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Multi-Objective Firefly Optimization Algorithm for Construction Site Layout Planning

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Abstract

Safety importance on construction site layout plan is an essential requirement to improve construction project management. In previous studies the safety objective function is considered without risk factors analysis. Metaheuristics are widely used to solve construction site layout problems (CSLP). Firefly Algorithm (FA) is employed as 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) connecting temporary facilities by considering total cost reduction. A case study is presented to find out accuracy of the proposed model. Finally, the performance of two metaheuristic algorithms called Firefly Algorithm (FA) and Ant Colony Optimization (ACO) are compared in terms of their effectiveness in resolving a practical construction site layout problem. Results show that the FA performs better than the ACO Algorithm.

Keywords:
Construction site layout planning
Firefly algorithm
Multi-objective
Optimization model
Metaheuristic

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INTRODUCTION

Construction site layout problems can be formulated as Quadratic Assignment Problem (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 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. In spite of the above-mentioned flexibility, the searching process of this approach is more complicated; therefore, robust methods are required for this type (Kaveh & Rastegar Moghaddam, 2018).

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 (Saberi & Sedaghat Shayegan, 2021).

Every metaheuristic algorithm consists of two phases: an exploration of the search space and 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 (Sedaghat Shayegan, Lork & Hashemi, 2020 & 2019). 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 (Mirjalili & Lewis, 2016)

In the beginning, project management knowledge is determined, and they are prioritized based on their importance and effectiveness. The relationships between the critical cases are determined according to PMBOK1 standard, and it is possible to extract the proposed basic table from the obtained relationships (Shahebrahimi, Lork & Sedaghat Shayegan, 2022).

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 site could be avoided by considering more safety into planning schemes (Weinstein & Gambatese, 2005). As consequence safety planning consideration in the pre-construction stage of construction projects seems necessary (Teo, Ofori, Tjandra & Kim, 2016).

Construction site layout planning usually treated as optimization problem. For example, safety objective function by reducing the noise pollution and intersections flow between facilities ((El-Rayes & Khalafallah, 2005) & (Hammad, Akbarnezhad, & Rey, 2016)), optimizing safe locations for hazardous facility such as tower cranes ((Zhang, Harris, Olomolaiye & Holt, 1999) & (Tam & Tong, 2003) & (Abdelmegid, Shawki & Abdel-Khalek, 2015)). In previous studies, safety objective functions have been assumed only with full risk factor. In this study the objective function is presented by considering onsite safety after risk factors analysis dependence with site layout.

Construction site layout planning is modelled as a quadratic assignment to realize an optimal site layout (Adrian, Utamima & Wang, 2015). By using of ant colony optimization (ACO) algorithm ((Lam, Tang & Lee, 2005) & (Safari, 2020)), harmony search algorithm (Gholizadeh, Amiri & Mohebi, 2010) and genetic algorithm (Paes, Pessoa & Vidal, 2017) as optimization technique this problem is solved. Also, we can utilize from the recently developed hybrid algorithms like the WOA-CBO (Paes, Pessoa & Vidal, 2017) or the MBF-CBO (Sedaghat Shayegan, Lork & Hashemi, 2020 & 2022 & 2021).

Xu and Li (Xu & Li, 2012) are presented the dynamic model of construction site layout by assuming the total cost as objective function and considering the possibility of safety and environmental accidents, also PSO used as optimization method. Ning et al. (Ning, Lam & Lam, 2010) is developed ant system to solve construction site layout problems by considering safety and cost as objective function. Singh and Singh (Singh & Singh, 2010) are 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 (Ning & Lam, 2013) are presented a model to realize optimal solution for cost and safety by trading-off solutions for an unequal-area site layout problem. Song et al. (Song, Peña-Mora, Shen, Zhang & Xu, 2019) are presented Modelling the effect of multi-stakeholder interactions on construction site layout planning using agent-based decentralized optimization.

Researches are employed Pareto and weighted sum method to find out optimal solution. Pareto method provides many solutions compared with the weighted sum method and its advantage provides multi provision of site managers with different solutions (Xu & Li, 2012). As consequence, in this paper Pareto optimization technique is preferred to determine dominance relation between solutions.

In this study by considering holistic risk factors analysis to improve the safety performance in construction site layout, 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' temporary facilities arrangements on the construction site are assumed with more safety factors.

INTERACTION RELATIONSHIP ANALYSIS

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

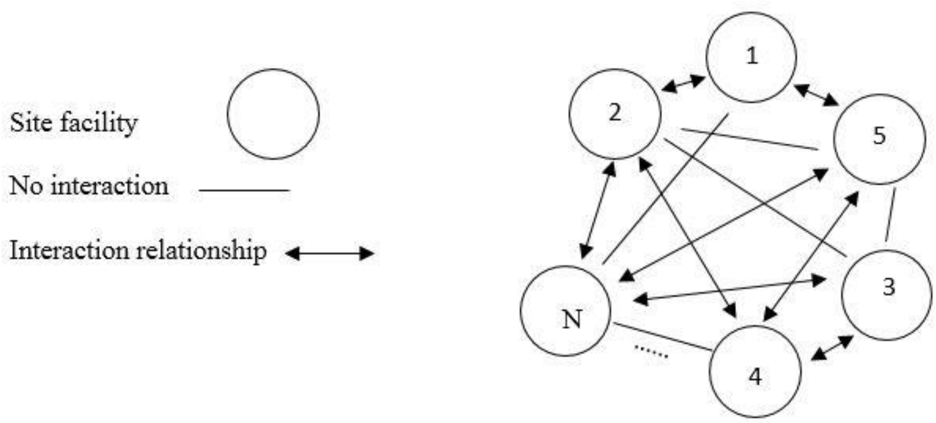


Fig.1. interaction relationship between facilities

In fig.1 facilities distance can be calculated when facilities are allocated to Free locations. The facilities should be far from away high potential risk facilities it means distance from high potential risk source or hazardous source facilities location should be maximised. Safety objective function can be defined as interaction relationship in safety or safety relationship. Site facilities consist of mobile and fixed facilities (heavy equipment, tower cranes location and material hoist location in construction site are fixed). In previous study, location problems are handled but facilities layout aren't (Moradi & Bidkhori, 2009). Hazardous materials are used and located on construction site, so people who worked on concentration site are exposed to safety risks ((Moradi & Bidkhori, 2009) & (Woodson, 2012)). Temporary facilities can be hazarding source because they can produce noise and dust (Fernández, Quintana, Chavarría & Ballesteros, 2009). Haul road is single fixed hazard source facility. Finding facilities location like haul road or tower crane (these facilities always can be considered as hazardous sources and have a safety interaction relationship with other facilities) location can be assumed as single facility location problem ((Lien & Cheng, 2014) & (Andayesh & Sadeghpour, 2014)). If fixed facilities positions are frozen in the construction site potential risk rising 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 that potential risk from the hazardous sources is not related to the categories of locations. it means that potential risk from different categories of the facilities when placed in the same location are equal. The safety between the facilities is influenced by potential risk factors (resources movement consist of quantitative flows of equipment, personal and materials). High levels of interactions flow between the facilities (equipment, personal and material) can be caused of accident 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 the result, construction safety 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) have a negative impact on temporary facilities (dangers arise from (GSR) and (FSR)). As mention previously (GSR) is related to the facilities location without considering kind of facilities placed in specific location. The (GSR) from the same hazardous sources are equal. (FSR) is related to interaction flows between the facilities that calculated by vary between the diverse facilities and construction activities. By increasing job demand between the facilities in construction site Facility safety relationship is increased.

OBJECTIVE FUNCTIONS

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 (Abune'meh, Meouch, Hijaze, Mebarki & Shahrour, 2016).

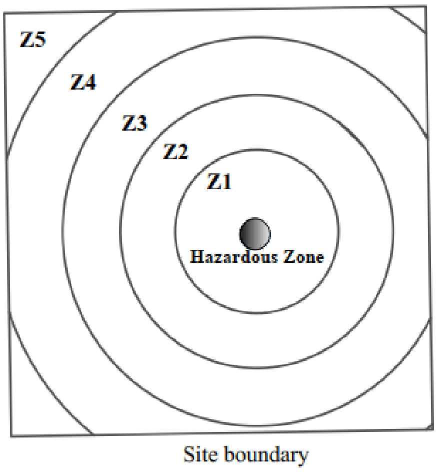


Fig.2. The risk degrees

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 (El-Rayes & Khalafallah, 2005). In fig.3 tower crane operation zone by considering potential risk are presented.

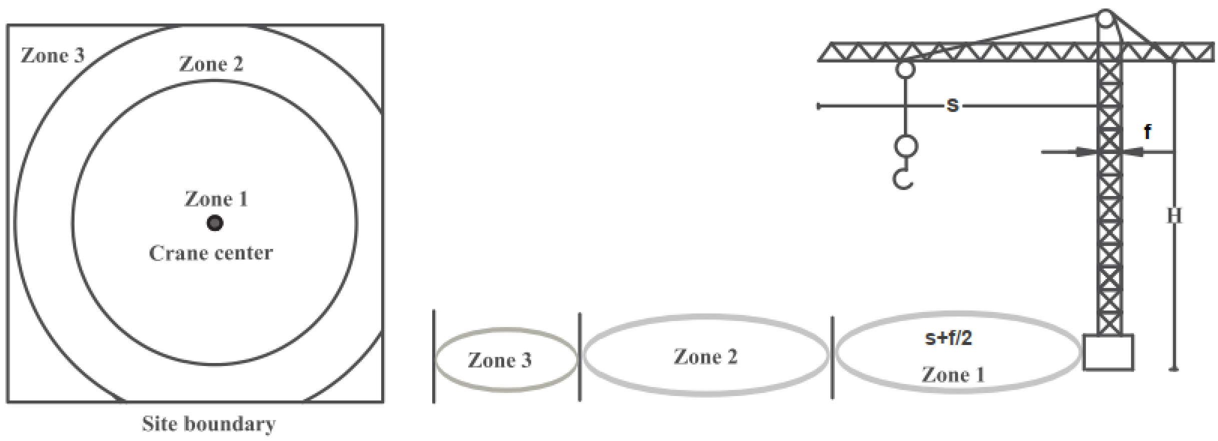


Fig.3. The tower crane risk degrees.

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. 1.

$$obj_1 = min \sum_{i=1}^{m} r_{1i} \qquad (1)$$

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) (Karray, Zaneldin, Hegazy & Shabeeb, 2000). 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_{i1} (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 (%) ($\boldsymbol{C_r}$)	Assumed value
$\boldsymbol{z_5}$	0-20	3
$\boldsymbol{z_4}$	20-40	9
$\boldsymbol{z_3}$	40-60	27
$\boldsymbol{z_2}$	60-80	81
$\boldsymbol{z_1}$	80-100	243

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 ((Lam, Tang & Lee, 2005) & (Xu, & Li, 2012) & (Ning, Lam & Lam, 2010)).

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 (El-Rayes & Khalafallah, 2005). To increase safety performance, the risk due to the (FSR) should be minimised as presented in Eq. 2.

$$obj_2 = \min\left(\sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{E=1}^{n}\sum_{F=1}^{n} r_{2ij} d_{EF}\right) \qquad (2)$$

when facility $i(i = 1,2, \dots, m)$ is assigned to location $E(E = 1,2, \dots, n)$ and $j(j = 1,2, \dots, m)$ is assigned to location $F(F = 1,2, \dots, n)$. 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.3.

$$C_r = \frac{\text{value of quantitative flow} - \text{minimum value of quantitative flows}}{\text{maximum value of quantitative flows} - \text{minimum value of quantitative flows}} \times 100 \qquad (3)$$

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% (MOHURD, 2016). 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. (4)

$$obj_3 = \min\left(\sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{E=1}^{n}\sum_{F=1}^{n} C_{ij} d_{EF}\right) \qquad (4)$$

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

MULTI-OBJECTIVE FIREFLY ALGORITHM

The basic Firefly algorithm

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 (Hashmi, Goel, Goel & Gupta, 2013). 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 (Fister, Yang & Brest, 2013).

Firefly attractiveness (β) is proportional to firefly flashing light brightness and can be computed as follows:

$$\beta = \beta_0 e^{-\gamma r^2} \qquad (5)$$

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:

$$I(r) = I_0 e^{-\gamma r^2} \qquad (6)$$

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:

$$r_{mn} = (\sum_{k=1}^{d}(x_{m,k} - x_{n,k})^2)^{0.5} \qquad (7)$$

Algorithmic firefly movement in search space is formulated as follows (Moradi & Bidkhori, 2009)

$$x_m^{t+1} = x_m^t + \beta_0 e^{-\gamma r_{mn}^2}(x_n^t - x_m^t) + \alpha\varepsilon \qquad (8)$$

Where x_m denote to current position of each firefly and the attractiveness of each firefly is presented by $\beta_0 e^{-\gamma r_{mn}^2}(x_n - x_m)$. 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.

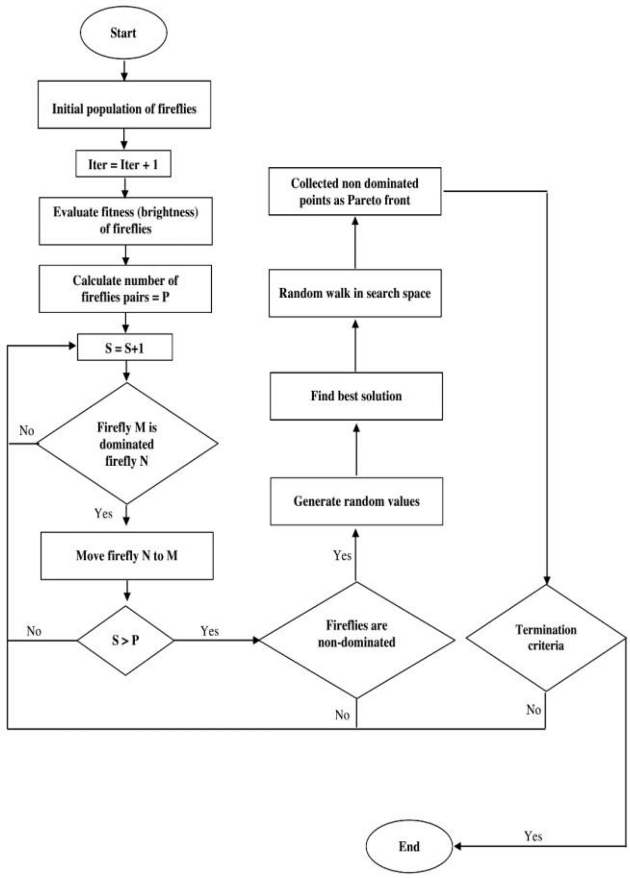


Fig.4. Firefly algorithm flow chart

Multi-Objective Firefly Algorithm

For multi-objective optimization, one way is to combine all objectives into a single objective so that algorithms for single objective optimization can be used without much modifications. For example, FA can be used directly to solve multi-objective problems in this manner, and a detailed study was carried out by Apostolopoulos and Vlachos.

Another way is to extend the firefly algorithm to produce Pareto optimal front directly. By extending the basic ideas of FA, we can develop the following Multi-objective Firefly Algorithm (MOFA), which can be summarized as the pseudo code listed in Fig. 5.

Define objective functions $f_1(x)$, ..., $f_K(x)$ where $x = (x1, ..., xd)^T$

Initialize a population of n fireflies x_i (i = 1, 2, ..., n)

while (t <MaxGeneration)

for i, j = 1: n (all n fireflies)

Evaluate their approximations PF_i and PF_j to the Pareto front

if i ≠ j and when all the constraints are satisfied

if PF_j dominates PFi,

Move firefly i towards j using (8)

Generate new ones if the moves do not satisfy all the constraints

end if

if no non-dominated solutions can be found

Generate random weights w_k (k = 1, ..., K)

Find the best solution g^t_* (among all fireflies) to minimize ψ in (9)

Random walk around g^t_* using (10)

end if

Update and pass the non-dominated solutions to next iterations

end

Sort and find the current best approximation to the Pareto front

Update t ← t + 1

end while

Postprocess results and visualisation;

Fig. 5. Pseudo Code: Multi-objective firefly algorithm (MOFA) (Yang, 2013)

The procedure starts with an appropriate definition of objective functions with associated nonlinear constraints. We first initialize a population of n fireflies so that they should distribute among the search space as uniformly as possible. This can be achieved by using sampling techniques via 4 uniform distributions. Once the tolerance or a fixed number of iterations is defined, the iterations start with the evaluation of brightness or objective values of all the fireflies and compare each pair of fireflies. Then, a random weight vector is generated (with the sum equal to 1), so that a combined best solution g^t_* can be obtained. The non-dominated solutions are then passed onto the next iteration. At the end of a fixed number of iterations, in general n non-dominated solution points can be obtained to approximate the true Pareto front.

In order to do random walks more efficiently, we can find the current best g^t_* which minimizes a combined objective via the weighted sum

$$\psi(x) = \sum_{k=1}^{K} w_k f_k \quad , \quad \sum_{k=1}^{K} w_k = 1 \qquad (9)$$

Here $w_k = p_k/K$ where p_k are the random numbers drawn from a uniform distributed Unif[0,1]. In order to ensure that $\sum_{k=1}^{K} w_k = 1$, a rescaling operation is performed after generating K uniformly distributed numbers. It is worth pointing out that the weights wk should be chosen randomly at each iteration, so that the non-dominated solution can sample diversely along the Pareto front.

If a firefly is not dominated by others in the sense of Pareto front, the firefly moves

$$x^{t+1}_i = g^t_* + \alpha_t \varepsilon^t_i \qquad (10)$$

where g^t_* is the best solution found so far for a given set of random weights. Furthermore, the randomness can be reduced as the iterations proceed, and this can be achieved in a similar manner as that for simulated annealing and other random reduction techniques. We will use

$$\alpha_t = \alpha_0 0.9^t \qquad (11)$$

where α_0 is the initial randomness factor.

CASE STUDIES

In this study the suggested model is presented to find out optimal results (construction site layout). In Table 2 temporary facilities located on the construction are listed.

Table 2: 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	25
Fixed	F_{13}	Field office	50

Facilities divided to fix and free facilities, five of them are frozen in their locations such as material hoist, security hut, tower crane, field office and eight of them are free and are assigned to free location by using of optimizing methods which is presented by the proposed algorithm (we use the fixed parameters: n = 50, $\alpha_0 = 0.25$, $\beta_0 = 1$ and $\gamma = 1$ (Yang, 2013)). The security hut and the field office are located next to the site entrance for site security and supervision. The material hoists are used to transport construction material and labour to the building's superstructure. The tower crane is structured to service two building's material transportation. In this study to simplify calculation, the site locations are assumed in terms of grids coordination so facilities distance can be determined once they are assigned. Facilities are considered by a collection of grid units (Huang & Wong, 2016). Each grid has 5-meter length and width and facilities can be located in there. For example, tower crane area is about 50 $m^2$and it can be presented by two grid unit. In Fig.6 (a) white grids represented by the number “1” and black grids represented by the number “0”. In Fig.6 (b) site locations which is not available for assignment to other facilities are presented by black grids and white grids available for assignment to other facilities.

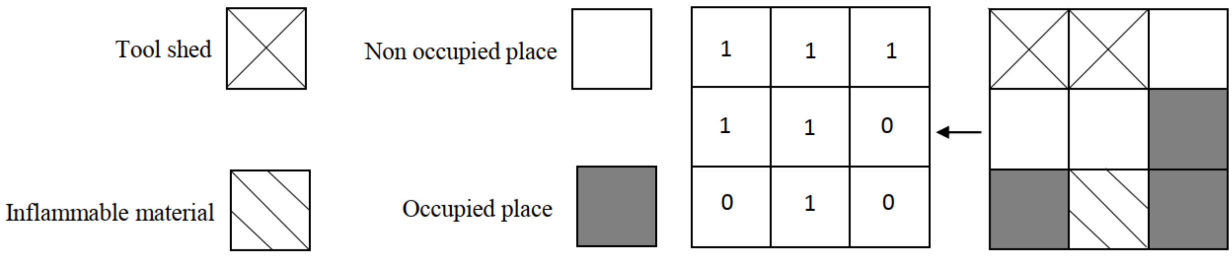


Fig.6. (a) site grids coordinate

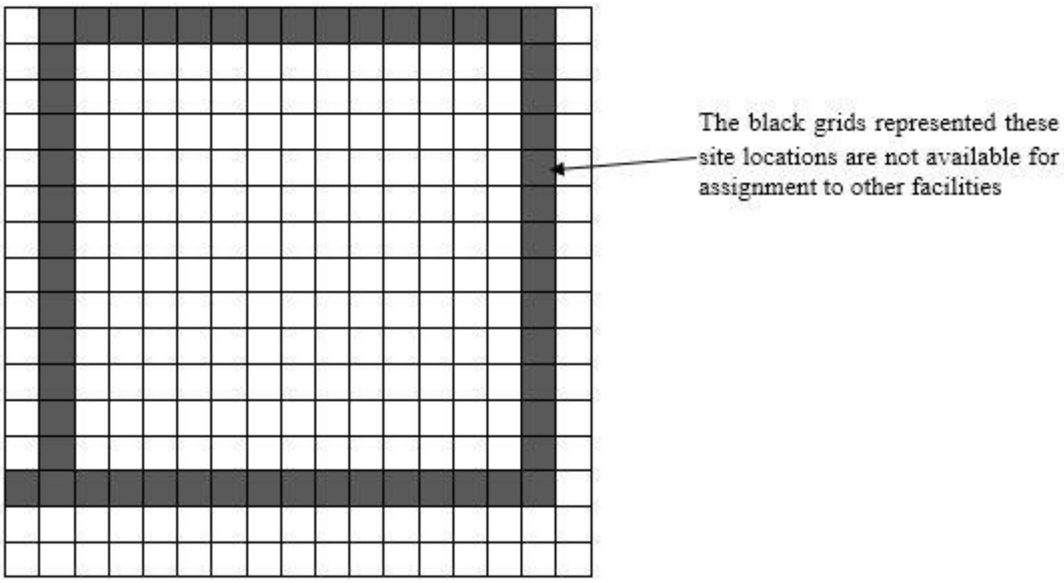


Fig.6. (b) site grids location

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

$$G_1 = (GX_i, GY_i) = (X_i - 0.5, Y_i - 0.5) \quad (12)$$

Where X_i and Y_i are refer to grid row and column. The Euclidean distance can be calculated by Eq. (15).

$$G_2 = \sqrt{(GX_i - GX_j)^2 + (GY_i - GY_j)^2} \quad (13)$$

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

$$G_3 = (FX_i, FY_j) = \left(\frac{\text{sum of the gravity } GX_i}{\text{grid untis}}, \frac{\text{sum of the gravity } GY_i}{\text{grid untis}}\right) \quad (14)$$

Finally, the distance can be presented as

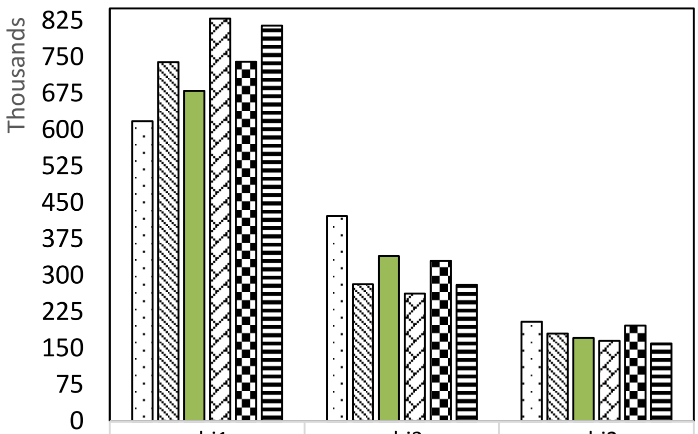
$$d_{ij} = \sqrt{(FX_i - FX_j)^2 + (FY_i - FY_j)^2} \quad (15)$$

RESULTS AND DISCUSSION

The Firefly algorithm is employed to find out construction site layout 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 maybe satisfy three objectives but cannot guarantee always generate minimum value, so multi result in optimization process seemed necessary. six optimal solutions by firefly algorithm were found.

The requirement for construction site layout is related to designer vision, so by 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.

Analytic Hierarchy Process is employed to calculate weights between the objective functions. Weight of (GSR), (FSR) and (RTC) are determined 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 Fig. 7.



	obj1	obj3	obj2
s1	617826.3	422368.5	204523.2
s2	739439.8	281653.4	180365.7
s3	680142.7	339854.7	170895.6
s4	829176.9	262895.8	164974.7
s5	739998.7	329874.2	197142.1
s6	814653.4	280223.1	159874.3

Fig.7. The optimal results for the six construction site layout alternatives

Finally, the performance of two metaheuristic algorithms called Firefly Algorithm (FA) and Ant Colony Optimization (ACO) are compared in Table 3.

Table 3: 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 [39]	ob1	618,654.2	747,873.5	679,986.7	831,255.5	742,072.1	813,656.8
	ob2	205,617.7	178,913.3	171,976.0	165,229.2	196,414.8	158,023.2
	ob3	421,227.4	282,551.0	340,169.7	263,599.7	330,156.9	279,424.3
	Weighted sum	439,281.9	450,512.0	434,151.0	477,196.8	465,820.4	471,509.9
FA	ob1	617,826/30	739,439/80	680,142/70	829,176/90	739,998/70	814,653/40
	ob2	204,523/20	180,365/70	170,895/60	164,974/70	197,142/10	159,874/30
	ob3	422,368/50	281,653/40	339,854/70	262,895/80	329,874/20	280,223/10
	Weighted sum	438,883/31	447,102/37	433,801/22	476,041/13	465,080/78	472,720/00

Minimum value for Geography Safety relationship in construction site layout S1is about 617826.3. In this situation, the temporary facilities are located far away from F11, F12 (material hoists) and F13 (tower crane).

The schematic of construction site layout by considering optimal results for each of S1, S2, and S3 are presented in Figs. 8 to 10, respectively. The optimal site layouts were generated to minimize the risk caused by (GSR), (FSR) and (RTC). Results shows there isn’t unique solution for the construction site layout.

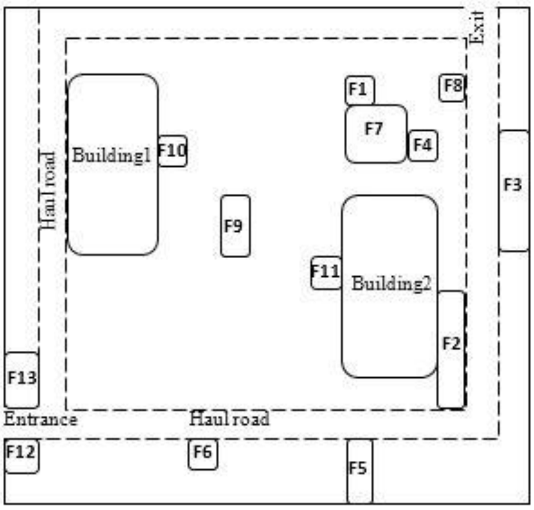


Fig.8. Schematic layout drawing for S1.

If the facilities are assigned in the specific lower safety zone the risk degrees are reduced. The health and safety of laborers are improved by placing labour hut away from the dangerous facilities. The labour hut is located adjacent to the haul road and the right of building 1, also potential risks from the tower crane are lower. Facility safety relationship has the highest value of 204,523.2. It means the distance between the facilities are great. For the disperse distribution of the facilities the resources transportation cost has the value of 422,368.5.

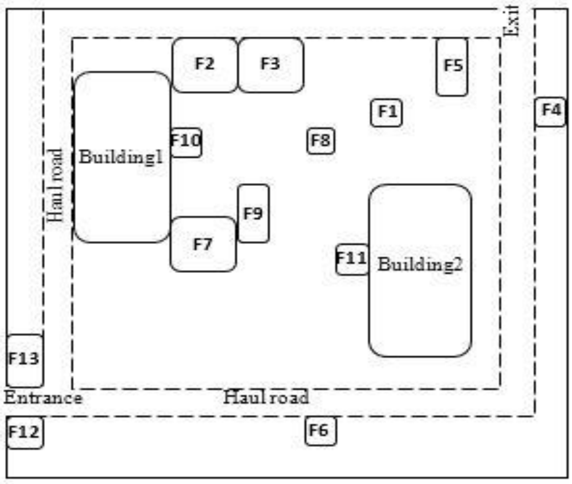


Fig.9. Schematic layout drawing for S2

By comparing the distribution of temporary facilities in S3 is more centralized than in S1. As consequence, facility safety relationship in S1 204,523.2 is higher than that of 170,895.6 in S3. the value for resources transportation cost and material handling cost are increased by placing carpentry workshop and rebar bending yard far away from material laydown area in S1 than that in S3. The risk degree from dangerous facilities in S3 is relatively high because tool shed is arranged around tower crane and material hoist. Higher distance between the facilities made the noise level shorter. Carpentry workshop and material laydown area are arranged next to the facilities of equipment maintenance plant and labour hut in S3 such that the noise pollution for them is relatively high.

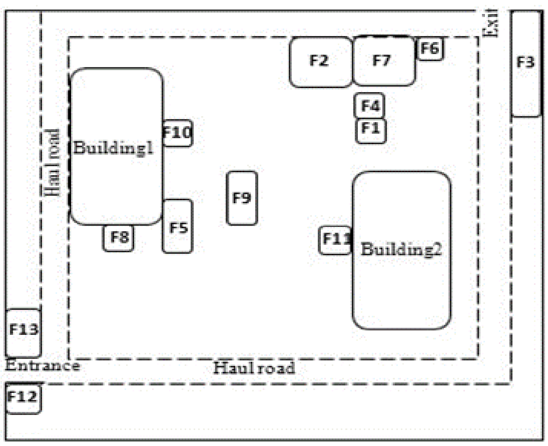


Fig.10. Schematic layout drawing for S3

Inflammable materials location in S3 is more reliable and reasonable than that in S1. As consequence the (GSR) 680,142.7 in S3 is higher than 617,826.3 in S1. Also, resources transportation cost in S3 is relatively lower because there is a shorter distance between material laydown area and carpentry workshop with a value of 339,854.7. When considering construction productivity in S3 layout labour hut to be close to material laydown area and carpentry workshop. Finally, for site managers it is simplifying layout alternative S3 with the minimum weighted sum is more suitable than 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, rebar bending yard and material laydown are adjacent to material hoist and carpentry workshop is assigned in the danger zone of tower crane. The risk degree for health and personnel safety related to hazardous materials and noise pollution in 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 maximum value of geography safety relationship 739,439.8. in S2 layout carpentry workshop and material laydown areas are assigned separately on both sides of tower crane, so the possibility of accident between these facilities is increased and productivity is decreased. Carpentry workshop is arranged near to material laydown area safety relationship in S3 layout is reduced and construction productivity is improved. Distance between the facilities in S3 is greater than in S2 so resources transportation cost is higher 339,854.7. Facility Safety Relationship and Geographic Safety Relationship are more important in construction site layout, therefore S3 is more reasonable than S2 layout.

CONCLUSION

In this study to improve the safety performance in construction site layout the importance of safety by revealing interaction flows has been assumed. By considering interaction relationship between the facilities innovatively presenting the two safety objective functions pertaining (Facility safety relationship and geographic safety relationship). Since construction cost is the basic and very important requirement for construction management, an additional objective function related to cost was also established as a supplementary objective for CSLP. Finally, a residential building was used as a case study to illustrate the applicability and feasibility of the proposed model. The results show that the objective function related to interaction relationship is congruent with resources transportation cost and have a conflicting relationship with the objective function related to geographic safety relationship. Firefly algorithm is employed as multi-objective optimization method to find out the optimal solution. The Firefly Algorithm generates pareto optimal solutions by calculating the dominance relation between the solutions. This study focused on safety optimization problems in construction site layout by developing Firefly multi-objective optimization algorithm for designing a safe construction site layout model based on analytical and numerical manner.

Pareto solution provides many site layout alternatives for decision-making. The site manager by assuming project requirements or personal preference can select the final construction site layout. It is better site manager put the facilities with higher resources movement closer to each to increase safety and reduce transportation cost. Also, for reducing (GSR) risk the facilities should be located far away from danger sources, such as material hoists, haul roads, tower crane. The (GSR) increases by closing distances between the temporary facilities, so to reduce (GSR) the non-productivity facilities, should be placed far away from heavy facilities.

Safety objective functions constructed (based on GSR and FSR) and construction cost are assumed to established an optimization model. Firefly algorithm is employed as optimization method by generating pareto optimal front according to the dominance relation between solutions. The results show that objective functions related to (GSR) and interaction relationship is congruent with (RTC). Also, safety improvements in the construction site layout are considered to establish multi objective optimization model to generate optimal site plans. The performance of FA and ACO are compared in terms of their effectiveness in resolving this problem and results showed that the FA performs better than the ACO Algorithm. This paper presents a scientific method to site managers to organize temporary facilities in construction sites by considering safety and resources transportation cost.

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