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Site Layout optimization with ACO algorithm

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Abstract: - Construction site layouts concerned with the existence, positioning, and timing of the temporary facilities that are used to carry out a construction project. Typically these problems are very complicated to formulate and difficult to solve. They are, however, very important to virtually any construction project, since the site layout can significantly affect the cost of the project. This paper attempts to solve a site layout problem for a construction project benefiting from Ant Colony Optimization (ACO) algorithm. Application of the developed site layout optimization model to a simple benchmark layout problem was quite promising with well improved results over reported GA solutions.

Key-words: - Site layout, Construction, ACO, Optimization, facility

1 Introduction

Site layout is a routine task for many site engineers and project managers, and it is obvious that a site layout affects worker travel time, activity interface, and, thus, productivity. Better layouts do pay off, if only managers could afford the time and effort needed to design better layouts. Modeling optimum space allocation to temporary facilities on construction sites has not received much attention due to the complexity of the problem, and the perceived marginal benefits to be gained from performing this task better.

Due to the complexity of facility layout problems, many algorithms have been developed and tested to generate solutions for the problems. The algorithms can be classified as layout improvement, entire layout and partial layout categories (Sirinaovakul and Thajchayapong 1996). The layout improvement algorithms are required to have an initial layout by which new (improved) layouts are generated through relocating the facilities to improve the initial layout. Typical examples include those algorithms developed by Buffa et al.(1964) and Moore (1976). The entire layout algorithms use the strategy of selecting and placing one facility each time according to a predetermined selecting and allocating order. The predetermined selecting and placing order represents some kind of fitness in placing a facility at a particular place. Examples include the algorithms developed by Fortenberry and Cox (1985). In the partial improvement algorithms, a facility is placed at all possible locations to generate all possible partial layout alternatives. Then, the best layout is selected from the alternatives. Another facility is added onto the best layout by repeating the same procedure until all facilities are located. Examples of the partial improvement algorithms include CORELAP (Lee and Moore 1967) and Sirinaovakul and Thajchayapong's algorithm (Sirinaovakul and Thajchayapong 1996). Very recently, artificial intelligence-based methods have been applied to solving facility layout problems. For example, knowledge-based systems have been developed to provide users with problem-specific heuristic knowledge in allocation facilities (Rad and James 1983; Tommelein et al.1991).Yeh (1996) applied annealed neural networks to solve construction site-layout facility problems.

This paper applies Ant Colony Optimization (ACO) algorithm to search for the optimal solution for a construction site layout problem.

2 Ant colony behavior

Ant colony algorithms have been founded on the observation of real ant colonies. By living in colonies, ants' social behavior is directed more to the survival of the colony entity than to that of a single individual member of the colony. An interesting and significantly important behavior of ant colonies is their foraging behavior, and in particular, their ability to find the shortest route between their nest and a food source, realizing that they are almost blind. The path taken by individual ants from the nest, in search for a food source, is essentially random (Dorigo et al. 1996). However, when they are traveling, ants deposit on the ground a substance called pheromone, forming a pheromone trail as an indirect communication means. By smelling the pheromone, there is a higher probability that the trail with a higher pheromone concentration will be chosen. The pheromone trail allows ants to find their way back to the food source and vice versa. The trail is used by other ants to find the location of the food source located by their nest mates. It follows that when a number of paths are available from the nest to a food source, a colony of ants may be able to exploit the pheromone trail left by the individual members of the colony to discover the shortest path from the nest to the food source and back (Dorigo and Di Caro 1999). As more ants choose a path to follow, the pheromone on the path builds up, making it more attractive to other ants seeking food and hence more likely to be followed by other ants.

Generally speaking, evolutionary algorithms search for a global optimum by generating a population of trial solutions. Ant colony optimization, as an evolutionary algorithm, has many features which are similar to genetic algorithms (GAs). The most important difference between GAs and ACO algorithms is the way the trial solutions are generated. In ACO algorithms, trial solutions are constructed incrementally based on the information contained in the environment and the solutions are improved by modifying the environment via a form of indirect communication called stigmergy (Dorigo et al. 2000). On the other hand, in GAs the trial solutions are in the form of strings of genetic materials and new solutions are obtained through the modification of previous solutions (Maier et al. 2003). Thus, in GAs the memory of the system is embedded in the trial solutions, whereas in ACO algorithms the system memory is contained in the environment itself.

Let $\tau_{ij}(t)$ be the total pheromone deposited on path ij at time t and $\eta_{ij}(t)$ be the heuristic value of path ij at time t according to the measure of the objective function. We define the transition probability from node i to node j at time period t as:

$$P_{ij}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}{\sum_{l \in allowed}[\tau_{il}(t)]^{\alpha}[\eta_{il}(t)]^{\beta}} & \text{if } j \in \text{allowed} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Where α and β = parameters that control the relative importance of the pheromone trail versus a heuristic value. Let q be a random variable uniformly distributed over $[0,1]$, and $q_0 \in [0,1]$ be a tunable parameter. Upon completion of a tour by all ants in the colony, the global trail updating is done as follows:

$$\tau_{ij}(t) \xleftarrow{iteration} \rho \cdot \tau_{ij}(t) + (1-\rho) \cdot \Delta\tau_{ij} \tag{2}$$

Where $0 \le \rho \le 1$; $(1-\rho)$ = evaporation (i.e., loss) rate; and the symbol $\xleftarrow{iteration}$ is used to show the next iteration. There are several definitions for $\Delta\tau_{ij}(t)$ (Dorigo et al. 1996; Dorigo and Gambardella 1997).

There are several definitions for $\Delta\tau_{ij}(t)$ but in this paper we use Ant Colony System-Global Best:

$$\Delta\tau_{ij}(t) = \begin{cases} Q / G^{k_{gb}}(m) & if \quad (i,j) \in T^{k_{gb}}(m) \\ 0 & if \quad (i,j) \notin T^{k_{gb}}(m) \end{cases} \tag{3}$$

Where Q is a constant and $G^{k_{gb}}$ = value of the objective function for the ant with the best performance within the past total iteration.

3 Construction site layout problem

The objective of site layout may be defined as minimizing the total traveling distance of site personnel between facilities.

$$Minimize \; TD = \sum_{i=1}^{n}\sum_{x=1}^{n}\sum_{j=1}^{n} \delta_{xi} f_{ij} d_{ij} \tag{4}$$

$$s.t: \sum_{x=1}^{n} \delta_{xi} = 1 \quad ,$$

$i = 1,2,3,...,n$

Where $n =$ number of facilities; and δ_{xi} = permutation matrix variable. Coefficient, f_{ij} is the frequencies of trips made by construction personnel between facility i and j. If there are two paths linking the two locations, then the shorter path is selected for calculating the distance (Fig. 1). Therefore, TD reflects the total traveling distance (cost) made by construction personnel.

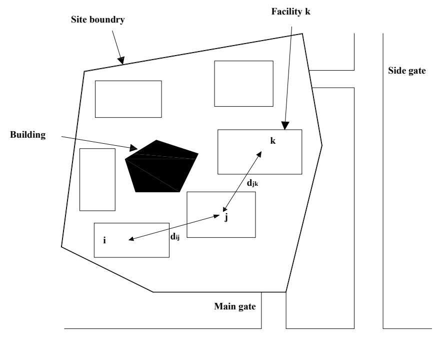

Fig. 1. *Layout Space Restriction (Lee and Love 1998)*

4 Implementation of ACO

To apply ACO algorithm to a specific problem, the following steps have to be taken: (1) problem representation as a graph or a similar structure easily covered by ants; (2) assigning a heuristic preference to generate solutions at each time step (i.e., selected path by ants); (3) Defining a fitness function to be optimized

Selecting an appropriate representation is an important step in applying ACO to an optimization problem. In this study, the representation for site layout is a permutation type. Each facility layout can be represented by a $n \times n$ permutation matrix (n is the number of facilities and locations) in which rows and columns are labels by facilities and locations, respectively. There is only one "1" in each row and column, and the rest of the elements are 0. The corresponding row and column number "1" indicate the location the facility is placed. Fig. 2 shows a permutation matrix with 11 facilities and locations.

The permutation matrix can also be represented in a graph form, as shown in Fig. 3. In graph the horizontal axis represents the location and the vertical axis represents the number of facility. Each ant must travel from one location to next and select the facilities for them. In each rout, ants are restricted not to select repetitive facility.

	Location										
Faci	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	0	0	0	0	1	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	0	0	0
4	0	0	0	1	0	0	1	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	1
8	1	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	0	0
11	0	0	0	0	0	0	0	0	0	1	0

Fig. 2. *Permutation Matrix with 11 Facilities*

In Fig. 3, an example of the layout indicates that 11 facilities are located in 11 locations. The 11 facilities are: 1) Site office, 2) False work workshop, 3) Labor residence, 4) Storeroom 1, 5) Storeroom 2, 6) Carpentry workshop, 7) Reinforced steel workshop, 8) Side gate, 9) Electrical, water, and other utilities control room, 10) Concrete batch workshop ,and 11) Main gate.

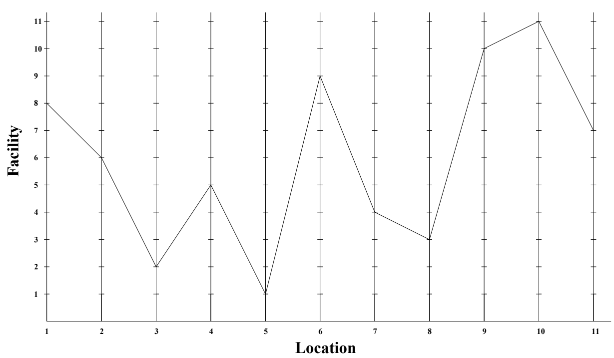

Fig. 3. *Graph of problem representation*

The frequencies of trips (in 1 day) made between facilities are assumes, as listed in Fig. 4 and directly taken. The distance of the 11 locations are listed in Fig. 5. The distances are measured in meters.

$$F = \begin{bmatrix} 0 & 5 & 2 & 2 & 1 & 1 & 4 & 1 & 2 & 9 & 1 \\ 5 & 0 & 2 & 5 & 1 & 2 & 7 & 8 & 2 & 3 & 8 \\ 2 & 2 & 0 & 7 & 4 & 4 & 9 & 4 & 5 & 6 & 5 \\ 2 & 5 & 7 & 0 & 8 & 7 & 8 & 1 & 8 & 5 & 1 \\ 1 & 1 & 4 & 8 & 0 & 3 & 4 & 1 & 3 & 3 & 6 \\ 1 & 2 & 4 & 7 & 3 & 0 & 5 & 8 & 4 & 7 & 5 \\ 4 & 7 & 9 & 8 & 4 & 5 & 0 & 7 & 6 & 3 & 2 \\ 1 & 8 & 4 & 1 & 1 & 8 & 7 & 0 & 9 & 4 & 8 \\ 2 & 2 & 5 & 8 & 3 & 4 & 6 & 9 & 0 & 5 & 3 \\ 9 & 3 & 6 & 5 & 3 & 7 & 3 & 4 & 5 & 0 & 5 \\ 1 & 8 & 5 & 1 & 6 & 5 & 2 & 8 & 3 & 5 & 0 \end{bmatrix}$$

Fig. 4. *Frequencies of trips*

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

Fig. 5. *Distance of the 11 Locations*

4.1 Heuristic information

The heuristic information on this problem is determined by considering the criterion as minimum distance between two locations:

$$\eta_{l_1 l_2 f_1 f_2} = \frac{1}{d_{l_1 l_2} f_{f_1 f_2}} \qquad (5)$$

Where $d_{l_1 l_2}$ =distance between location l_1 and location l_2; $f_{f_1 f_2}$ =frequency between facility f_1 and facility f_2 .

4.2 Fitness function

The fitness function is a measure of the goodness of the generated solutions according to the defined objective function. For this study, Total Distance is defined as Eq. (4)

5 Model application

The developed site layout model was solved using number of ants ranging from 30 to 100. According to Jalali (2005), Single partial path replacement (PPR) was added to the original ant colony system with minor modification to facilitate feasible solution generation .If in the two newly generated solutions, some facilities can allocated to two different locations, they are transferred to non-allocated locations in the other new solution .In this case all solutions generated after PPR implementation will now be feasible.

The developed model was applied to a semi-benchmark site layout problem previously defined and solved by Li and Love (1998) (Fig. 1). Using GA, Li and Love came up with an objective function value of 15090 with 100 population size and 90 generation .The global optimum for the problem was found to have an objective function value of 12546 employing a full direct search by the authors. Results of the proposed ACO model are presented in Figs. (6) and (7) for different number of agents and different values of heuristic exponent (β) in the transition rule (Eq. 1). As is clear the best solution convergence occurred for $\beta = 0$. For $\beta = 0$ and $\rho = 0.9$, all solutions with number of ants ranging from 30 to 100 converged to the global optimum with objective function value of 12546. Final layout for the defined problem is presented in Table 1.

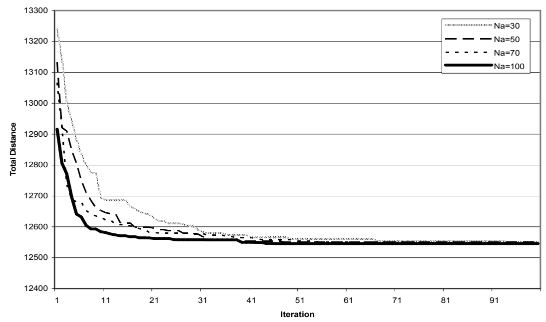

Fig. 6. *Total Traveling Distance with different number of ants*

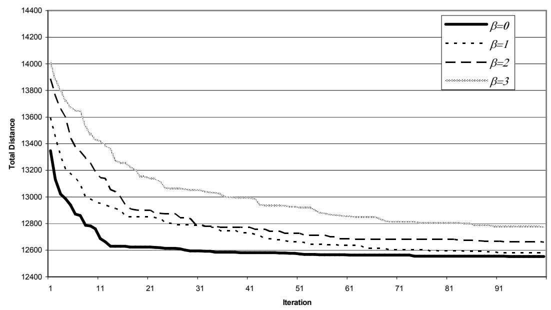

Fig. 7. *Total Traveling Distance with different value of β*

Table 1. *The best Layout*

	Location										
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}
Facility	8	6	9	7	4	3	5	10	1	11	2

6 Conclusion

This paper has introduced a representation scheme for representing construction site layout problems into a graph suitable for ACO algorithms. It then demonstrated the robustness of the ACO approach in solving layout problems as combinatorial optimization problems that are difficult to solve by conventional methods. Also the proposed method has been compared with a similar algorithm (GA).

For medium or large construction projects, it is not unusual to have up to 40 temporary facilities that need to be located on site. It is expected that the system developed in this study can easily handle the problem size. However, extensive tests will be conducted to ensure the usefulness of the system in dealing with facility allocation problems with larger sizes.

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