A CAD-BASED SITE LAYOUT FOR IRREGULAR FACILITIES USING ACO

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ABSTRACT

This paper introduces a novel approach to enhance the general practice of layout planning of construction sites for producing the efficient utilization. In this work, a solution to the problem is attempted for unequal and irregular temporary facility using robust search and optimization capabilities of Ant Colony Optimization (ACO) algorithm, inspired by the foraging behaviour of real ants. The problem is solved in four stages, namely (1) discretising construction space and formation of representative matrix of site and temporary facilities, (2) identifying all practical constraints in this optimization problem, (3) dividing the construction project in various time interval and identifying the temporary facility for the corresponding time interval, and (4) implementing ACO to get the optimum position and orientation of temporary facilities

KEYWORDS

Site Layout Planning (SLP), Irregular Temporary Facility, Ant Colony Optimization (ACO)

1. INTRODUCTION

Spatial planning of all activities in construction project is a fundamental necessity for successful completion of the project. Construction site layout involves coordinating the use of limited site space to accommodate temporary facilities needed to support construction operation such as fabrication shops, trailers, materials, or equipments so that they can function efficiently on site. The layout problem is generally defined as the problem of (1) identifying the shape and size of the facilities to be laid out, (2) identifying constraints between facilities, and (3) determining the relative positions of these facilities within the boundaries of the available space on the site so that it satisfies the constraints between them and allow them to function efficiently.

Despite its importance, site planning is often neglected, and the attitude of engineers has been that it will be done as the project progresses. Conventionally, the site layout is planned purely based on past experience of construction manager. It could not be possible to handle efficiently and judiciously a large number of facilities, factors and complexity involved in the site plan based on knowledge gained by experience only. This lack of proper site layout planning results in loss of productivity in the form of increased transportation cost, reduced safety, increased frequency of trips, and increased relocation costs. An efficient planned site could result in (i) reduction in project cost, (ii) decrease time and effort spent on material handling, (iii) improvement in quality of work (iv) increase productivity, (v) improvement in safety of operation of the project, and (vi) decrease of completion time of project. One of the main ways in which a site layout can achieve the objective is by the minimization of travel time and removal of unnecessary movement of resources and handling material.

In present work a novel approach to enhance the general practice of site layout planning for producing efficient layout is presented using Ant Colony Optimisation (ACO).

2. LITERATURE REVIEW

A number of studies were conducted in order to improve site layout planning in construction projects. These studies adopted a wide range of methodologies and development tools including neural networks, simulation, knowledge-based systems, and genetic algorithms. Tommelein et. al. [1] used artificial intelligence techniques to solve site plan layout. Yeh [2] used annealed neural networks to arrange a set of predetermined facilities on a set of predetermined locations on construction sites. Several expert systems and knowledge-based systems were also developed to integrate domain knowledge of experts and assist in facility layout planning tasks [3, 4]. Other studies proposed heuristic algorithms including the use of the early commitment criterion to design site layouts [5]. Tam et. al. [6] investigated and analyzed the relationship between the key storage areas and the tower crane and to develop a GA model to optimize the facilities, taking into account the complexity of the relationship between these facilities. A single-tower-crane optimization model is applied with assumptions. The function is total cost as a sum of the product of Hook Travel Time [7], quantity of material flow and cost of material flow from Source to Destination per unit quantity and unit time. Genetic algorithms were used in several studies to optimize the layouts of construction sites [6, 8-11]. These genetic algorithms have shown improvements in the search process for near optimal solutions, especially in this type of problem that is characterized by a large search space.

Elbeltagi et. al. [12] recognized site layout as a dynamic problem at various schedule to accommodate operational need considering both safety and productivity. As construction evolves, however, the site layout may need to be dynamically reorganized at various schedule intervals to accommodate operational needs. As opposed to considering only productivity issues during site planning, this paper presents a layout planning approach that considers both safety and productivity. First, safety issues on construction sites are discussed and the factors that contribute to unsafe sites are outlined. A procedure for optimum layout of temporary facilities is then developed in integration with a scheduling tool. This paper presents an effort to provide a practical model for dynamic site layout planning in construction that when implemented will assist in maintaining safety and productivity on construction sites.

Chau [13] solved the large size problem using GA as a two-stage dynamic mode developed to assist construction planners to formulate optimal strategy for establishing potential intermediate transfer centers for site level facilities. Zouein and Tommelein [5] also solved problem as dynamic layout planning using a Hybrid Incremental Solution Method.

Fuzzy based [14] site plan layout problem is solved for multi-objective evaluation of transport cost, safety, and visibility. The paper investigates the use of fuzzy based multi-objective optimization approach in making a more infirmed strategic decisions regarding the movement path of people and vehicles on construction sites, and detailed decisions regarding travel distance and operational paths on workplaces, enabling site planners to examine path scenarios that are subjected to high degree of uncertainty and subjectivity.

An attempt has been made by investigators [15, 16] to integrate the computer aided design and site layout planning. Osman et. al. [16] employed GA for site layout optimization integrated with CAD drawing. Sadeghpour et. al. [15] employed object based model for integration. Varghese and O'Connor [17] has integrated expert system, geographic information system and CAD for route planning on construction site.

In the present work, a CAD based site optimization has been carried out considering Ant colony optimization. The present work is a contribution in the field of automation for design-construction operation.

3. SITE LAYOUT OPTIMIZATION

3.1 Site Layout Problem

To arrange a set of predetermined facilities into appropriate locations, while satisfying a set of layout constraints, is a difficult problem as there are many possible alternatives. Site layout planning can generally be classified according to two main aspects:

1. Method of facility assignment and
2. Layout planning technique.

With regard to the method of facility assignment, or in other words, the manner in which temporary facilities are assigned on site, two distinct methods are commonly encountered. The two methods are

1. Facility to location assignment and
2. Facility to site assignment.

With regard to layout planning, two distinct techniques are commonly encountered. The two techniques are called

1. Mathematical planning
2. Knowledge based planning

In this work, mathematical planning based approach has been used. We shall write objective function for site optimization.

3.2 The Objective Function

Effective placement of temporary facilities within the site improves the movement of resources, or the interactions among facilities. Such interactions are referred to as closeness relationships (weights) among the facilities and represent the desirability of having the facilities close or apart from each other [9]. Traditionally, closeness relationships have represented aspects that relate only to productivity and could be set as the actual amount material moved between facilities or the actual transportation cost. In the literature, six closeness relationships are usually set in advance, and the user can give desired weight values associated with category as shown in Table 1.

Although example presented considers only static site optimization, dynamic site layout has been presented for objective function.

Depending on the type and extent of the construction problem, a period can be given in terms of months, quarters, year etc. The major question involved in the site layout is what should be the layout in entire period of construction. The objective of dynamic site layout is what should be the layout in each period, or to what extent, if any changes in the layout should be made.

Table 1 (Osman et al. 2003) [4]

Desired Relationship between facilities	Proximity weight
Absolutely necessary (A)	81
Especially Important (E)	37
Important (I)	9
Ordinary closeness(O)	3
Unimportant (U)	1
Undesirable (X)	0

The costs associated with the dynamic site layout are those pertaining to the flow of the personnel and material and those involved with rearrangement of the layouts. The material flow costs are a product of proximity weight and distance. Cost of installation of facility at different location of site may be different. Rearranging of facility will result in some shifting cost considering this shifting the installation cost at same position in different time span may be different. The rearrangement cost may be obtained as cost, depending on the facilities involved and the distance between the various locations. Cost associated with site layout are:

(1) Flow cost of the personnel and material define as:-

$$f1 = \sum_{i=1}^{m} \left(\sum_{j=1}^{n} \sum_{k=1}^{n+p} f_{ijk} \, d_{X_{ij} X_{ik}} \right) \quad \ldots\ldots\ldots\ldots(1)$$

Where i is index for period; m is total number of period; *j,k* is index for facility, *n* is total number of temporary facility, *p* is total number of permanent facility, f_{ijk} is cost per unit length for material flow, x_{ij} is location allotted for facility k in period i,

$d_{x_{ij}x_{ik}}$ is distance between facility j and k in period i. f_{ijk} value representing either the actual transportation cost per unit distance between facilities i and j (taking into consideration the number of trips made) or a relative proximity weight that reflects the required closeness between facilities i and j. Using actual transportation costs to represent, the term f_{ijk} has the clear objective of minimizing the total transportation costs between site facilities. The objective is not as apparent when using the relative proximity weight representation. However, obtaining accurate values for the actual inter-facility transportation costs can become quite difficult, especially during project planning stages. This limitation promotes the use of proximity weights instead as they are generally much easier for the site planner to provide.

(2) The cost of rearrangement of the facilities defined as:-

$$f2 = \sum_{i=0}^{m+1}\left(\sum_{j=1}^{n}\left(\frac{|X_{i+1,j} - X_{i,j}|}{|X_{i+1,j} - X_{i,j}| + \varepsilon}\right)b_{j,X_{i,j}} + c_{i,j}\right) \quad ..(2)$$

Where i=0 and i=m+1 are for calculating the installation cost in the first period and remove cost in last period, when construction is over or there is no need of temporary facility at construction site.

Considering both total cost interaction of facility as well as installation and removal cost of facility, the objective function will be:-

$$f = \min(f_1 + f_2) \quad \ldots\ldots\ (3)$$

Dynamic site layout problem will be converted to static layout problem if value of $m = 1$. For this value, total no of time span for which temporary facility to be locate at construction site will be one so intermediate shifting or relocating of facility will happen but it will include initial allocation and final removal cost.

Input to the model will consist of three types of matrices named as F, B, C. Here F is an n×n matrix which indicates the flow cost between facilities in m period, B is an n×n matrix which represent installation cost and C is also an n×n matrix which defines the removal cost.

4. PROBLEM IMPLEMENTATION

Case studies have been done to check the performance of the model in different stages of development. In the initial stage, the model was applied to a hypothetical problem with rectangular temporary facility and rectangular irregular facilities. The details of the implementation for integrating CAD with ACO based site optimization are shown in the flow chart in Figure 1. Detailed implementation is given elsewhere in the project report [18, 19].

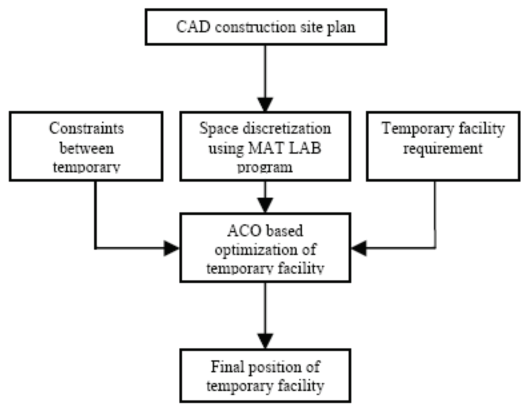

Figure 1 Flow Chart for Implementation

The performance of the model is compared with the result obtained by GA. It was modified for irregular temporary facility in the same problem.

4.1 Application to the Simplified Hypothetical Problem

The details of the problem are as follows. Boundary is 500m x 400m; No. of permanent facilities is 5; No. of temporary facilities is 5 (Rectangular).

Table 2 Details of Facilities

Permanent Facilities		Temporary Facilities	
Facility No.	Access Point Location (x,y)	Facility No.	(Lx, Ly)
1	128, 294	1	(50, 50)
2	348, 260	2	(40, 30)
3	217, 192	3	(30, 30)
4	81, 97	4	(20, 20)
5	350, 68	5	(30, 50)

Where (Lx, Ly) = (Length along x-axis, Length along y-axis) and (x, y) = (x-coordinate, y-coordinate). Affinity matrix is considered based on the six-value scale presented in Table 3.

The result of site layout using GA and ACO is shown in Table 4 for rectangular shape of temporary facilities.

Table 3 Affinity Matrix

Facilities	T1	T2	T3	T4	T5	P1	P2	P3	P4	P5
T1	X	E	I	O	X	X	O	O	A	X
T2	E	X	X	U	X	E	X	O	E	E
T3	I	X	X	X	X	E	A	O	E	I
T4	O	U	X	X	X	A	O	O	X	X
T5	X	X	X	X	X	A	A	X	X	X

Table 4 Site Layout for Rectangular Shape

Temporary facility no.	Position of centroid	
	X,Y (GA)	X,Y (ACO)
1	91,55	92,56
2	110,105	110,106
3	286,229	286,228
4	129,283	129,283
5	215,251	210,252
Objective function	**69223.15**	**68844.50**

Table 5 Temporary Facility

Temporary facility no	Maximum dimension		Shape
	X	Y	
1	50	50	Triangular
2	40	30	Triangular
3	30	30	Triangular
4	20	20	Circular
5	30	50	Elliptical

4.2 Modified Hypothetical Problem (Irregular Shape or TF)

The problem considered is same as the previous problem with irregular boundary of temporary facility. All Permanent facility have the same position and shape as mentioned in previous problem but shape and size of temporary facility is changed from regular to irregular. Temporary facilities changed to different shape and size having maximum x and y length same as previous problem. The result of the ACO is shown in Table 6. Figure 2 shows the final result of the integrated CAD and site optimisation program for irregular temporary facilities.

Table 6 Result of Actual vs. Rectangular Shape

Temporary facility no.	Position(X,Y) of Centroid (using ACO)	
	Assuming rectangular	Taking Actual shape
1	92,56	59,71
2	110,106	108,103
3	286,228	300,233
4	129,283	128,283
5	210,252	220,250
Objective function	**68844.50**	**66349.15**

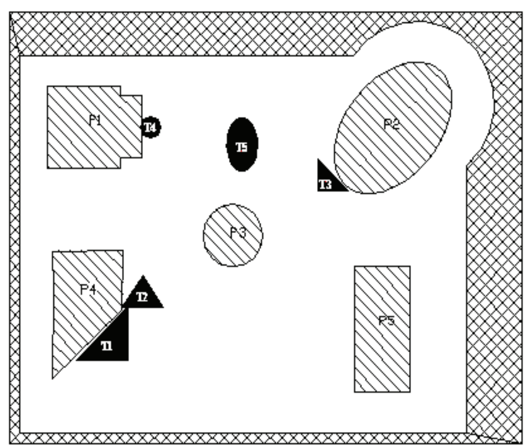

Figure 2 Site Layout of Irregular Temporary Facility

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