Construction Management and Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

The application of the ant colony optimization algorithm to the construction site layout planning problem

Ka-Chi Lam , Xin Ning & Thomas Ng

To cite this article: Ka-Chi Lam , Xin Ning & Thomas Ng (2007) The application of the ant colony optimization algorithm to the construction site layout planning problem, Construction Management and Economics, 25:4, 359-374, DOI: 10.1080/01446190600972870

To link to this article: https://doi.org/10.1080/01446190600972870

Published online: 02 May 2007.

Submit your article to this journal

Article views: 419

View related articles

Citing articles: 43 View citing articles

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=rcme20

Construction Management and Economics (April 2007) **25**, 359–374

The application of the ant colony optimization algorithm to the construction site layout planning problem

KA-CHI LAM[1]*, XIN NING[1] and THOMAS NG[2]

[1] *Department of Building and Construction, City University of Hong Kong, Hong Kong*
[2] *Department of Civil Engineering, University of Hong Kong, Hong Kong*

Received 11 November 2005; accepted 23 August 2006

A good site layout is vital to ensure the safety of the working environment, and for effective and efficient operations. Moreover, it minimizes travel distance, decreases materials handling, and avoids the obstruction of materials and plant movement. Based on studies in the manufacturing industry, the cost of materials handling could be reduced by 20–60% if an appropriate facility layout is adopted. In designing a site layout, a planner will first position the key facilities that influence the method and sequence of construction, and then assign the remaining facilities in the available space that is left over. This process is similar to the positioning of facilities in the ant colony optimization (ACO) algorithm. The general principle of the ACO algorithm is to assign facilities to a location one by one, and the occupied locations are deleted from the location scope in the next assignment. In the study, ACO algorithm is employed to resolve the construction site layout planning problem in a hypothetical medium-sized construction project. By applying fuzzy reasoning and the entropy technique, the study calculates the closeness relationship between facilities, in which the optimal site layout is affected by the mutual interaction of facilities.

Keywords: ACO algorithm, site layout, heuristic, closeness relationship

Introduction

Site layout planning is an important task in site management of a construction project, as an appropriate layout boosts the effectiveness and efficiency of the construction work. However, the arrangement of site facilities is hindered by many constraints, such as the limits on the site area, adjacent buildings, access, the location and orientation of the building to be constructed. Moreover, the complex and dynamic nature of the construction industry increase the difficulty of layout planning. Therefore, traditional construction sites are generally found to be messy, disorderly, and to lack proper planning.

The site layout problem is a non-polynomial hard (NP-hard) problem, and the complexity increases exponentially with the number of facilities. The algorithms that are commonly used in site layout problems can be categorized as: exact algorithms, heuristic algorithms and AI-based algorithms. Exact algorithms (Christofides and Benavent, 1989) are for resolving site layout problems and provide a global optimal solution to the problem. However, they are only feasible for small-scale problems, and cannot meet the requirements of practical construction.

Heuristic algorithms, such as tabu search (TS), simulated annealing (SA) and genetic algorithms (GAs), are popularly used to solve site layout problems. TS is a local search method, which is used for the laying out of multi-floor facilities (Abdinnour-Helm and Hadley, 2000). SA is a method for solving combination problems, and is generally applied to the laying out of multi-objective facilities (Suresh and Sahu, 1993). Li and Love (2000) and Osman *et al.* (2003) used GAs to solve site layout problems in unequally sized facilities. The objective functions of those algorithms were the optimization of the interaction of facilities, such as the total cost of transporting resources between facilities, and the frequency of trips made by construction

*Author for correspondence. E-mail: bckclam@cityu.edu.hk

Construction Management and Economics
ISSN 0144-6193 print/ISSN 1466-433X online © 2007 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/01446190600972870

personnel between facilities. Hegazy and Elbeltagl (1999) developed a comprehensive system for site layout planning based on GAs. Combining a knowledge-based system, fuzzy logic and GAs, a practical model for schedule-dependent site layout planning in construction was presented in Elbeitagi *et al.* (2001). AI-based algorithms were demonstrated by Yeh (1995) and Elbeitagi and Hegazy (2001), who used a hybrid neural network to find an optimal site layout.

Based on previous research, the algorithms that are most commonly used to solve site layout problems are GAs, SA and TS. Previous research has focused on solving different optimization problems by applying these algorithms under different constraints, which means that the quality of the solution is limited by the capability of the algorithm. SA is a heuristic method which tries to overcome local optimality in solving hard combination optimization problems. The main drawback of SA is the relatively high number of control parameters and the absence of a widely accepted and well-argued strategy for choosing their values. However, a careful tuning of the control parameters often yields high quality solutions. When the running time limits increase, SA gets more easily stuck in local optima (Cela, 1998). The strength of GAs lies in their ability to locate the global optimum using random yet directed searching operators. Therefore, the GA is less likely to restrict the search to a local search (Li and Love, 2000). While the great advantage of GAs is the fact that they find a solution through evolution, this is also the biggest disadvantage. Evolution is inductive; natural life does not evolve towards a good solution—it evolves away from bad circumstances. This can cause a species to evolve into an evolutionary dead end. Likewise, GAs risk finding a suboptimal solution. Another main disadvantage of GAs is the excessively long run-time that is needed to deliver satisfactory results for large instances of complex design problems (Beasley *et al.*, 1993a, 1993b). As for TS, the efficiency of TS is often due to a significant fine-tuning effort of a large collection of parameters and different implementation choices (Hertz *et al.*, 1997).

Ant colony optimization algorithm

Ant colony optimization (ACO) algorithm is a population-based, general search technique for finding the solution of difficult combinatorial problems. It was inspired by the pheromone (a chemical that foraging ants deposit on the ground to increase the probability that other ants will follow the same path) trail laying behaviour of real ant colonies (Stützle, 2005). The first ACO algorithm, which was called the ant system (AS), was first proposed by Dorigo *et al.*, (1991) to solve the travelling salesman problem.

The main idea of the ACO algorithm is that the self-organizing principles that allow highly coordinated behaviour among the real ants can be exploited to coordinate populations of artificial agents that collaborate to solve computational problems (Dorigo and Stützle, 2004, p. 1). The ACO algorithm was inspired by the foraging behaviour of ant colonies. In the process of searching for food, ants coordinate their activities using pheromones. When ants are looking for food, they always choose the shortest branch to reach a food source and return to the nest. When subsequent ants must make a decision between a short and long branch while foraging, the higher lever of pheromone on the shorter branch will bias their decision in favour of that branch. Consequently, pheromones accumulate faster on the shorter branch (the length of the branch here is heuristic information; the shorter branch the higher the level of heuristic information), which will eventually be used by all of the ants because of the autocatalytic process. The ACO algorithm aims to solve discrete optimization problems, such as routing problems, assignment problems, scheduling problems, subset problems, machine learning, and network routing. Several aspects of the behaviour of ant colonies have inspired different kinds of ACO algorithms, for example, foraging, brood sorting, cooperative transport and division of labour.

There are three different versions of the ACO algorithm: ant-density, ant-quantity and ant-cycle. Whereas in the ant-density and ant-quality versions the ants update the pheromone directly in every step, in the ant-cycle version the pheromone update is only carried out after all of the ants have found a solution. Thus, the ant-cycle algorithm performs better than the other two algorithms because global information about the value of a result is used (Dorigo *et al.*, 1991). The ant-cycle algorithm is used here to solve the site layout planning problem.

ACO algorithm approach to site layout planning

In the ACO algorithm, the ants choose a solution by using pheromone and heuristic information between free locations. Heuristic information is defined in accordance with the attribution of the objective function of the problem, which affects the convergence time and direction in which the ants move. Different problems determine different heuristic parameters, and this makes ACO algorithms more applicable to solving real-life problems. According to Dorigo and Gambardella (1997), the ACO algorithm has been found in other operational research to outperform GAs. To support their claim, they compare the work of Bersini *et al.* (1995) with the work of Whitley *et al.* (1989). For SA algorithm, they also compare the work of Lin *et al.* (1993) with the work of Eilon *et al.* (1969) in terms of solution quality and number of steps to obtain the best solution.

In site layout planning, the project manager will first position the key facilities that most influenced the method and sequence of construction, and then assign the remaining facilities in the available space that is left over. This process is similar to the positioning of facilities in the ACO algorithm. First, the sequence to position facilities will be made in accordance with flow between facilities. The main factor affecting the result will be the facilities which have high flows compared with other facilities. The facilities which have higher flow are the key facilities. Second, the predetermined facilities will be positioned to the location one by one by the ACO algorithm. The general principle of the ACO algorithm is to assign facilities to a location one by one, after which the occupied locations are deleted from the location scope in the next assignment. Most of the previous research work in this area only focused on GAs, SA and TS, in which the solutions are obtained by the iteration of the initial feasible solutions, which differ from the reality fundamentally. Ants choose a solution in accordance with the level of pheromones and the heuristic information that they find between locations, and controllable parameters increase the application and convergence so that less time is required to reach an optimal solution, which improves the effectiveness of the algorithm. An ACO algorithm is selected in this study to search for an optimal site layout for a medium-sized project because of its good performance in solving combination optimal problems, such as the travelling salesman problem (Dorigo and Gambardella, 1997) and assignment problems (Maniezzo *et al.*, 1994).

The proposed model for the site layout problem

A model is proposed for site layout planning in medium-sized projects. Basically, this model involves three mathematical approaches: the entropy technique and fuzzy logic for analysing the collected data and the ACO algorithm for optimizing the results.

Objective function

Based on the study and consultation with practitioners in the construction industry, the objective function is found to depend mainly on two attributes: the closeness relationship (f) between the facility (i,j) and the distance (d) between the location (k,l). The objective function aims to minimize the sum of the interaction flow between facilities:

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

subject to the constraints

$$\sum\nolimits_{i=1}^{n} x_{ij} = 1 \tag{2}$$

$$\sum\nolimits_{j=1}^{n} x_{ij} = 1 \tag{3}$$

$$x \in \{0,1\} \tag{4}$$

The location of each facility is assigned and located in accordance with these constraints, where f_{ij} is the closeness relationship between facilities i & j, $f_{ij} = w_1 C_{WF_{ij}} + w_2 C_{IF_{ij}} + w_3 C_{SE_{ij}} + w_4 C_{PP_{ij}}$, where w is the corresponding weight of each closeness index, $C_{WF_{ij}}$ is the closeness index of the work flow (WF) between facilities i & j, $C_{IF_{ij}}$ is the closeness index (IF) of the information flow between facilities i & j, $C_{SE_{ij}}$ is the closeness index of the level of safety and the environment (SE) between facilities i & j, $C_{PP_{ij}}$ is the closeness index of personal preference (PP) between facilities i & j; d_{kl} is the distance between locations k & l; x_{ik} and x_{jl} mean when facility i is assigned to location k and facility j is assigned to location l, the constraint of x_{ij} will be a binary variable which takes value 1 if facility i is assigned to location j and 0 otherwise.

Closeness relationship between site facilities

According to Lam *et al.* (2005), the closeness relationships between site facilities are mainly work flow, information flow, safety and environment, and personal preference. These attributes are defined as follows:

Work flow (WF): work in process, transportation of materials, equipment, and so forth from one facility to another.
Information flow (IF): communication between facilities, including personnel flow, supervision of personnel, conveying information and inspection.
Safety and environment (SE): safety and environment factors, such as requirements, regulations, access, site tidiness and noise.
Personal preference (PP): decision attributes of planners based on their preference or experience.

Importance indices of factors in the site layout planning

The importance indices are determined by adopting an entropy technique to remove the uncertainty between respondents, and to obtain more accurate results in deducing the weighting of each factor. The concept of entropy technique is used for the quantitative measurement of the uncertainty that exists in every probability distribution. The method of providing information using this technique focuses on the removal of uncertainty. Although it originates from thermodynamics, it has been adopted in a variety of disciplines, including communication theory, statistical information theory, and the social and life sciences. Shannon (1948) first created a measure of uncertainty for a probability distribution by addressing the communicating information that is lost across noisy channels in determining the quantity of information that is sent, received and lost. Entropy is still being adopted by new research fields.

Each factor has its own importance index that governs the decision making involved in site layout planning in medium-sized projects. The equations that are used to apply entropy technique are summarized as follows.

First, to determine the expected value (V_i) of ith factor,

$$V_i = \frac{\sum_{j=1}^{n} S_{ij}}{n} \quad (i=1,\ldots,m) \tag{5}$$

where S_{ij} is the collected scores for the importance index from respondents; n is the number of respondents in the survey; and m is the number of the factors.

If the probability distribution (P) of each importance index from individual respondents is

$$P_{S_{ij}} = \frac{S_{ij}}{\sum_{i=1}^{n} S_{ij}} \tag{6}$$

then the entropy E_i of ith factor is

$$E_i = \frac{-1}{\ln n} \sum_{1}^{n} P_{S_{ij}} \ln P_{S_{ij}} \tag{7}$$

Finally, the weighting (w_i) of the ith factor is

$$w_i = V_i \times E_i \Big/ \sum_{1}^{m} V_i \times E_i \quad (i=1,\ldots,m) \tag{8}$$

where V_i and E_i are the values and entropy of the ith factor; m is the number of the factors.

Closeness indices of the site facilities

According to Rescher (1969), Lukasiewicz was the first person to propose fuzzy sets, and Zadeh (1965) carried out further work on this possibility theory to create a formal mathematical representation of fuzzy terms that is known as fuzzy logic. To consider the vagueness of subjective selections that are represented in data, triangular fuzzy numbers (Chan *et al.*, 1999) have been used to determine the final rating of closeness indices. The modification of the membership functions for the triangular fuzzy numbers in Hanss (1999) gives the following triangular fuzzy numbers for the closeness indices (C_f) in this study:

$$C_f = \begin{cases} C_u = C_m + \sigma(\mathit{upper\ bound}) \\ C_m(\mathit{mean\ bound}) \\ C_l = C_m - \sigma(\mathit{lower\ bound}) \end{cases} \tag{9}$$

where C_m is the mean value of the collected closeness indices $\frac{\sum C_i}{n}$ and σ is the standard deviation of the collected closeness indices $\sqrt{\frac{\sum (C_i - C_m)^2}{n}}$.

Procedure for the application of an ACO algorithm to a site layout decision model

With reference to the work of Stützle and Dorigo (1999), the ACO algorithm is established by the following steps.

Step 1. Define the heuristic information

The heuristic parameter of the ACO algorithm is defined in accordance with the characteristics of the problem that is to be solved, and therefore the heuristic parameter of the ACO algorithm is determined by different problems case by case. This makes the ACO algorithm more applicable in solving real-world problems, and increases the ability to find high quality solutions to combinatorial optimization problems in a reasonable time (Dorigo and Stützle, 2004).

The heuristic information (e) is defined as

$$e_{ij} = f_i \cdot d_j \tag{10}$$

The heuristic desirability (η) of assigning facility i to location j is then given by

$$\eta_{ij} = 1/e_{ij} \tag{11}$$

The two vectors d and f are calculated such that the ith component represents the sum of the distances from location j to all other locations and the sum of the flows (closeness relationship) from facility i to all of the other facilities, respectively. The lower the value of d_j, which is the distance potential of location j, the more central the location is considered to be, and the higher the value of f_i, which is the flow (closeness relationship) potential of facility i, the more important the facility.

Step 2. Select assignment sequence for the facilities

The assignment sequence for the facilities is sorted in non-increasing order by the flow (closeness relationship) potentials (f_i). The assignment sequence determines the position of the facilities.

Step 3. Assign facilities to a location

At each construction step, an ant k assigns the next unassigned facility i to a free location j with a probability of

$$p_{ij}^{k}(t) = \frac{\left[\tau_{ij}(t)\right]^{a} \cdot \left[\eta_{ij}\right]^{\beta}}{\sum_{l \in N_i^k} \left[\tau_{ij}(t)\right]^{a} \cdot \left[\eta_{ij}\right]^{\beta}} \quad \text{if } j \in N_{\mathrm{i}}^{k} \tag{12}$$

where $\tau_{ij}(t)$ is the pheromone trail at iteration t, η_{ij} is the heuristic information between facility i and location j, α, and β are the parameters that determine the relative influence of the pheromone strength and the heuristic information, and N_i^k is the feasible neighbourhood of node i, that is, only those locations that are still free (note that $\sum_{l \in N_i^k} p_{ij}(t) = 1$). This step is repeated until a complete solution is found.

Step 4. Pheromone update

The pheromone is updated after all of the ants have found a solution in accordance with the following equation:

$$\tau_{ij}(t+1) = \rho \cdot \tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{13}$$

where $\rho(0<\rho<1)$ is the persistence of the pheromone trail such that $(1-\rho)$ represents the evaporation. The parameter ρ is used to avoid an unlimited accumulation of pheromone trails, and allows the algorithm to forget previous bad choices. $\Delta\tau_{ij}^{k}$ is the amount of pheromone that ant k puts on the coupling (i,j)

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{Q}{L^k} & \text{if the facility is assigned to location} \\ & j \text{ in the solution of ant } k \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

where L_k is the objective function value and Q is the amount of pheromone that is deposited by an ant.

Step 5. A local search is used to improve the quality of the solution that is found through ACO algorithm

To find a more satisfying solution and avoid a local optimal solution, the combination of the ACO algorithm and the local search algorithm is adopted, where the initial solution that is used in the local search algorithm is obtained from the ACO algorithm.

An ACO algorithm is combined with a 2-opt local search procedure (Buffa *et al.*, 1964) for the quadratic assignment problem.

Let φ be a solution for the site layout planning. Then its 2-opt neighbourhood $\acute{\varphi}$ is defined as the set of all possible solutions resulting from φ by swapping two distinct elements. The 2-opt local search algorithm searches the neighbourhood of a current solution for a better solution. If such a solution is found, it replaces the current solution and the search continues. Otherwise, a local optimum has been reached.

Case study

Assumptions of the proposed ACO algorithm site layout model

In the site layout problem, two assumptions are made:

(1) There is no difference in the size of facilities.
(2) All locations are assumed to be capable of accommodating any of the facilities.

The hypothetical site

A medium-sized government project is adopted as a hypothetical construction site for the application of an ACO algorithm to find the optimal site layout. The hypothetical project is a traditional seven-storey reinforced concrete school block, and works include laying the foundations, structural works, external works and building services installation. The simplified layout of the construction site is shown in Figure 1.

Site facility

The number and type of facilities depend on the size and nature of the construction project. For large-scale projects, it may be economical to establish a concrete batching plant on site. However, ready-mix concrete is preferred in medium-sized projects, because they are generally congested (Lam *et al.*, 2005, p. 136). To illustrate the method of applying an ACO algorithm to the site layout planning problem, a simplified construction site is used. Some common site facilities, such as a site office, a labour hut, a materials storage area, a main gate and a refuse storage area, are considered in this study. The numbered site facilities are listed in Table 1. The main gate, materials hoist and refuse chute are regarded as fixed facilities. The location of the main gate is usually determined in the hoarding plan, and is therefore seldom relocated until the end of the project. For a medium-sized project, the materials hoist is used for the transportation of materials to the superstructure, rather than a tower crane. There is no doubt that the flexibility of a tower crane is much greater, but its high installation and operation costs offset its

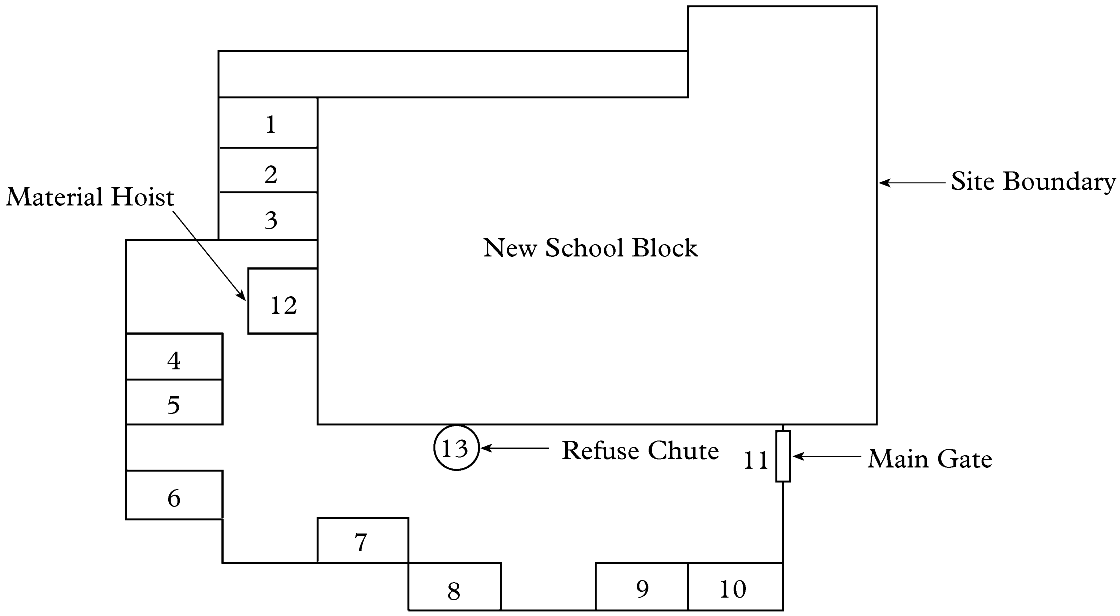

Figure 1 Layout of the hypothetical site

advantages in a medium-sized project (Lam *et al.*, 2005, p. 136). Further layout planning consideration is necessary when using a materials hoist, as its location is dependent on the structural element to which it is tied, and thus site planners always freeze this facility in a certain location. As with the materials hoist, the refuse chute is planned in a desired location. The locations of these fixed facilities and their location indices are shown in Figure 1.

Travel distance between site locations

The travel distance between locations is measured using the rectangular distance that represents the actual operations and resource movements on site. Moreover, travel units are used instead of actual measurements to simplify the scenario. Table 2 shows the travel distances between the possible locations of the facilities.

Table 1 Assumed facilities on the case study construction site

Index	Site facilities
1	Site office
2	Debris storage area
3	Reinforcement bending/storage yard
4	Carpentry workshop and store
5	Labour hut
6	Materials storage area
7	Main gate (fixed)
8	Materials hoist (fixed)
9	Refuse chute (fixed)

Determination of the variables

To obtain the values for the variables, including the importance indices of factors in the site layout planning and the closeness indices of the facilities, a survey was conducted among 15 respondents in the construction industry, including five project managers, five site agents and five foremen. A nine-point scale was employed in the questionnaire, and the respondents were required to give opinions on the degree of importance of the four factors (work flow, information flow, safety and environment, and personal preference) that influence site layout planning and the degree of closeness between the nine predetermined site facilities (site office, main gate, rebar bending/storage yard, carpentry workshop and store, labour hut, materials storage area, debris storage area, materials hoist and refuse chute) for the four factors.

Deducing the weighting of the importance index

The collected figures for the importance index of each factor are shown in Table 3, where 9 represents extremely important and 1 represents not important.

Through the application of entropy technique, the weightings for each factor can be deduced and the results are shown in Table 4.

Finding the closeness index

To determine the closeness index for each factor, the nine predetermined site facilities were used to collect data. A pre-set nine-point rating scale was used to show

Table 2 Travel distance between locations

Location	Travel distance												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	–	1	2	6	7	9	12	14	16	17	13	4	9
2	1	–	1	5	6	8	11	13	15	16	12	3	8
3	2	1	–	4	5	7	10	12	14	15	11	2	7
4	6	5	4	–	1	3	7	9	11	12	9	2	5
5	7	6	5	1	–	2	6	8	10	11	8	3	4
6	9	8	7	3	2	–	3	5	7	8	8	5	4
7	12	11	10	7	6	3	–	2	4	5	7	6	3
8	14	13	12	9	8	5	2	–	2	3	5	8	3
9	16	15	14	11	10	7	4	2	–	1	3	11	6
10	17	16	15	12	11	8	5	3	1	–	2	12	7
11	13	12	11	9	8	8	7	5	3	2	–	9	5
12	4	3	2	2	3	5	6	8	11	12	9	–	4
13	9	8	7	5	4	4	3	3	6	7	5	4	–

Table 3 Importance index of the factors to be considered in the site layout planning

Factor	Importance index (S) of respondents														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Work flow	7	8	8	8	9	9	8	8	8	7	9	7	7	9	7
Information flow	9	9	7	8	9	7	8	9	5	8	6	8	5	9	7
Safety and environment	6	8	6	8	9	8	6	8	7	9	8	7	9	9	6
Personal preference	8	6	3	6	6	4	3	7	5	6	6	8	5	7	8

Table 4 Deduced weighting of the factors to be considered in the site layout planning

Factor	Expected value	Entropy	Weighting
Work flow	7.9333	0.9983	0.2748
Information flow	7.6000	0.9938	0.2620
Safety and environment	7.6000	0.9957	0.2626
Personal preference	5.8667	0.9856	0.2006

the crisp values of the collected closeness indices for each factor, where 1 (point) indicates that the facilities should be as far away from each other as possible or that the closeness is irrelevant, and 9 indicates that the facilities should be arranged as close together as possible.

By applying the fuzzy logic technique, the triangular fuzzy closeness indices (lower bound, mean and upper bound) are generated, and are summarized in Tables A1, A2, and A3 as per Appendix A.

Calculating the closeness relationship

The closeness relationship between the site facilities is determined in accordance with the equation $f_{ij} = w_1 C_{WF_{ij}} + w_2 C_{IF_{ij}} + w_3 C_{SE_{ij}} + w_4 C_{PP_{ij}}$, where w and C are the data in Tables 4, A1, A2 and A3. This study concentrates on the upper bound, mean and lower bound, and the finalized closeness relationship is shown in Table A4 in Appendix A.

Objective function

The defined objective function $\min \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{l=1}^{n} \sum_{k=1}^{n} f_{ij} d_{kl} x_{ik} x_{jl}$ aims to minimize the sum of the interaction flow between facilities, where f_{ij} is the closeness relationship between the facilities and d_{kl} is the travel distance between location k&l as given in Table 2. The objective function is used to update the pheromone in the ACO algorithm and to find the optimal solution in the local search.

Results and comments on the optimal site layout

After obtaining all of the values for the variables of f and d, ACO algorithm was used to optimize the objective function to find the optimal site layout $\tau_0 = m/C^{mm}$, where m is the number of ants and C^{mm} is the length of a tour that is generated by any reasonable tour construction procedure. The reason for this choice is that if the initial pheromone value τ_0 is too low, then the search is quickly biased by the first tours of the ants, which in general leads toward the exploration of inferior zones in the search space. However, if the initial pheromone values are too high, then many iterations are wasted in waiting until evaporation reduces the amount of pheromone to a sufficient degree that the pheromone that is added by ants can start to bias the search (Dorigo and Stützle, 2004, p. 70). The emphasis is therefore not on the algorithm that is used, but on the initial value of τ_0. The original site layout is shown in Table 5. The number of ants m=6. The results from four perspectives, ρ=0.95, ρ=0.90, ρ=0.80, ρ=0.50, are obtained, and are shown in Table 6. The different optimal solutions for layouts A, B, C and D are shown in Figures 2 to 5, respectively.

The initial site layout is generated by an experienced project manager. After the application of the optimization of the site layout, the initial interaction flow was found to be reduced by 6.3%~10.8%. From this result, we can see that the value of parameter ρ is critical to the ant search iteration. If it is too high, then too much pheromone is deposited and stagnation may take place, which means that a local optimal solution will be obtained. However, if it is too low, then too little information is conveyed from the previous solution, and it is too difficult to find an optimal solution within a reasonable time.

Site layouts A and D are not reasonable in terms of the location of the site office, which is too far from the main gate. It is preferred that the site office be near the main gate so that site staff can enter the site office via the shortest route. Furthermore it is dangerous for the site manager/staff to have to travel from the main gate to the office site through the debris storage area and rebar bending yard and around the materials hoist. The labour hut should be adjacent to the site office so that the residential area for the site staff and workers can be concentrated in a particular zone, and to convey the construction plan conveniently. In this respect, layout A is better than layout B. Layouts A, B and D place a facility in location 3. These site layout solutions can lead to preventing the set-up of temporary scaffolding in location 3 and therefore hindering the finishing of the building façade in that location; and obstructing the movement of construction equipment and crews around the building which could disrupt the flow of construction material and equipment from the storage area to the north side of the building. In addition to these comments, the construction managers who were surveyed agreed with the location of the materials store and debris storage area, because the two site facilities should be separated to achieve efficient housekeeping. The short distance between the materials hoist and materials store means that site workers can efficiently transport materials to the superstructure. In this respect, layout D is better than layout A.

A comparison of layouts B and C shows that layout C is more reasonable in terms of the location of the rebar bending area and site office. As a materials hoist is the main form of lifting equipment on site, a large volume of operations will be carried out daily, which will make

Table 5 The original site layout

Location	1	2	3	4	5	6	7	8	9	10	11	12	13
Facility	0	0	0	3	4	6	1	5	2	0	7	8	9

Table 6 Results of the optimization of the objective function

α=0.5 β=0.7	Closeness relationship (f)	Original objective function	Optimal objective function	Optimal result	Reduction (%)
ρ=0.95	Lower bound	752.8	675.2	A	10.3
	Middle bound	1614.0	1470.2	A	9.0
	Upper bound	2459.4	2249.8	A	8.5
ρ=0.90	Lower bound	752.8	671.5	B	10.8
	Middle bound	1614.0	1467.0	B	9.1
	Upper bound	2459.4	2246.5	B	8.7
ρ=0.80	Lower bound	752.8	675.2	A	10.3
	Middle bound	1614.0	1470.2	A	9.0
	Upper bound	2459.4	2249.8	A	8.5
ρ=0.50	Lower bound	752.8	690.3	D	8.3
	Middle bound	1614.0	1479.0	C	8.4
	Upper bound	2459.4	2305.2	D	6.3

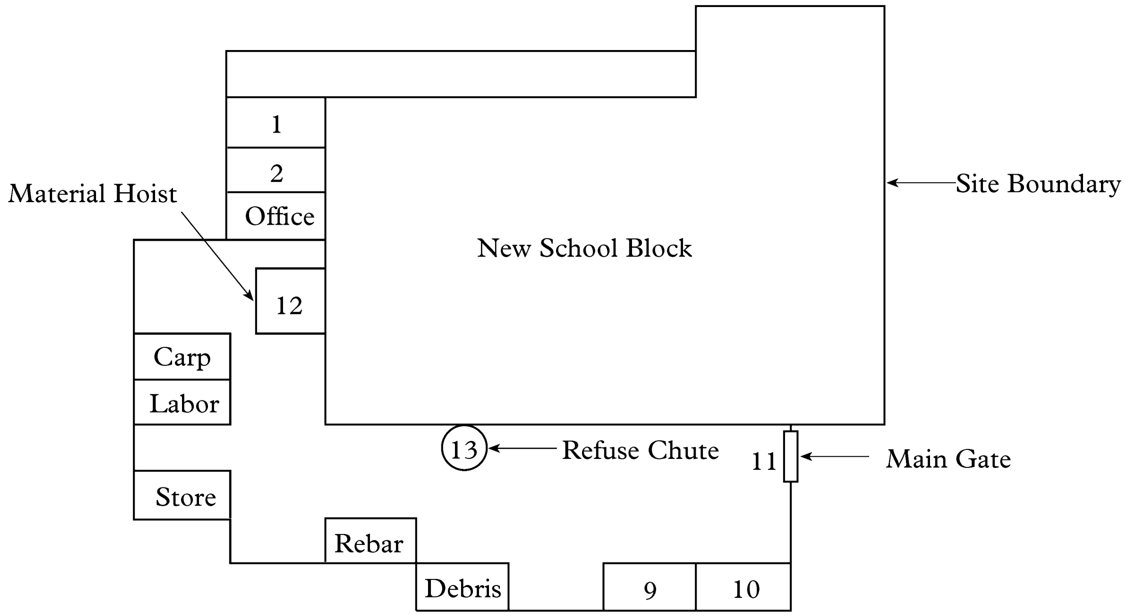

Figure 2 Final optimal site layout A

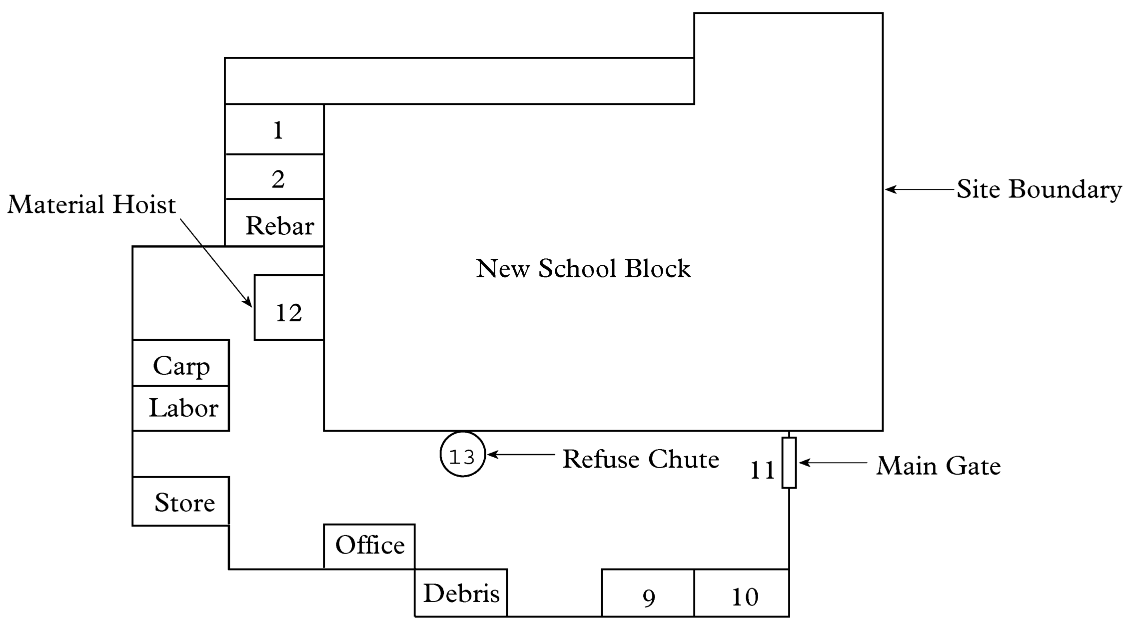

Figure 3 Final optimal site layout B

transportation of the rebar difficult. In layout C, the site office is located near the main gate, and there is little danger of encountering falling debris in approaching the office, and the rebar bending yard, carpentry workshop and materials storage area are located reasonably near to the materials hoist for the convenient transportation of materials to the superstructure.

The surveyed construction managers appreciated layout C, which was generated by an ACO algorithm, as it was a reasonable layout that minimizes the flow cost. However, if certain site facilities are predetermined by past experience, such as the site office, then the layout may be different. Therefore, past experience should be taken into consideration before setting the constraints and assumptions in the model to obtain a genuinely optimal site layout.

Conclusion

In this paper, the ant colony optimization algorithm, entropy technique and fuzzy logic are explored and

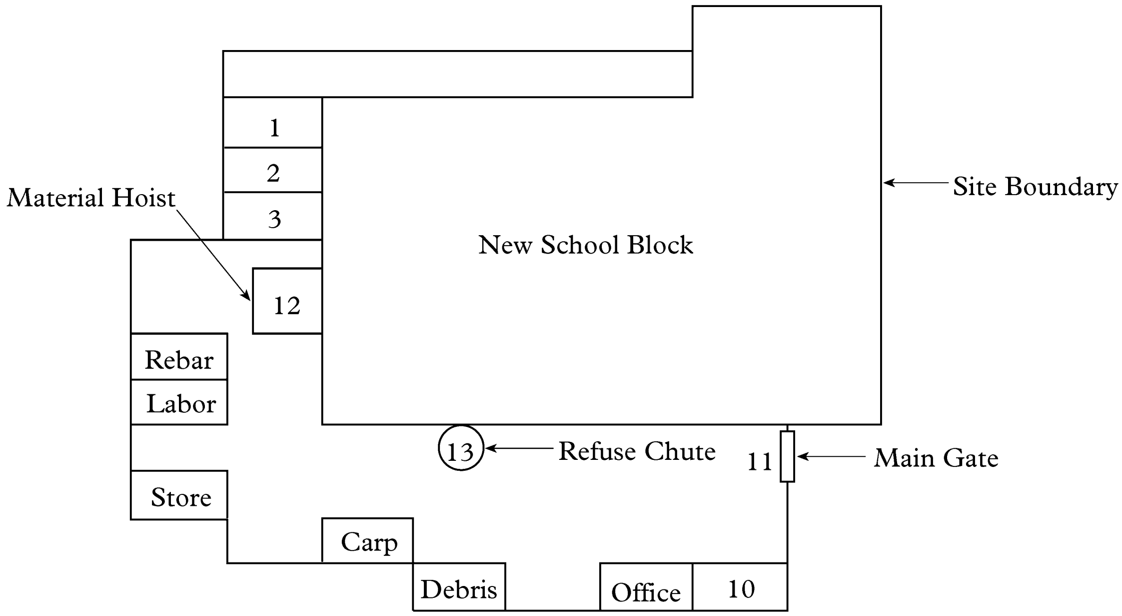

Figure 4 Final optimal site layout C

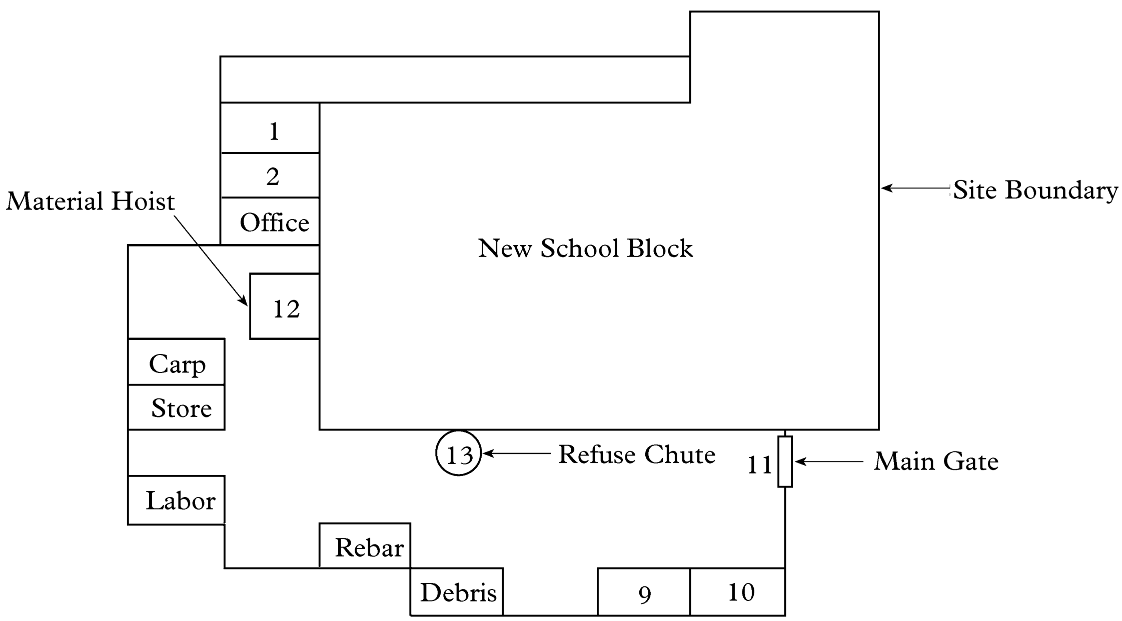

Figure 5 Final optimal site layout D

successfully applied to determine the optimal site layout for a hypothetical medium-sized project. Site layout problem here is modelled as an equal-area facility layout, in which each of the predetermined places is capable of accommodating any of the facilities. The fuzzy arithmetic and entropy method are introduced to analyse data on weightings and closeness indices that were collected from respondents in the construction industry on the degree of importance of four predetermined factors that influence site layout planning, and the degree of closeness between nine predetermined site facilities for the mentioned four factors. The weightings of the four predetermined factors are also explored. Gird approach was used when setting the hypothetical construction site, which could make the problem easy to be specified and solved. But it is only a simplification of a real case, as the size and shape of the temporary facilities are variables.

Using the ACO algorithm, the optimal site layout was generated and the initial flow cost was found to be reduced by 6.3%~10.8%. Layout C can reduce the flow cost by 8.3%, and the site office is located near to the main gate in order to provide safe access for visitors and office personnel. The rebar bending yard, carpentry workshop and materials storage area are located reasonably near to the materials hoist for the convenient transportation of materials to the superstructure. This optimal layout shows that ACO algorithm is a feasible and efficient method of optimizing and solving site layout planning.

The advantages of applying the ACO algorithm to site layout planning are as follows. First, in site layout planning, the project manager would choose certain key facilities to assign, and will then assign other facilities to the available locations that are left over. This process is the same as the computational procedure of the ACO algorithm, which assigns facilities to locations one by one, and deletes the occupied locations from the location scope in the next assignment. In reality, the sequence of assignment will affect the outcome, and thus the ACO algorithm is easy in principle. A high-quality solution can be achieved in a reasonable time because of the simplicity of the calculation of the ACO algorithm. The parameters of the ACO algorithm are few and the physical definition is clear, and thus it can be easily controlled. Secondly the ACO algorithm is that the ants choose the solution in accordance with the level of pheromone and the heuristic information about the locations. The fewer controllable parameters of the ACO algorithm means that less time is required to reach an optimal solution, which improves the effectiveness of the algorithm.

A limitation of this method is the problem of defining ρ, which is another parameter that affects the ant search iteration. If the value of ρ is too high, then too much pheromone is deposited and stagnation may take place, which results in a local optimal solution. If the value of ρ is too low, then too little information is conveyed from previous solutions, and it is too difficult to find an optimal solution in a reasonable time. Therefore, in order to obtain good heuristic information that is in line with the objective function, a proper value of the parameter ρ should be examined in future studies.

References

Abdinnour-Helm, S. and Hadley, S.W. (2000) Tabu search based heuristics for multi-floor layout. *International Journal of Production Research*, **38**(2), 365–83.

Beasley, D., Bull, D.R. and Martin, R.R. (1993a) An overview of genetic algorithms. Part 1: fundamentals. *University Computing*, **15**(2), 58–69.

Beasley, D., Bull, D.R. and Martin, R.R. (1993b) An overview of genetic algorithms. Part 2: research topics. *University Computing*, **15**(4), 170–81.

Bersini, H., Oury, C. and Dorigo, M. (1995) Hybridization of genetic algorithms. Technical Report IRIDIA/95-22, Université Libre de Bruxelles, Belgium.

Buffa, E.S., Armour, G.C. and Vollmann, T.E. (1964) Allocating facilities with CRAFT. *Harvard Business Review*, **42**(2), 136–58.

Cela, E. (1998) *The Quadratic Assignment Problem Theory and Algorithms*, Kluwer Academic Publishers, Boston.

Chan, L.K., Kao, H.P., Ng, A. and Wu, M.L. (1999) Rating the importance of customer needs in quality function deployment by fuzzy and entropy methods. *International Journal of Production Research*, **37**(11), 2499–518.

Christofides, N. and Benavent, E. (1989) An exact algorithm for the quadratic assignment problem. *Operations Research*, **37**(5), 760–8.

Dorigo, M. and Gambardella, L.M. (1997) Ant colony system: a cooperative learning approach to traveling salesman problem. *IEEE Transactions on Evolutionary Computation*, **1**(1), 53–66.

Dorigo, M. and Stützle, T. (2004) *Ant Colony Optimization*, MIT Press, Cambridge, MA and London.

Dorigo, M., Maniezzo, V. and Colorni, A. (1991) Ant system: an autocatalytic optimizing process. Technical Report, No. 91-016 Politecnico di Milano, Italy.

Eilon, S., Watson-Gandy, C.D.T. and Christofides, N. (1969) Distribution management: mathematical modeling and practical analysis. *Operational Research Quarterly*, **20**(1), 37–53.

Elbeitagi, E. and Hegazy, T. (2001) A hybrid AI-based system for site layout planning in construction. *Computer-Aided Civil and Infrastructure Engineering*, **16**(2), 79–93.

Elbeitagi, E., Hegazy, T., Hosny, A.H. and Eldosouky, A. (2001) Schedule-dependent evolution of site layout planning. *Construction Management and Economics*, **19**(7), 689–97.

Hanss, M. (1999) On the implementation of fuzzy arithmetical operations for engineering problems in Dave, R. N. and Sudkamp, T. (eds) *Proceedings of the 18th International Conference of the North American Fuzzy Information Processing Society—NAFIPS 99*, IEEE Press, New York, pp. 462–6.

Hegazy, T. and Elbeltagl, E. (1999) EvoSite: evolution-based model for site layout planning. *Journal of Computing in Civil Engineering*, **13**(3), 198–206.

Hertz, A., Taillard, E.D. and de Werra, D. (1997) A tutorial on tabu search in Aarts, E.H.L. and Lenstra, J.K. (eds) *Local Search in Combinatiorial Optimization*, John Wiley and Sons, Chichester, UK, pp. 121–36.

Lam, K.C., Tang, C.M. and Lee, W.C. (2005) Application of the entropy technique and genetic algorithms to construction site layout planning of medium-size projects. *Construction Management and Economics*, **23**(2), 127–45.

Li, H. and Love, P.E.D. (2000) Genetic search for solving construction site-level unequal-area facility layout problems. *Automation in Construction*, **9**(2), 217–26.

Lin, F.T., Kao, C.Y. and Hsu, C.C. (1993) Applying the genetic approach to simulated annealing in solving some NP-hard problems. *IEEE Transactions on Systems, Man, and Cybernetics*, **23**(6), 1752–67.

Maniezzo, V., Colorni, A. and Dorigo, M. (1994) The ant system applied to the quadratic assignment problem. Technical Report IRIDIA/94-28, Université Libre de Bruxelles, Belgium.

Osman, H.M., Georgy, M.E. and Ibrahim, M.E. (2003) A hybrid CAD-based construction site layout planning system using genetic algorithms. *Automation in Construction*, **12**(6), 749–64.

Rescher, N. (1969) *Many-Valued Logic*, McGraw-Hill, New York.

Shannon, C.E. (1948) A mathematical theory of communication. *Bell System Technical Journal*, **27**(3), 379–423.

Stützle, T. and Dorigo, M. (1999) ACO algorithm for the quadratic assignment problem in Corne, D., Dorigo, M. and Glover, F. (eds) *New Ideas in Optimization*, McGraw-Hill, London, pp. 33–50.

Stützle, T. (2005) Ant colony optimization—an introduction. *Technische Universität Darmstadt Fachbereich Informatik*, **20**(April), 1–48.

Suresh, G. and Sahu, S. (1993) Multiobjective facility layout using simulated annealing. *International Journal of Production Economics*, **32**(2), 239–54.

Whitley, D., Starkweather, T. and Fuquay, D. (1989) Scheduling problems and traveling salesman: the genetic edge recombination operator in Schaffer, J. D. (ed.) *Proceedings of the 3rd International Conference Genetic Algorithms*, Morgan Kaufmann, Palo Alto, CA, pp. 133–40.

Yeh, I.C. (1995) Construction site layout using annealed neutral network. *ASCE Journal of Computing in Civil Engineering*, **9**(3), 201–8.

Zadeh, L.A. (1965) Fuzzy sets. *Information and Control*, **8**(3), 338–53.

Appendix A

Table A1 Lower closeness indices of the site facilities

Site facilities	Lower closeness indices C_l			
	Work flow (WF)	Information flow (IF)	Safety and environment (SE)	Personal preference (PP)
Site office: main gate	2.024450	3.101725	3.929063	6.551997
Site office: rebar bending yard	1.885028	3.789609	1.696915	3.000000
Site office: carpentry workshop and store	1.895619	4.441213	1.847352	3.104650
Site office: labour hut	2.284524	2.547967	4.287302	4.239126
Site office: materials storage area	2.543159	2.088422	3.728289	4.103994
Site office: debris storage area	1.193344	0.503994	0.839753	0.617884
Site office: materials hoist	1.508748	0.966940	1.378283	1.580775
Site office: refuse chute	0.405383	0.249561	0.325937	0.286360
Main gate: rebar bending yard	3.612852	1.776291	3.199048	4.545276
Main gate: carpentry workshop and store	3.064584	1.915308	3.171475	4.558862
Main gate: labour hut	2.295619	1.682788	2.985115	3.104650
Main gate: materials storage area	3.633590	1.547190	3.308748	3.142611
Main gate: debris storage area	3.219639	1.152610	1.781576	3.405383
Main gate: materials hoist	2.511754	0.892933	2.183398	3.262397
Main gate: refuse chute	1.745073	0.939089	1.573991	1.942291
Rebar bending yard: carpentry workshop and store	1.554789	1.776291	1.816742	3.079535
Rebar bending yard: labour hut	1.895619	1.728289	2.019640	2.373291
Rebar bending yard: materials storage area	1.236922	1.536669	2.244246	2.417605
Rebar bending yard: debris storage area	2.067816	1.193344	1.728289	1.415204
Rebar bending yard: materials hoist	5.160392	2.823180	2.737401	4.946504
Rebar bending yard: refuse chute	0.824016	0.788940	0.367094	0.594879
Carpentry workshop and store: labour hut	1.828605	1.929063	2.260928	2.532381
Carpentry workshop and store: materials storage area	2.139323	1.571816	2.330954	2.724577
Carpentry workshop and store: debris storage area	1.915308	1.072050	2.118731	1.355006
Carpentry workshop and store: materials hoist	5.127964	2.393702	2.731746	5.759167
Carpentry workshop and store: refuse chute	0.633660	0.267619	0.322261	0.630623
Labour hut: materials storage area	2.244246	3.685028	2.288123	2.749455
Labour hut: debris storage area	1.477109	1.915308	1.039209	1.132381
Labour hut: materials hoist	1.524577	2.114886	1.543159	2.312467
Labour hut: refuse chute	0.614732	0.633590	0.373509	0.645800
Materials storage area: debris storage area	1.508748	1.054800	1.219693	1.161180
Materials storage area: materials hoist	4.468628	2.195242	3.886360	5.425834
Materials storage area: refuse chute	0.859437	0.571475	0.157677	0.325504
Debris storage area: materials hoist	1.188133	1.033810	1.087475	0.896915
Debris storage area: refuse chute	3.054633	1.400000	3.115653	3.122684
Materials hoist: refuse chute	0.439380	0.494455	0.127964	0.384900

Table A2 Mean closeness indices of the site facilities

Site facilities	Mean closeness indices C_m			
	Work flow (WF)	Information flow (IF)	Safety and environment (SE)	Personal preference (PP)
Site office: main gate	5.466667	6.000000	6.533333	7.733333
Site office: rebar bending yard	3.933333	5.933333	4.400000	5.000000
Site office: carpentry workshop and store	3.800000	6.200000	4.733333	5.133333
Site office: labour hut	4.266667	4.666667	6.000000	5.866667
Site office: materials storage area	4.800000	4.733333	5.933333	6.466667
Site office: debris storage area	3.200000	2.866667	3.000000	3.466667
Site office: materials hoist	3.600000	3.000000	3.333333	4.133333
Site office: refuse chute	2.466667	2.466667	2.733333	2.533333
Main gate: rebar bending yard	6.200000	4.600000	5.533333	6.400000
Main gate: carpentry workshop and store	5.200000	4.266667	5.133333	6.200000
Main gate: labour hut	4.200000	3.466667	4.933333	5.133333
Main gate: materials storage area	5.800000	4.266667	5.400000	5.533333
Main gate: debris storage area	5.466667	3.333333	3.600000	5.466667
Main gate: materials hoist	5.200000	3.333333	4.333333	5.866667
Main gate: refuse chute	4.200000	2.866667	3.466667	4.666670
Rebar bending yard: carpentry workshop and store	4.133333	4.600000	3.666667	4.800000
Rebar bending yard: labour hut	3.800000	3.933333	3.933333	4.466667
Rebar bending yard: materials storage area	3.866667	4.200000	4.733333	4.933333
Rebar bending yard: debris storage area	4.000000	3.200000	3.933333	3.600000
Rebar bending yard: materials hoist	7.200000	5.400000	5.466667	7.133333
Rebar bending yard: refuse chute	2.200000	2.000000	1.666667	2.333333
Carpentry workshop and store: labour hut	4.533333	4.533333	4.200000	4.866667
Carpentry workshop and store: materials storage area	4.733333	4.266667	4.200000	5.266667
Carpentry workshop and store: debris storage area	4.266667	3.133333	3.800000	3.600000
Carpentry workshop and store: materials hoist	7.200000	4.866667	5.533333	7.466667
Carpentry workshop and store: refuse chute	2.333333	2.600000	1.933333	2.066667
Labour hut: materials storage area	4.733333	5.733333	4.866667	4.533333
Labour hut: debris storage area	3.600000	4.266667	3.400000	3.466667
Labour hut: materials hoist	4.066667	4.533333	3.800000	4.133333
Labour hut: refuse chute	2.266667	2.800000	2.400000	2.466667
Materials storage area: debris storage area	3.600000	2.933333	3.466667	3.466667
Materials storage area: materials hoist	6.733333	5.000000	6.133333	7.133333
Materials storage area: refuse chute	2.400000	2.533333	3.066667	2.600000
Debris storage area: materials hoist	3.066667	2.200000	3.533333	3.600000
Debris storage area: refuse chute	6.200000	4.600000	6.266667	6.466667
Materials hoist: refuse chute	2.733333	2.000000	2.200000	2.600000

Table A3 Upper closeness indices of the site facilities

Site facilities	Upper closeness indices C_u			
	Work flow (WF)	Information flow (IF)	Safety and environment (SE)	Personal preference (PP)
Site office: main gate	8.908888	8.898275	9.137603	8.914670
Site office: rebar bending yard	5.981639	8.077058	7.103085	7.000000
Site office: carpentry workshop and store	5.704381	7.958787	7.619315	7.162017
Site office: labour hut	6.248809	6.785366	7.712698	7.494207
Site office: materials storage area	7.056841	7.378245	8.138378	8.829339
Site office: debris storage area	5.206656	5.229339	5.160247	6.315448
Site office: materials hoist	5.691252	5.033060	5.288384	6.685892
Site office: refuse chute	4.527950	4.683772	5.140729	4.780307
Main gate: rebar bending yard	8.787148	7.423709	7.867619	8.254724
Main gate: carpentry workshop and store	7.335416	6.618026	7.095192	7.841138
Main gate: labour hut	6.104381	5.250545	6.881552	7.162017
Main gate: materials storage area	7.966410	6.986144	7.491252	7.924056
Main gate: debris storage area	7.713640	5.514057	5.418424	7.527950
Main gate: materials hoist	7.888246	5.773734	6.483269	8.470937
Main gate: refuse chute	6.654927	4.794244	5.359343	7.391042
Rebar bending yard: carpentry workshop and store	6.711877	7.423709	5.516592	6.520465
Rebar bending yard: labour hut	5.704381	6.138378	5.847027	6.560042
Rebar bending yard: materials storage area	6.496411	6.863331	7.222421	7.449062
Rebar bending yard: debris storage area	5.932184	5.206656	6.138378	5.784796
Rebar bending yard: materials hoist	9.239608	7.976820	8.195932	9.320163
Rebar bending yard: refuse chute	3.575984	3.211060	2.966239	4.071787
Carpentry workshop and store: labour hut	7.238026	7.137603	6.139072	7.200952
Carpentry workshop and store: materials storage area	7.327344	6.961518	6.069046	7.808757
Carpentry workshop and store: debris storage area	6.618026	5.194617	5.481269	5.844994
Carpentry workshop and store: materials hoist	9.272036	7.339632	8.334920	9.174166
Carpentry workshop and store: refuse chute	4.033007	4.932381	3.544406	3.502711
Labour hut: materials storage area	7.222421	7.781639	7.445211	6.317217
Labour hut: debris storage area	5.722891	6.618026	5.760791	5.800952
Labour hut: materials hoist	6.608757	6.951781	6.056841	5.954200
Labour hut: refuse chute	3.918602	4.966410	4.426491	4.287533
Materials storage area: debris storage area	5.691252	4.811867	5.713640	5.772216
Materials storage area: materials hoist	8.998038	7.804758	8.380307	8.840833
Materials storage area: refuse chute	3.940563	4.495192	5.975657	4.874496
Debris storage area: materials hoist	4.945200	3.366190	5.979192	6.303085
Debris storage area: refuse chute	9.345367	7.800000	9.417681	9.810650
Materials hoist: refuse chute	5.027287	3.505545	4.272036	4.815100

Table A4 Finalized closeness relationship between the site facilities

Site facilities	Closeness relationship $f_{ij} = w_1 C_{WF_{ij}} + w_2 C_{IF_{ij}} + w_3 C_{SE_{ij}} + w_4 C_{PP_{ij}}$		
	Lower bound	Mean	Upper bound
Site office: main gate	3.715118556	6.341219055	8.967319554
Site office: rebar bending yard	2.558408740	4.793950253	7.029491766
Site office: carpentry workshop and store	2.792565041	4.941463981	7.090362921
Site office: labour hut	3.271537715	5.147580414	7.023623113
Site office: materials storage area	3.048292979	5.414459085	5.422852921
Site office: debris storage area	0.804414996	3.113633958	5.612531702
Site office: materials hoist	1.346961440	3.479746571	4.780303588
Site office: refuse chute	0.319812894	2.550058241	8.081611746
Main gate: rebar bending yard	3.209988035	5.645799890	7.185804025
Main gate: carpentry workshop and store	3.091254387	5.138529206	6.296872000
Main gate: labour hut	2.478366804	4.387617002	7.576274947
Main gate: materials storage area	2.903060558	5.239667753	6.296867200
Main gate: debris storage area	2.337667309	4.417506012	7.576274947
Main gate: materials hoist	2.151916480	4.617026452	6.497344716
Main gate: refuse chute	1.528509540	3.751672280	7.082136425
Rebar bending yard: carpentry workshop and store	1.987497325	4.266834857	5.974835020
Rebar bending yard: labour hut	1.980161012	4.003690731	6.546172390
Rebar bending yard: materials storage area	1.816819289	4.395560327	6.027220450
Rebar bending yard: debris storage area	1.618590613	3.692610730	5.766630847
Rebar bending yard: materials hoist	3.868825157	6.259823678	8.650822198
Rebar bending yard: refuse chute	0.648884597	2.034303777	3.419722958
Carpentry workshop and store: labour hut	2.109629762	4.512682681	6.915735601
Carpentry workshop and store: materials storage area	2.158333112	4.578002485	6.997671858
Carpentry workshop and store: debris storage area	1.635340170	3.713404649	5.791469127
Carpentry workshop and store: materials hoist	3.908916181	6.204439294	8.499962406
Carpentry workshop and store: refuse chute	0.455367263	2.244690335	4.034013407
Labour hut: materials storage area	2.734674331	4.990268966	7.245863602
Labour hut: debris storage area	1.407804601	3.695438278	5.983071956
Labour hut: materials hoist	1.842206918	4.132313319	6.422419720
Labour hut: refuse chute	0.562569446	2.481557757	4.400546069
Materials storage area: debris storage area	1.244156276	3.363543175	5.482930075
Materials storage area: materials hoist	3.912033043	6.201820252	8.491607460
Materials storage area: refuse chute	0.492604922	2.650105985	4.807607047
Debris storage area: materials hoist	1.062841280	3.069081098	5.075320917
Debris storage area: refuse chute	2.650710634	5.851721850	9.052733067
Materials hoist: refuse chute	0.361115951	2.374380491	4.387645032