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Optimization of construction site layout planning with combination of metaheuristic algorithms

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Abstract

Safety is important in construction site layout plans, and it is an essential requirement to improve construction project management. Previous studies considered the safety objective function without risk factor analysis. Metaheuristics are widely used to solve construction site layout problems (CSLP). Invasive Weed Optimization (IWO) is employed as a multi-objective optimization method to design and optimize two safety objective functions and total cost. Safety objective functions (due to potential risks arising from hazardous sources and interaction flows) connect temporary facilities by considering total cost reduction. A case study is presented to find out the accuracy of the proposed model. Finally, the performance of four metaheuristic algorithms called Invasive Weed Optimization (IWO), Firefly Algorithm (FA) and Ant Colony Optimization (ACO), previously studied by researchers, is compared in terms of their effectiveness in resolving a practical construction site layout problem. To take advantage of a more optimal response, a combination of firefly and weed algorithms was also investigated. Results show that the combination of FA and IWO algorithms works better than ACO, FA and IWO algorithms separately.

Keywords: invasive weed optimization algorithm, firefly algorithm, construction site layout planning (CSLP), multi-objective optimization model
2020 MSC: 90C31, 90C29

1 Introduction

Construction site layout problems can be formulated as Quadratic Assignment Problems (QAP). The QAP is a classic combinatorial optimization problem and is well known for its various applications. QAP is known as a non-polynomial hard (NP-hard) problem, and due to its combinatorial complexity, it cannot be solved exhaustively for reasonably sized layout problems. As an instance, for n facilities, the number of feasible configurations is $n!$ with larger growth than e^n. This is a huge number, even for a small n. For 10 facilities, the number of possible alternatives is already well over 3,628,000 or for 15 facilities, it is a 12-digit number. In real problems, a project with n = 15 is known as a small project. Despite the above-mentioned flexibility, the searching process of this approach is more complicated; therefore, robust methods are required for this type [13].

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Optimization has always been a human concern from ancient times to the present day. Also, in light of advances in computing equipment and systems, optimization techniques have become increasingly important in different applications. The role of metaheuristic algorithms in optimizing and solving engineering problems is expanding every day [24]. Every metaheuristic algorithm consists of two phases: an exploration of the search space and an exploitation of the best solutions found. One of the most important subjects in a good metaheuristic algorithm is to keep a reasonable balance between the exploration and exploitation abilities [27, 28]. Meta-heuristic optimization algorithms are becoming more and more popular in engineering applications because they: (i) rely on rather simple concepts and are easy to implement; (ii) do not require gradient information; (iii) can bypass local optima; (iv) can be utilized in a wide range of problems covering different disciplines [18].

In the beginning, project management knowledge is determined, and they are prioritized based on its importance and effectiveness. The relationships between the critical cases are determined according to the PMBOK1 standard, and it is possible to extract the proposed basic table from the obtained relationships [30]. Construction site layout planning involves sizing and placing temporary facilities in the pre-construction stage of construction projects. Different researchers have studied on importance of "design for safety" and most of them indicated that accidents in construction sites could be avoided by considering more safety in planning schemes [35]. As a consequence, safety planning consideration in the pre-construction stage of construction projects seems necessary [34]. Construction site layout planning is usually treated as an optimization problem. For example, the safety objective functions by reducing the noise pollution and intersection flow between facilities [5, 10], optimizing safe locations for hazardous facilities such as tower cranes [1, 33, 39]. In previous studies, safety objective functions have been assumed only with full risk factors. In this study, the objective function is presented by considering onsite safety after risk factors analysis, dependence on site layout. Construction site layout planning is modelled as a quadratic assignment to realize an optimal site layout [3]. By using of ant colony optimization (ACO) algorithm [14, 25], harmony search algorithm [9], and genetic algorithm [23] as optimization techniques, this problem is solved. Also, we can utilize the recently developed hybrid algorithms like the WOA-CBO [23] or the MBF-CBO [26, 28, 29]. Xu and Li [37] presented the dynamic model of construction site layout by assuming the total cost as an objective function and considering the possibility of safety and environmental accidents, also using PSO as an optimization method. Ning et al. [21] developed a system to solve construction site layout problems by considering safety and cost as objective functions. Singh and Singh [31] proposed a new model that uses the weighted sum method to combine material handling time, closeness rating and workflow as multiple objectives. Ning and Lam [20] presented a model to realize optimal solutions for cost and safety by trading off solutions for an unequal-area site layout problem. Song et al. [32] presented Modelling the effect of multi-stakeholder interactions on construction site layout planning using agent-based decentralized optimization. Researchers employed the Pareto and weighted sum method to find out optimal solution. The Pareto method provides many solutions compared with the weighted sum method, and its advantage provides multi-provision of site managers with different solutions [37]. As a consequence, in this paper Pareto optimization technique is preferred to determine the dominance relation between solutions.

In this study by considering holistic risk factors analysis to improve the safety performance in construction site layout, the Firefly multi-objective algorithm is employed to find out safe construction site layout plans in the pre-construction stage of construction projects. To help construction site managers with their temporary facilities arrangements on the construction site are assumed with more safety factors are assumed.

2 Research method

2.1 Interaction relationship analysis

Interaction relationships between participating facilities in construction sites exist. By considering A site facilities need to be assigned to B locations (B greater than A) and B refers to free locations. interaction relationship between facilities or presented in fig 1.

In fig., 1 facilities distance can be calculated when facilities are allocated to Free locations. The facilities should be far away from high-potential-risk facilities, which means the distance from high-potential-risk sources or hazardous source facilities should be maximised. Safety objective function can be defined as an interaction relationship in a safety or safety relationship. Site facilities consist of mobile and fixed facilities (heavy equipment, tower cranes, location and material hoist locations i the n construction site are fixed). In the previous study, location problems are handled, but facilities layouts aren't [19]. Hazardous materials are used and located on construction sites, so people who work on construction sites are exposed to safety risks [19, 36]. Temporary facilities can be a hazard source because they can produce noise and dust [6]. Haul Road is a single fixed hazard source facility. Finding facility locations like haul roads or tower cranes (these facilities can always be considered as hazardous sources and have a

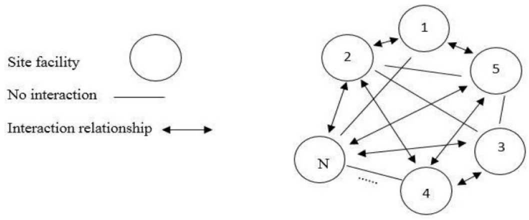


Figure 1: Interaction relationship between facilities

safety interaction relationship with other facilities), the location can be assumed as a single facility location problem [4, 15]. If fixed facilities positions are frozen in the construction site, potential risk rises from fixed facilities (such as haul road and heavy-duty equipment). Temporary facilities are dependent on the associated location occupied by the facilities. Geographic Safety Relationship (GSR) refer to potential risk from hazardous sources that are not related to the categories of locations. It means that the potential risk from different categories of facilities when placed in the same location is equal. The safety of the facilities is influenced by potential risk factors (resource movement consists of quantitative flows of equipment, personnel and materials). High levels of interaction flow between the facilities (equipment, personnel and material) can be caused by accidents on the construction site, as shown in Fig. 1, so collusions or conflicts between equipment, personnel and materials are dependent on transportation of resources between the facilities. As a result, construction safety is influenced by interaction flows (negative impact). Potential risk from interaction flows between the facilities can be defined as the Facility Safety Relationship (FSR).

Geographic Safety Relationship (GSR) and Facility Safety Relationship (FSR) hurt temporary facilities (dangers arise from GSR) and (FSR). As mentioned previously, GSR is related to the facility's location without considering the kind of facilities placed in a specific location. The (GSR) from the same hazardous sources are equal. (FSR) is related to interaction flows between the facilities that are calculated by varying between the diverse facilities and construction activities. By increasing job demand between the facilities in a construction site, the Facility safety relationship is increased.

2.2 Objective functions

2.2.1 Objective functions related to (GSR)

Geographic Safety Relationship (GSR) can be defined as the potential risk which is influenced by distance from hazardous sources such as foundation ditches, hazardous material, material hoists, tower cranes and facilities producing noise. (GSR) is reduced by increasing facilities distance from hazardous. A linear relationship can be assumed between the distance from hazardous sources and risk degree [2].

In fig. 2 the risk degree can be classified from no risk zone (z_5) to very high zone (z_1) according to the distance from the danger sources. Risk from hazardous sources may increase when two facilities are close to each other but some facilities have dangerous zone for example tower crane operation zone can be divided into 3 dangerous zones. In zone 1, there is very high risk (caused by falling materials) so probability of accidents occurring are higher than other zones. In zone 2(caused by crane collapse) the risk degree set to medium and in zone3 (caused by rare danger) set to low [5]. In fig. 3 tower crane operation zone by considering potential risk are presented.

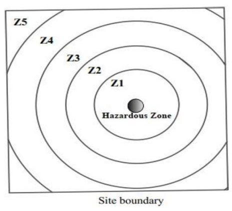


Figure 2: The risk degrees

Facilities in construction sites to increase the safety level should be located far from hazardous sources to minimize the risk degree so objective function related to the (GSR) as calculated in Eq. (2.1).

$$obj1 = \min \sum_{i=1}^{m} r_{1i} \tag{2.1}$$

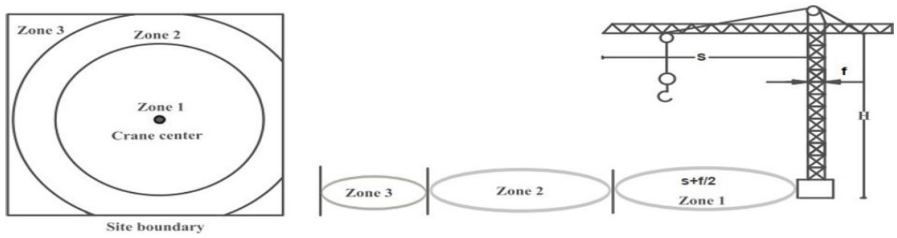


Figure 3: The tower crane risk degrees

where r_{1i} is value for the risk degrees when facilities located to the hazardous zone with different risk degree from (z_1) to (z_5). In Table 1, the interaction relationship is divided into five degrees (corresponding assumed values of 243, 81, 27, 9 and 3) [12]. The (GSR) is described based on risk degree value. The values for risk degrees 243, 81, 27, 9 and 3 are also set to (z_1), (z_2), (z_3), (z_4) and (z_5), respectively. The r_{1i} (risk degree) for each facility is determined by waiting up from different hazardous sources and if an accident does happen the risk value between facilities determined by negative results.

Table 1: Assessment levels for quantitative flows

Assessment level	**Categories range (%)** (C_r)	**Assumed value**
z_5	0–20	3
z_4	20–40	9
z_3	40–60	27
z_2	60–80	81
z_1	80–100	243

2.2.2 Objective function of (FSR)

Facility Safety Relationship (FSR) is the risk increasing from the interaction flows such as personnel flow, material flow, which can be determined by number of employee trips and transportation unit per day [14, 21, 37]. Higher interaction flow between facilities, equipment, personal and material makes more collisions or conflicts between facilities. Positive relationship between risk and interaction flow can be found. Longer distance between facilities needs more travel distance for the resources transportation as consequence more accident can be happened. So positive relationship between risk degree and distance can be found. To increase safety performance, the risk due to the (FSR) should be minimised as presented in Eq. (2.2).

$$obj2 = \min(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{E=1}^{m}\sum_{F=1}^{m} r_{2ij} d_{EF}), \tag{2.2}$$

when facility $i (i = 1, 2, ..., m)$ is assigned to location $E(E = 1, 2, ..., n)$ and $j (j = 1, 2, ..., m)$ is assigned to location $F (F = 1, 2, ..., n)$. r_{2ij} is considered as (FSR) value by assuming quantitative flows of personnel, equipment and material. Distance between location E and location F is presented by d_{EF}. In table 1, five assessment levels for quantity flows are shown and categories range can be calculated as Eq. (2.3).

$$C_r = \frac{\text{value of quantitative flow} - \text{minimum value of quantitative flows}}{\text{maximum value of quantitative flows} - \text{minimum value of quantitative flows} \times 100}. \tag{2.3}$$

2.2.3 Objective function of (RTC)

Cost is usually an important factor for construction management. Statistical analysis shows profit margin for construction industry is around 3.06% to 3.69% [17]. So, it is an important to reduce total cost without reducing safety construction site layout. The Resources Transportation Cost (RTC) is calculated by distance between the facilities and resource flows. The information flows can be determined by the number of communications (oral or reports) between facilities per time unit. By assuming information, equipment, material, personnel and distance between the facilities, minimum transportation cost when site facilities assigned to free locations can be calculated as

Eq. (2.4).

$$obj3 = \min(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{E=1}^{m}\sum_{F=1}^{m} C_{ij} d_{EF}), \tag{2.4}$$

where C_{ij} is the value for quantitative flows, which is derived from Table 1.

2.3 Multi-objective

2.3.1 Algorithms

Swarm intelligence (SI) is type of artificial intelligence. During last decade innovative swarm intelligence inspired by natural social swarms such as firefly, bee, fish etc. have been developed. Firefly algorithm (FA) was created and developed based on swarming behavior of firefly. Different methods and algorithms are applied in optimization problems but (FA) is more reliable and suitable in optimization problems. Fireflies flashing lights is employed in (FA) as randomization technique to find out set of solutions. Flashing lights of fireflies decreases, by increasing distance and vice versa [8] Also, attraction and attractiveness of firefly can change by distance. Fireflies are classified to different groups according to attraction and attractiveness. Each group swarms around the local brightest firefly (local optimum solution) so the best global solution is detected among these local optimum solutions. Some idealized rules in (FA) should be assumed. (a) Fireflies can be attracted to another firefly regardless of their gender. (b) The attractiveness is proportional to flashing brightness it means by increasing firefly distance attractiveness decreases. Fireflies are attracted to brightest. (c) The brightness is considered as an objective function [7, 38]. Firefly attractiveness (β) is proportional to firefly flashing light brightness and can be computed as follows:

$$\beta = \beta_0 e^{-\gamma r^2}, \tag{2.5}$$

where β_0 and r denote to the initial attractiveness at $r = 0$ and distance of a firefly from firefly respectively. The light intensity is calculated as:

$$I(r) = I_0 e^{-\gamma r^2}, \tag{2.6}$$

where the light intensity (brightness) at the source is presented by I_0 and the light intensity at specific distance r presented by $I(r)$. The firefly distance from another one is defined as follows:

$$r_{mn} = \left(\sum_{k=1}^{d}(x_{m,k} - x_{n,k})^2\right)^{0.5}. \tag{2.7}$$

Algorithmic firefly movement in search space is formulated as follows [19].

$$x_m^{t+1} = x_m^t + \beta_0 e^{-\gamma mn^{r^2}}(x_n^t - x_m^t) + \alpha\varepsilon, \tag{2.8}$$

where x_m denote to current position of each firefly and the attractiveness of each firefly is presented by $\beta_0 e^{-\gamma mn^{r^2}}(x_n^t - x_m^t)$. Also, randomization term is described by $\alpha\varepsilon$. Term of α is the randomization parameter, which is changed and update during iterations and ε is vector of random number. In firefly algorithm change in flashing light absorption is significant factor for convergence. Initially the flashing light absorption during optimization process is assumed a fixed value. According to situations this value is modified during optimization process. Finally, fireflies are ranked according to attractiveness and distance value. The flowchart of (FA) is shown in Fig. 4.

The Invasive Weed Optimization algorithm, or IWO, is a numerical optimization algorithm inspired by weed growth. The algorithm was proposed in 2006 by Mehrabian and Lucas in the form of an article [16]. Weeds are plants whose aggressive growth is an essential threat to agricultural plants. Weeds are very stable and adaptable to environmental changes. So by drawing inspiration and simulating their properties, a robust optimization algorithm can be reached. Weeds are plants that grow globally and prominently in a specific geographical area so that they cannot be removed and controlled by humans. One claim about weeds is that weeds always win. In general, the reasons for this claim can be expressed as follows.

1. The presence of weeds after thousands of years of farming
2. The presence of weeds even after the use of various toxins.
3. The emergence of new species of weeds on the ground

The above features indicate that weeds are solid and annoying plants in agriculture. It also reflects that weeds adapt to the environment and change their behavior to grow. Weeds' success depends on their ecology and biology [16].

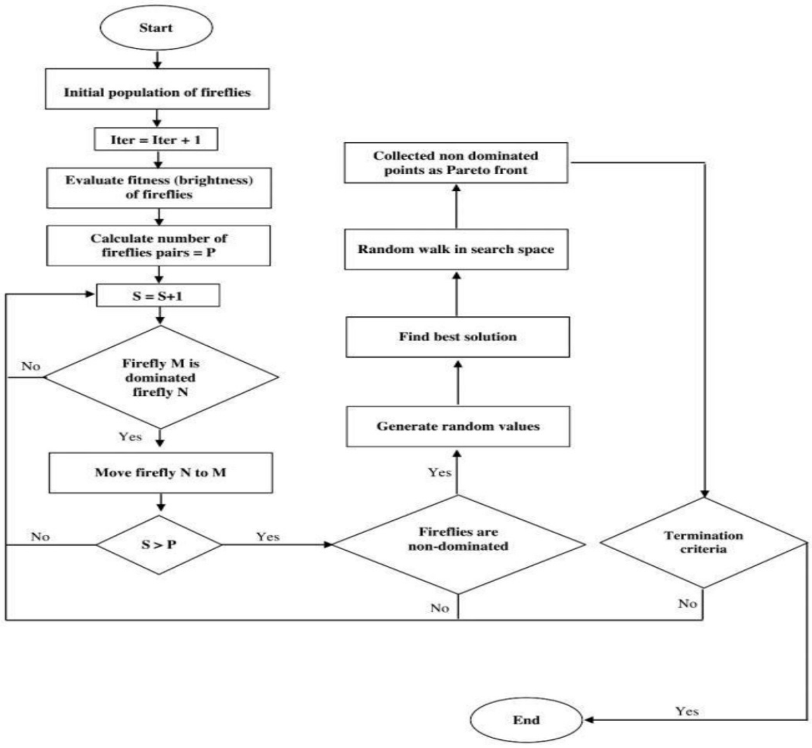


Figure 4: Firefly algorithm flow chart

2.4 Simulation of invasive weed behavior

The steps to simulate weed behavior include:

- Step one: spread the seeds in the desired space.
- Step two: grow seeds according to the desirability of the birth and environmental dispersion.
- Stage three: the continuation of grass life with greater desirability Competitive Elimination
- Step Four: continue the process until you reach the best plants.

The flowchart on how weeds work is shown in Figure 5.

Input parameters considered for the proposed weed algorithm of this research are listed in Table 2. The study assessed two conditions of cessation. Condition one: the difference in the value of the target function is the sum of the substitution costs. Condition two: the number of repetitions. The number of iterations in this algorithm is considered equal to 100.

Table 2: Input parameters of weeds

Primary population numbers	NO	13
Maximum number of populations	P_{max}	20
Minimum number of seeds	S_{min}	0
Maximum number of seeds	S_{max}	3
Initial value of standard deviation	$Sigma_{Init}$	3
The final value of the standard deviation	$Sigma_{Final}$	0.001
Number of repetitions	It_{max}	100

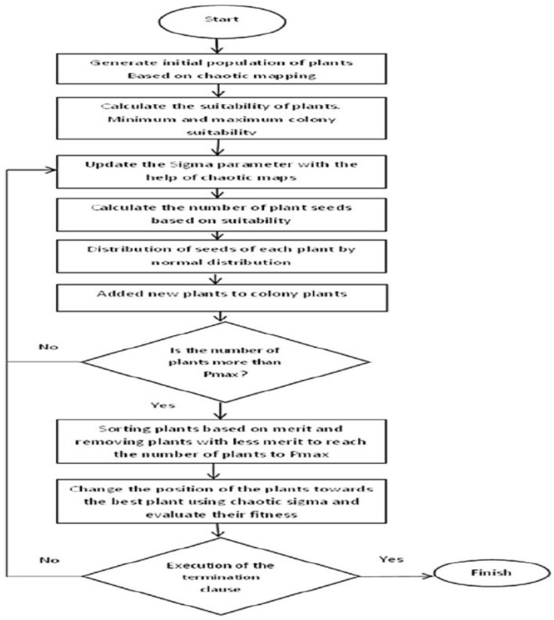


Figure 5: Weed Algorithm Flowchart

Table 3: Temporary facilities

status	**Facility No**	**Facilities**	**Area** (m^2)
Free	F_1	Labour hut	25
Free	F_2	Material laydown area	100
Free	F_3	Reba bending yard	100
Free	F_4	Equipment maintenance plant	25
Free	F_5	Tool shed	50
Free	F_6	Fire equipment storage	25
Free	F_7	Carpentry workshop	100
Free	F_8	Inflammable materials storage	25
Fixed	F_9	Tower crane	50
Fixed	F_{10}	material hoist1	25
Fixed	F_{11}	material hoist2	25
Fixed	F_{12}	Security hut	100
Fixed	F_{13}	Field office	50

2.5 Case studies

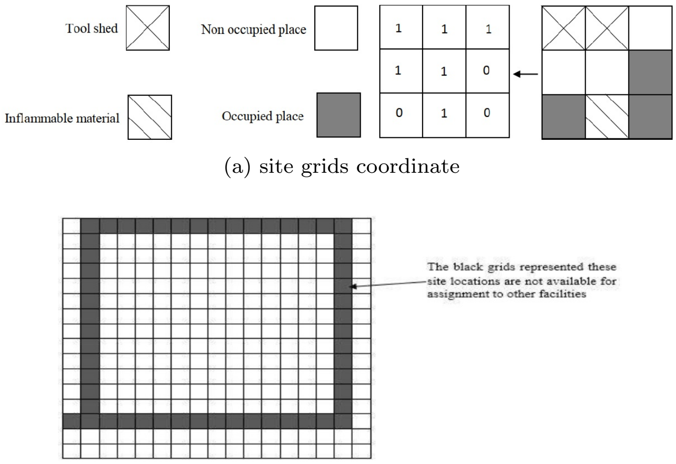
The site locations are assumed in terms of grid coordination so facilities distance can be determined once they are assigned. Facilities are considered by a collection of grid units [11]. Each grid has a 5-meter length and width and facilities can be located in there. For example, the tower crane area is about 50 m^2 and it can be presented by two grid units. In Fig. 6a white grids are represented by the number "1" and black grids are represented by the number "0". In Fig., 6b site locations which are not available for assignment to other facilities are presented by black grids and white grids available for assignment to other facilities.

In this study to find out distance between facilities the Euclidean distance between the gravity center of facility (G_1) can be presented. The gravity center of the grid (G_1) can be presented as follows:

$$G_1 = (GX_i, GY_i) = (X_i - 0.5, Y_i - 0.5) \tag{2.9}$$

where X_i and Y_i are refer to grid row and column. The Euclidean distance can be calculated by Eq. (2.10).

$$G_2 = \sqrt{(GX_i - GX_j)^2 + (GY_i - GY_j)^2}. \tag{2.10}$$



(a) site grids coordinate

(b) site grids location

Figure 6

The gravity centre of facility by determining the gravity centre of each grid can be presented as follows:

$$G_3 = (FX_i, FY_j) = \left(\frac{\text{sum of the gravity} GX_i}{\text{grid units}}, \frac{\text{sum of the gravity} Gy_i}{\text{grid units}} \right). \tag{2.11}$$

Finally, the distance can be presented as

$$d_{ij} = \sqrt{(FX_i - FX_j)^2 + (FY_i - FY_j)^2}. \tag{2.12}$$

3 Results and discussion

The Firefly algorithm is employed to find out the construction site layout's optimal dimension to satisfy (GSR), (FSR) and (RTC). Pareto optimal solutions are generated for multi-objective optimization because one solution cannot satisfy all objectives in multi-objective optimization. In multi-objective optimization, one solution may satisfy three objectives but cannot guarantee always generate the minimum value, so multi results i the n optimization process seem necessary. Six optimal solutions by the firefly algorithm were found. The requirement for construction site layout is related to the designer's vision, so asking site managers to state the importance of objective functions (GSR), (FSR) and (RTC) to focus on the quality of the construction site layout plans for further decision-making.

The Analytic Hierarchy Process is employed to calculate weights between the objective functions. The weights of (GSR), (FSR) and (RTC) are determined to be 0.43, 0.31, and 0.26, respectively. By assuming weights impact between the objective functions, the results for the former construction site layout alternatives are calculated in Table 4. Finally, the performance of four metaheuristic algorithms called Invasive Weed Optimization (IWO), Firefly Algorithm (FA), Ant Colony Optimization (ACO) and a combination of FA and IWO algorithms is compared in Table 4. In the combined FA and IWO algorithm, feature selection from the FA algorithm and the analysis and response phase from the IWO algorithm was used, the result of which is more optimal than each algorithm separately, and the answers in cost are towards the most downward mode and they went to the highest level in safety.

The minimum value for the Geography Safety relationship in construction site layout S1 is about 617216.2. In this situation, the temporary facilities are located far away from F11, F12 (material hoists) and F13 (tower crane). The schematic of the construction site layout by considering optimal results for each of S1, S2, and S3 is presented in Figs. 7 to 9, respectively. The optimal site layouts were generated to minimize the risk caused by (GSR), (FSR) and (RTC). Results show there isn't a unique solution for the construction site layout.

If the facilities are assigned in the specific lower safety zone, the risk degrees are reduced. The health and safety of labourers are improved by placing labour huts away from dangerous facilities. The labour hut is located adjacent to the haul road and to the right of building 1, also potential risks from the tower crane are lower. The facility safety relationship has the highest value of 204216.2. It means the distance between the facilities is great. For the dispersed distribution of the facilities, the transportation cost has the value of 420408.5.

Table 4: The optimal results for the six construction site layout alternatives

Algorithm	Objective function	P1 (S1 for FA)	P2 (S2 for FA)	P3 (S3 for FA)	P4 (S4 for FA)	P5 (S5 for FA)	P6 (S6 for FA)
ACO [22]	ob1	618654.2	747873.5	679986.7	831255.5	742072.1	813656.8
	ob2	205617.7	178913.3	171976.0	165229.2	196414.8	158023.2
	ob3	421227.4	282551.0	340169.7	263599.7	330156.9	279424.3
	Weighted sum	439281.9	450512.0	434151.0	477196.8	465820.4	471509.9
FA [8]	ob1	617826.30	739439.80	680142.70	829176.90	739998.70	814653.40
	ob2	204523.20	180365.70	170895.60	164974.70	197142.10	159874.30
	ob3	422368.50	281653.40	339854.70	262895.80	329874.20	280223.10
	Weighted sum	438883.31	447102.37	433801.22	476041.13	465080.78	472720.00
IWO	ob1	617642.6	739226.1	681201.3	830201.3	740038.1	813878.6
	ob2	204319.4	179318.7	170984.1	165102.4	196820.6	158917.2
	ob3	421781.2	282221.3	339468.6	263045.6	330021.3	280422.1
	Weighted sum	438638.8	447089.6	433706.0	476207.3	465304.4	471638.1
FA & IWO	ob1	617216.2	738831.5	680120.4	828476.6	738821.4	813222.3
	ob2	204216.2	180201.3	170876.2	164384.6	196109.2	158847.2
	ob3	420408.5	281523.2	338741.4	262289.0	328863.7	279789.4
	Weighted sum	437528.7	446489.2	433019.3	474367.2	464367.9	470360.0

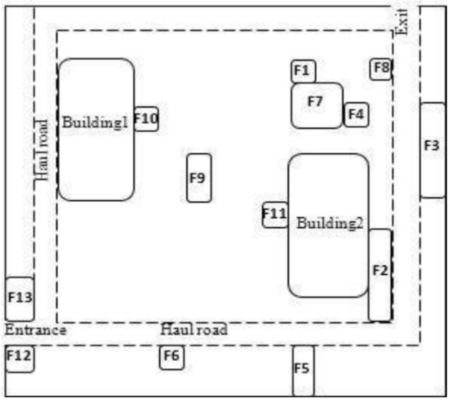


Figure 7: Schematic layout drawing for S1

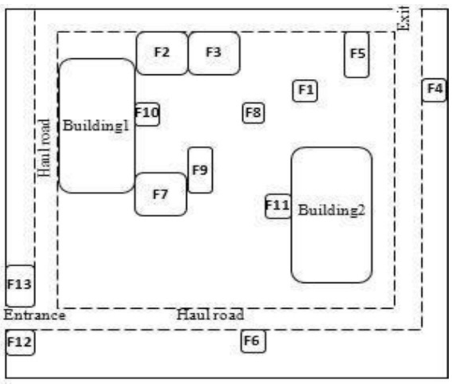


Figure 8: Schematic layout drawing for S2

By comparing the distribution of temporary facilities in S3 is more centralized than S1. As a consequence, the facility safety relationship in S1 204216.2 is higher than that of 170876.2 in S3. The value for the resources transportation cost and material handling cost is increased by placing the carpentry workshop and rebar bending yard far away from the material laydown area in S1 than that in S3. The risk degree from dangerous facilities in S3 is relatively high because the tool shed is arranged around the tower crane and material hoist. The higher distance between the facilities made the noise level shorter. The carpentry workshop and material laydown area are arranged next to the facilities of the equipment maintenance plant and labour hut in S3, such that the noise pollution for them is relatively high.

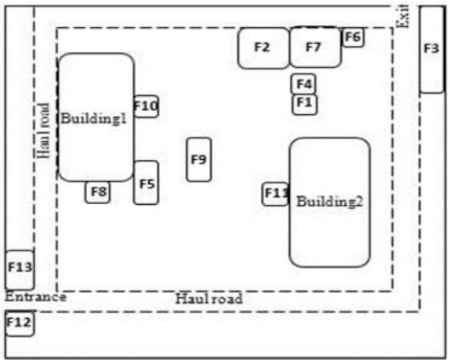


Figure 9: Schematic layout drawing for S3

Inflammable materials location in S3 is more reliable and reasonable than that in S1. As a consequence, the (GSR) 680120.4 in S3 is higher than 617216.2 in S1. Also, resource transportation cost in S3 is relatively lower because there is a shorter distance between the n material laydown area and the carpentry workshop, with a value of 338741.4. When considering construction productivity in the S3 layout labour hut to be close to the material laydown area and carpentry workshop. Finally, for site managers, it simplifies layout; the alternative S3 layout with the minimum weighted sum is more suitable than the S1 layout. By comparing layout alternatives, S2 and S3 rebar bending yard, carpentry workshop, and material laydown area in S2 are closer to dangerous facilities than they are in S3. Also, the rebar bending yard and material laydown are adjacent to the material hoist, and the carpentry workshop is assigned in the danger zone of a tower crane. The risk degree for health and personnel safety related to hazardous materials and noise pollution in the S2 layout is higher because the labour hut is placed around inflammable materials storage, tower crane and Reba bending yard. As mentioned previously, S3 has a maximum value of geography safety relationship of 738831.5. In the S2 layout, carpentry workshop and material laydown areas are assigned separately on both sides of the tower crane, so the possibility of an accident between these facilities is increased, and productivity is decreased. A carpentry workshop is arranged near to material laydown area safety relationship in the S3 layout is reduced, and construction productivity is improved. The distance between the facilities in S3 is greater than in S2, so resources transportation cost is higher, 338741.4. Facility Safety Relationship and Geographic Safety Relationship are more important in construction site layout, therefore, S3 is more reasonable than S2 layout.

4 Conclusion

In order to improve the safety performance in the construction site layout and reduce the cost of construction in light of safety and optimal decisions, this study was conducted. By considering the interrelationship between innovative facilities, providing two related safety objective functions (facility safety relationship and geographical safety relationship). Since construction cost is a fundamental and very important requirement for construction management, an additional related objective function, Cost, was also created as a supplementary objective to the CSLP. Finally, a residential building was used as a case study to demonstrate the applicability and feasibility of the proposed model. The results show that the objective function related to the mutual relationship with the resource transportation cost is consistent and has a contradictory relationship with the objective function related to the geographical safety relationship. The Invasive Weed Optimization (IWO) algorithm is used as a multi-objective optimization method to find the optimal solution. The Invasive Weed Optimization (IWO) algorithm generates Pareto optimal solutions by calculating the dominance relationship between the solutions.

The Pareto solution provides many site layout options for decision-making. Assuming the requirements of the project, the site manager can choose the final design of the construction site, and it is better to move the facilities closer to each other to increase safety and reduce transportation costs. Also, to reduce risk (GSR), facilities should be located away from sources of risk such as material lifters, transport roads, and tower cranes. GSR increases as gaps between temporary facilities close, so to reduce GSR, non-productive facilities should be located away from heavy facilities. Constructed safety objective functions (based on GSR and FSR) and construction costs are assumed to create an optimization model. The firefly algorithm is used as an optimization method by generating the optimal Pareto front according to the dominant relationship between the solutions. The results show that the objective functions related to (GSR) and the reciprocal relationship with (RTC) are consistent. Also, improving safety in construction site layout is considered to create a multi-objective optimization model to generate optimal site plans. This study focused on safety optimization problems in construction site layout by developing IWO multi-objective optimization algorithms and comparing firefly, IWO and ACO algorithms to design a construction site safe layout model based on analytical and numerical methods. It brought about 11% cost reduction and about 13% increase in safety compared to checking algorithms individually.

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