO, CBO, ECBO, WOA, and WOA-CBO which had been proposed by other papers of the solution of EA-CSLP example. In Table 7, Imp% is calculated by (the best solution by this paper-the best solution by the other works) the best solution by the other works.

Table 7. A comparison between the results of the current work and previous papers in EA-CSLP case study.

Works	Optimal Layout											Obj. function	System specifics		C. Time (in sec.)	Tech.	Imp. %
	1	2	3	4	5	6	7	8	9	10	11		CPU	RAM			
[3]	11	5	8	7	2	9	3	1	6	4	10	15090	N/A	N/A	N/A	GA	16.85
[14]	9	11	6	5	8	2	4	1	3	7	10	12578	Core2 2.66 GHz	4 GB	1.15	ACO-PA	0.25
[13]	9	11	6	5	7	2	4	1	3	8	10	12546	N/A	N/A	N/A	ACO	0

Works		[15]	[15]	[15]	[19]	[19]	Current work
Optimal Layout	1	9	9	9	9	9	9
	2	11	11	11	11	11	11
	3	5	6	4	4	4	5
	4	6	5	5	5	5	6
	5	7	7	7	7	7	7
	6	4	4	6	6	6	2
	7	3	3	3	3	3	4
	8	1	1	1	1	1	1
	9	2	2	2	2	2	3
	10	8	8	8	8	8	8
	11	10	10	10	10	10	10
Obj. function		12546	12546	12546	12546	12546	12546
System specifics	CPU	Core7 1.73 GHz	Core7 1.73 GHz	Core7 1.73 GHz	Core7 1.73 GHz	Core7 1.73 GHz	Core3 2.30
	RAM	4 GB	4 GB	4 GB	4 GB	4 GB	2 GB
C. Time (in sec.)		N/A	N/A	N/A	N/A	N/A	0.006
Tech.		PSO	CBO	ECBO	WOA	WOA-CBO	SA
Imp. %		0	0	0	0	0	-

4.2. The Solution of the Un-equal Area Construction Site Layout Problem (UA-CSLP)

Second case study (UA-CSLP) is taken from [7]. In this problem, all of the locations are not capable of accommodating each facility (un-equal area); unlike the previous problem, the facilities 1, 3, and 10 cannot be located in the locations 7 and 8.

In the following, like the first case study, DOE is performed and the results for investigating the relationship between SA parameters and the computational time are shown in Table 8. For this experiment, SA parameters were valued by the same values, which were considered for the previous DOE. Also, experiments were done with 6 iterations for central points and totally 32 points in order to investigate the relationship between each SA parameters and the computational time. Also, at the experiments of UA-CSLP, the relation between SA parameters and the solution quality were not investigated, because most of the experiment points reached the optimal solution.

Table 8. Statistical analysis for investigating the relation between SA parameters and the computational time (UA-CSLP case study).

ANOVA for Response Surface Quadratic model						
Source	Sum of Squares	df	Mean Square	FValue	p-value	significant
Model	128.10	20	6.41	27.95	< 0.0001	YES
A-T_{max}	3.85	1	3.85	16.80	0.0018	YES
B-T_{min}	5.11	1	5.11	22.31	0.0006	YES
C-L	5.85	1	5.85	25.51	0.0004	YES
D-α	30.77	1	30.77	134.25	< 0.0001	YES
E-m	35.56	1	35.56	155.16	< 0.0001	YES
AB	2.05	1	2.05	8.96	0.0122	YES
AC	0.76	1	0.76	3.32	0.0957	NO
AD	1.05	1	1.05	4.59	0.0553	NO
AE	1.20	1	1.20	5.24	0.0428	YES
BC	0.13	1	0.13	0.57	0.4660	NO
BD	1.79	1	1.79	7.81	0.0174	YES
BE	2.93	1	2.93	12.79	0.0043	YES
CD	3.29	1	3.29	14.35	0.0030	YES
CE	4.25	1	4.25	18.56	0.0012	YES
DE	19.69	1	19.69	85.90	< 0.0001	YES
A^2	0.13	1	0.13	0.55	0.4719	NO
B^2	0.050	1	0.050	0.22	0.6504	NO
C^2	0.019	1	0.019	0.084	0.7776	NO
D^2	1.43	1	1.43	6.24	0.0296	YES
E^2	0.79	1	0.79	3.45	0.0901	NO
Residual	2.52	11	0.23			
Lack of Fit	1.73	6	0.29	1.83	0.2610	not significant
Pure Error	0.79	5	0.16			
Cor Total	130.62	31				

As it is clear from Table 8, all parameters of SA are significant, so that α and m are significant strongly at the 0.05 level. So, we can see from Table 9 that most of the dual compositions are distinguished significant. Also, the significance of the other dual compositions is shown. From

Table 8, we can say that the lack of fit of the model is insignificant, so the quadratic model fits correctly and the results are valid. By the help of DOE, the optimal values of the parameters of SA are obtained, as it is shown in Table 9. These optimal values minimize the computational time of UA-CSLP case study.

Table 9. Optimal values for minimization of the computational time of UA-CSLP case study.

Parameter	Optimal value by DOE
T_{max}	15
T_{min}	0.08
L	7
α	0.94
M	3

Thus, by the optimal values of SA parameters, UA-CSLP case study has been solved by the proposed algorithm as it is shown in Table 10, and also the comparison of the results with the other papers is shown. For UA-CSLP, our proposed algorithm reached the better objective function value than the first algorithm, and also the proposed SA was as efficient as GA, ACO-PA, WOA, and WOA-CBO which has been proposed by other papers of the solution of UA-CSLP example. Also, to our best knowledge, the proposed SA is the fastest algorithm of the solution of the EA-CSLP and UA-CSLP case studies according to the data from the literature.

Table 10. A comparison between the results of the current work and previous papers in UA-CSLP case study.

Works	Optimal Layout	Obj. Function	System specific	C. time (sec.)	Tech.	Imp. %
[7]	11 5 9 7 2 8 3 1 6 4 10	15160	N/A N/A	N/A	GA	16.84
[19]	11 9 5 6 8 3 7 1 4 2 10	12606	Core7 1.73 4 GB	N/A	WOA	0
[19]	11 9 5 6 8 3 7 1 4 2 10	12606	Core7 1.73 4 GB	N/A	WOA-CBO	0
[14]	11 9 6 5 8 3 7 1 4 2 10	12606	Core2 2.66 4 GB	1.15	ACO-PA	0
Current Work	11 9 6 5 8 3 7 1 4 2 10	12606	Core3 2.30 2 GB	0.21	SA	-

At the end of this section, the comparison between the proposed SA and the totally stochastic algorithm is shown in Figure 3. By Figure 3, we could see that the stochastic algorithm, which searches the solution space randomly, even cannot get closer to the optimal solution accidentally, so this figure shows the artificial intelligence of the proposed SA.

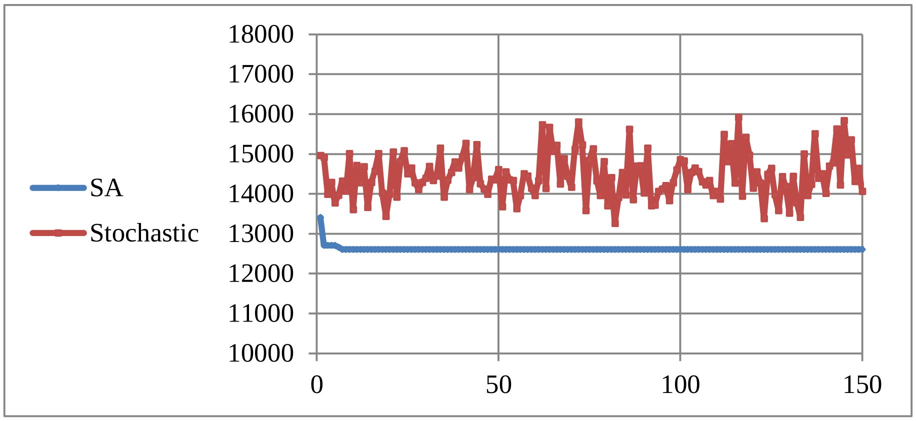

Figure 3. Comparison of convergence of SA with the totally stochastic algorithm of UA-CSLP case study (vertical axis: objective function value, horizontal axis: iterations).

5. Conclusions

In this paper, we solved two case studies namely EA-CSLP and UA-CSLP in the literature related to CSLP. After executing DOE, optimal values of SA parameters were obtained and then the results of the solution of the case studies were compared with the other algorithms proposed by other researchers. The comparisons showed the efficiency of the proposed algorithm of the discrete CSLP examples, also SA was as capable as other meta-heuristics of solving the combinatorial optimization problems like CSLP problem, while the hardware properties and computational times were compared because in this paper CSLP was formulated by QAP. Furthermore, the experiments showed the relationship between each parameter and the performance of the algorithm, for example, the parameters T_{max}, L, α and m, were significant at both example, especially α and m were distinguished significant, so that they had impact on the computational time significantly. Finally, the history of convergence of the proposed SA showed the high speed of reaching to the optimal solution, also the artificial intelligence of the proposed SA to reach the best solution, while it was executed by the system with the low RAM and not strong CPU. For future studies, it is recommended to solve the other case studies of CSLP like continues examples by the proposed SA. Also, the efficiency of the proposed algorithm can be assessed by solving the dynamic time (DCSLP) problems which are more complicated and comparisons will be better in these cases.

References

[1] Liao, T. W., Egbelu, P. J., Sarker, B. R., & Leu, S. S. (2011). Metaheuristics for project and construction management–A state-of-the-art review. *Automation in construction*, *20*(5), 491-505.

[2] Li, H., & Love, P. E. (2000). Genetic search for solving construction site-level unequal-area facility layout problems. *Automation in construction*, *9*(2), 217-226.

[3] Li, H., & Love, P. E. (1998). Site-level facilities layout using genetic algorithms. *Journal of computing in civil engineering*, *12*(4), 227-231.

[4] Andayesh, M., & Sadeghpour, F. (2014). The time dimension in site layout planning. *Automation in construction*, *44*, 129-139.

[5] Sadeghpour, F., & Andayesh, M. (2015). The constructs of site layout modeling: an overview. *Canadian journal of civil engineering*, *42*(3), 199-212.

[6] Yeh, I. C. (1995). Construction-site layout using annealed neural network. *Journal of computing in civil engineering*, *9*(3), 201-208.

[7] Li, H., & Love, P. E. (2000). Genetic search for solving construction site-level unequal-area facility layout problems. *Automation in construction*, *9*(2), 217-226.

[8] Tam, C. M., Tong, T. K., & Chan, W. K. (2001). Genetic algorithm for optimizing supply locations around tower crane. *Journal of construction engineering and management*, *127*(4), 315-321.

[9] Tam, C. M., Tong, T. K., Leung, A. W., & Chiu, G. W. (2002). Site layout planning using nonstructural fuzzy decision support system. *Journal of construction engineering and management*, *128*(3), 220-231.

[10] Cheung, S. O., Tong, T. K. L., & Tam, C. M. (2002). Site pre-cast yard layout arrangement through genetic algorithms. *Automation in Construction*, *11*(1), 35-46.

[11] [11] H. Zhang, J.Y. Wang, Particle swarm optimization for construction site unequal-area layout, Journal of construction engineering and management, 134 (2008) 739-748.

[12] Lien, L. C., & Cheng, M. Y. (2012). A hybrid swarm intelligence based particle-bee algorithm for construction site layout optimization. *Expert systems with applications*, *39*(10), 9642-9650.

[13] Gharaie, E., Afshar, A., & Jalali, M. R. (2006, February). Site layout optimization with ACO algorithm. *Proceedings of the 5th WSEAS international conference on artificial intelligence, knowledge engineering and data bases* (pp. 90-94). World Scientific and Engineering Academy and Society (WSEAS).

[14] Calis, G., & Yuksel, O. (2015). An improved ant colony optimization algorithm for construction site layout problems. *Journal of building construction and planning research*, *3*(04), 221.

[15] Kaveh, A., Khanzadi, M., Alipour, M., & Moghaddam, M. R. (2016). Construction site layout planning problem using two new meta-heuristic algorithms. *Iranian journal of science and technology, transactions of civil engineering*, *40*(4), 263-275.

[16] Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P. (1983). Optimization by simulated annealing. *science*, *220*(4598), 671-680.

[17] Abbasi, B., Shadrokh, S., & Arkat, J. (2006). Bi-objective resource-constrained project scheduling with robustness and makespan criteria. *Applied mathematics and computation*, *180*(1), 146-152.

[18] Park, M. W., & Kim, Y. D. (1998). A systematic procedure for setting parameters in simulated annealing algorithms. *Computers & operations research*, *25*(3), 207-217.

[19] Kaveh, A., & Rastegar Moghaddam, M. (2018). A hybrid WOA-CBO algorithm for construction site layout planning problem. *Scientia iranica*, *25*(3), 1094-1104.