Minimize the total crane hoisting cost in the construction sites by the aids of genetic algorithm

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Site layout planning is a complicated issue because of the vast number of trades and interrelated planning constraints especially in case of using a tower crane. Tower cranes are the major site facilities to construct high-rise buildings. The location of a tower crane affects on his efficiency and utilization. The dependent activities such as concreting, transporting reinforcement bars, and formwork, the correct estimation of the hoisting times can improve the utilization of tower crane and avoid imbalance-hoisting schedule. In this research, minimization of hoisting time is our target by determined the optimum location of a single tower crane. The proposed model is created to determine the optimum location with the aids of Genetic Algorithm (GA). GA is an effective tool in handling this kind of nondeterministic polynomial optimization. A practical example is presented to verify the proposed model and demonstrate the application value of this model.

أن تخطيط مواقع الانشاء من المهام الصعبة نتيجة العدد الهائل من المهن المتداخلة وعوائق التخطيط المتشابكة وبخاصة في حالة استخدام ونش برجي، وتعد الاوناش البرجية من اللمعدات الهامة لانشاء المباني العالية، وموقع الونش البرجي يوثر علي كفاءة ومدي المنفعة العائدة من الونش علي الموقع، معتمد فقط علي الخبرة الشخصيةو لكي نقضي علي هذه الصعوبة يتم الدراسة في هذا البحث علي منطقة محددة للانشاء لبناء الهيكل الخرساني لمشروع برج سكني. في هذا البحث نهدف الي اختيار أفضل مكان للونش البرجي و يتم اعداد نموذج باستخدام الخوارزمية الجينية لحساب أفضل مكان للونش البرجي واعطاء مثال تطبيقي. و قد كانت نتائج الاختيار الافضل للمواقع مبشرة جدا مما يوضح القيمة التطبيقية للنموذج.

Keywords: Construction engineering, Tower cranes, Hoisting cost, Genetic algorithm

1. Introduction

In the construction industry, site layout is a very important planning problem. The objective of site layout is to position temporary facilities both geographically and at the correct time such that the construction work can be served satisfactorily with minimal costs and improved safety and working environment. Accurate construction planning is a major determinant in ensuring the completion of a project on time. Scheduling tools currently available in the construction industry, in particular the Critical Path Method (CPM), do not provide much assistance to the project manager in updating the project schedule in terms of alleviating the latest expected deviations. Rather, they leave the project manager to reach passively only after the deviations become apparent on site. Accurate estimation of activity duration is a prerequisite to planning. In planning crane dependent activities such as concreting, transporting reinforcement bars, and formwork, the correct estimation of the hoisting times can improve the utilization of tower crane and avoid imbalance-hoisting schedule. Among the overall housing market, pubic housing has apportioned more than 50% in the last decades. Owing to the shortage of land supply, high-rise residential buildings become a norm. Consequently, tower cranes have been used extensively in pubic housing construction.

2. Background

Some researchers deal with problem estimating crane place which implementing minimum time for crane movements and accordingly minimizing cost.

Warszawski [1] established a time distance formula by which quantitative evaluation of location was possible.

Kogan [2] described the horizontal simultaneous movement of crane operations

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in lifting objects for experienced crane operators is assumed 76% of the total duration of the cycle.

Rodriguez, R. et al. [3] developed a mathematical model to establish the optimal location of a single tower crane within a construction site. The model aimed at locating the best position of the crane hook when waiting between movements. The objective of this model was to minimize the total crane hoisting cost between crane and the construction supportive facilities that were serviced by the crane.

Furusaka et al. [4] presented a dynamic programming model with the objective function being hire cost, but without consideration of location.

Gray L. [5] developed a systematic approach to the selection of an appropriate crane for a construction site. They described the process and criteria for the selection of two categories of crane, namely, tower cranes and mobile cranes. A computer – based expert system was developed and used to simplify the selection process.

Wijesundera et al. [6] designed a dynamic simulation model to reconstruct operation times and equipment cycles when handling concrete.

Choi et al. [7] adopted the basic mathematical expressions of Rodriguez R. et al. [3] for computing the angular and radial movement. However, they considered that the angular and radial movements were carried out simultaneously with the hoisting movement. Instead of locating the optimal hook waiting position for a crane, they suggested to locate the optimal position of a tower crane to serve the predetermined supportive facilities.

Choi et al. [8] introduced another model to optimize single tower crane location by calculating total hoisting times incurred.

Zhang et al. [9] developed a stochastic simulation model to optimize the location of a single tower crane. One of the objectives of their research was to use the simulation technique to reflect the real world practices, which is different from the deterministic models described later. Similarly, to the former researchers, this model also alleged that the vertical movement time did not vary when the crane location changed.

Philip et al. [10] and Li et al. [11] and applied Genetic Algorithms (GA) to optimize a set of predetermined facilities. However, their approach has been much simplified, shapes of facilities were considered as rectangular, and size constraint and space competition between facilities were not taken into account.

Zhang et al. [12] analyze the relationship between hook movement in radial and tangential directions in the horizontal plane. They concluded that the degree of coordination of hook movement in radial and tangential directions in the horizontal plane α could be assumed 25%. In addition, the vertical simultaneous movement of crane operations is assumed to be small for high-rise building construction where the object needs to be lifted to a level that is clear of the building before radial movements can be activated. The coefficient β that represents degree of coordination of hook movement in vertical and horizontal planes is assumed to be 100%; i.e., the hook moves consecutively in two planes. This model did not give the optimum location of tower crane to minimize the hoisting time.

Existing models have their limitations. They tend to oversimplify the site space allocation and positions of tower cranes. In addition, they neglect the interdependent and space competition relationships where site facilities.

The objectives of this paper are to investigate and analyze the tower crane location and to create a GA model to optimize the above facilities, taking into account the complexity of the relationship between these facilities.

3. GA modeling

GA is directed randomized search procedures. They derive their power from the mechanics of natural selection and the survival of the fittest principles. GA has been popular in many research areas (constrained and/or unconstrained optimization, scheduling and sequencing, hoisting, reliability optimization). In the broadest sense, a GA creates a set of solutions that reproduce based on their fitness in given environment.

The following process can generate the proposed model: (1) an initial population of random solution is created. (2) Each member of the population is assigned a fitness value based on its evaluation against the current problem. (3) Solution with a higher fitness value is most likely to parent new solution during reproduction. (4) The new solution set replaces the old, a new generation is complete, and the process continues by returning to second step.

This sequence implements, in a most simplistic way, the concept of survival of the fitness. The reproductive success of a solution is directly tied to the fitness value it is given during evaluation. In this stochastic process, the least fit solution has a small chance at reproduction whereas the fit solution may not reproduce at all. The outcome of a GA is based on probabilities, lust as biological success is grounded in chance. In site facilities layout optimization, there exist many problems to be solved (for example, the nonlinearity of the site facilities layout planning system, discreteness of the number, and positions of facilities). Among these problems, one of the important issues is the optimal placement of facilities in sites, on the condition that all facilities are considered simultaneously. GA is heuristic random search techniques based on the concept of natural selection and natural genetics of a population (Holland; Goldberg [13]).

GA presumes that the potential solution of any problem is unique and can be represented by a set of parameters. These parameters are regarded as the genes of a chromosome and can be structured a string of values in binary form. A positive value, generally known as a fitness value, is used to reflect the degree of "goodness" of the chromosome for the problem that would be a highly related to its objective value. Because of the distinctive features such as domain independence, nonlinearity, robustness, and parallel nature, GA has been proven a versatile and effective approach for solving optimization problems.

4. Definition and assumptions

The proposed model is created to search for the optimal location in terms of minimal hook hoisting time. The following assumptions were suggested to create the proposed model:

1. Geometric layout of all demand and supply points are predetermined and fixed.
2. Radius of crane is similar over the tasks.
3. The area of each supplied points are large enough to accommodate the storage requirements.
4. For each supply and demand pair, demand levels for hoisting are known (e.g., total number of lifts, maximum load, unloading delays, and so on).
5. The material hoisting between a supply-demand pair is handled by crane only.
6. The horizontal simultaneous movement of crane operations in lifting objects for experienced crane operators is assumed 76% of the total duration of the cycle.
7. The coefficient α that represents the degree of coordination of hook movement in radial and tangential directions in the horizontal plane is assumed 25%.
8. The vertical simultaneous movement of crane operations is assumed to be small for high-rise building construction where the object needs to be lifted to a level that is clear of the building before radial movements can be activated.
9. The coefficient β that represents degree of coordination of hook movement in vertical and horizontal planes is assumed to be 100%.

5. Proposed algorithm

To minimize the total crane hoisting cost in the construction sites by the aids of genetic algorithm, three processes was suggested.

1. The supply points are determined and fixed from the site layout with the consideration of the length of the tower crane jib and its capacity radius. The demand points are fixed by geometric shape of the permanent building.
2. The possible locations of the tower crane are plotted, which are dependent on the structural design layout, space provisions of the permanent structure, convenience to other site activities.

3. A GA model is applied to optimize output: the tower crane location for various trades.

If (XSJ, YSJ, ZSJ), (XDJ, YDJ, ZDJ) refer, respectively, to the location of supply and demand of task, for a crane located at (X, Y), hook travel time *T* can be expressed as:-

$$T = \max (Th, Tv) + \beta . \min (Th, Tv). \tag{1}$$

Hook hoisting time is calculated from the next equation.

$$TR = T(D_{J'}, S_J) + N_J[L(S_J) + T(S_J, D_J) + U(D_J) + T(D_J, S_J)] - T(D_J, S_J). \tag{2}$$

Where:

$T(D_J, S_J)$	is the hook travel time without load from *D* of task *J'* (produced by last request) to *S* of present request *j*,
$T(D_J, S_J)$	is the hook travel time with loads form *SJ* to *DJ*,
$T(D_J, S_J)$	is the hook travel time without loads form *DJ* to *SJ*,
$L(S_J)$	is the hook delay time for loading at *SJ*,
$U(D_J)$	is the hook delay time for unloading at *DJ*, and
NJ	is the repeat lifting load of crane, which is calculated by $N_j = \frac{Q.R}{C}$.

Where:

Q	is the total quantity of material transport between pair *S-D*,
R	is the radius of crane, and
C	is the load capacity of crane.

Repetition is considered an essential factor in defining total time of lifting through this relationship. In addition, total cost is calculated by:

$$T.c = \sum TR.C_J . \tag{3}$$

Where, *CJ* cost of material flow from *SJ* to *DJ* per unit quantity and unit time.

Here, hook vertical travel time

$$T_v = \frac{|Zi - Zj|}{Vv} . \tag{4}$$

$$T_h = \max(T_a, T_w) + \alpha \min(T_a, T_w) . \tag{5}$$

In addition, *Ta, Tw* = times for trolley radial and tangent movement respectively, being calculated from fig.1.

$$\rho(D_J) = \sqrt{(XD_J - X)^2 + (YD_J - Y)^2} . \tag{6}$$

$$\rho(S_J) = \sqrt{(XS_J - X)^2 + (YS_J - Y)^2} . \tag{7}$$

$$L_J = \sqrt{(XD_J - XS_J)^2 + (YD_J - YS_J)^2} . \tag{8}$$

The following equation calculate the time for trolley radial movement

$$T_a = \frac{|\rho(D_J) - \rho(S_J)|}{V_a} \tag{9}$$

$$T_\omega = \frac{1}{\omega} Arc\ Cos \left(\frac{L_J{}^2 - \rho(S_J)^2 - \rho(D_J)^2}{2\rho(S_J)\rho(D_J)} \right)$$
$$(0 \le arc\ cos\ (\theta) \le \pi). \tag{10}$$

Where:

Va	is the radial velocity of trolley (m/min),
ω	is the slewing velocity of jib (r/min), and
Vv	is the hoist velocity of hook (m/ min).

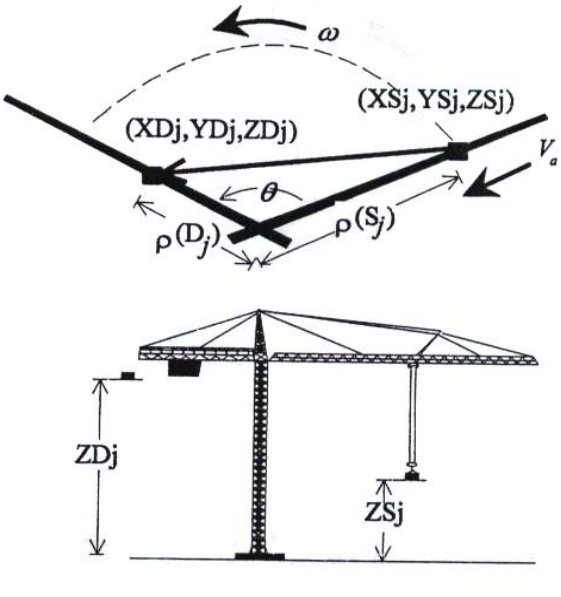

Fig. 1. Hook travel time.

6. Genetic algorithm

The proposed GA model is composed of the following subroutines:

1. Defining the demand Di (XDi, YDi, ZDi) and supply point Sn (XSn, YSn, ZSn) locations by specifying their 3D coordinate.
2. A series of chromosomes are generated, which are mapped to the various location points Cri (XCri, YCri, ZCri) (including supply and demand points).
3. The fitness value of the first attempt is calculated from the fitness function defined.
4. Crossover and mutation are then applied to change the chromosomes.
5. The fitness value of the new generation is compared with the previous one.
6. The process is repeated until the termination condition has been reached.

Subject to the constraints that the distance between the supply points Si and tower crane Cri and between demands points Di to tower crane Cri, plus a margin that allows for the size of the storage area, should be within the jib length on the lifting capacity radius.

7. Illustrative example

This example had been concentrated to illustrate idea genetic algorithm model. The material to be handled by tower crane is fresh concrete. Therefore, it is clear that location of tower crane is our essence of this search, assuming that all supply materials are (S). So coordinate point (S) and coordinates points of demands D1, D2, D3 are determined in a give drawing. In addition, quantities needed for building to be handled by tower crane per stages shall be defined from each point of supply to demands points. Fig. 2 shows the layout of site. Tables 1, 2 show coordinates of demands and supply points respectively and table 3 shows repeat lifting of material transported between every S-D pair.

The crane traveling speeds were obtained by site measurement from public housing sites the averages are recorded as follows:

Vv (hoisting velocity of hook) =60 m/min

Va (radial velocity) =53.3 m/ min

ω (slewing velocity of Jib) = 7.57 rad /min

The quantities of material flow for each element per concrete floor is defined in table 3. The β- value (degree of coordination of hook movement in vertical and horizontal planes) is assumed to be 0.25, and the α – value (degree of coordination of hook movement in radial and tangential direction in the horizontal planes) is 1. In the GA modeling, the mutation rate is 0.01 and the crossover rate used is 0.70. Mutation and crossover are then applied to change the chromosomes. The fitness value of new generation is compared with the previous one. The process is repeated until the termination condition has been reached (for illustrative example, no change, or no improvement of the fitness value in 50 rounds of attempts for each radius of tower crane.

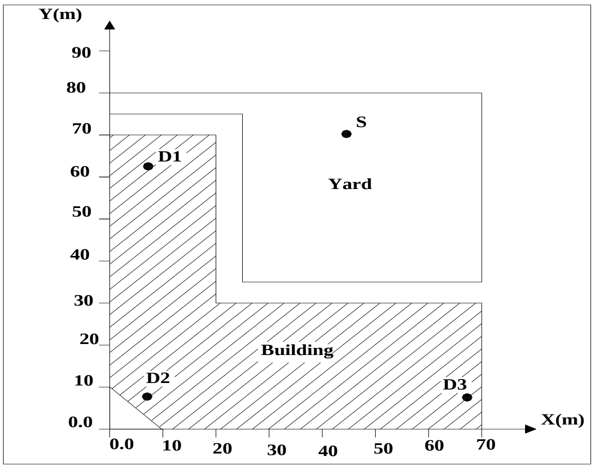

Fig. 2. Layout of the site.

Table 1
Coordinate of demand points

Demand	X (m)	Y(m)	Z (m)
D1	7.50	62.50	30.00
D2	7.50	7.50	3.000
D3	67.50	7.50	30.00

Table 2
Coordinate of supply points

Supply	X	Y	Z
S	45.00	70.00	0.0

Table 3
Repeat lifting of material for pair S-D

Supply	D1	D2	D3
S	1000	800	1200

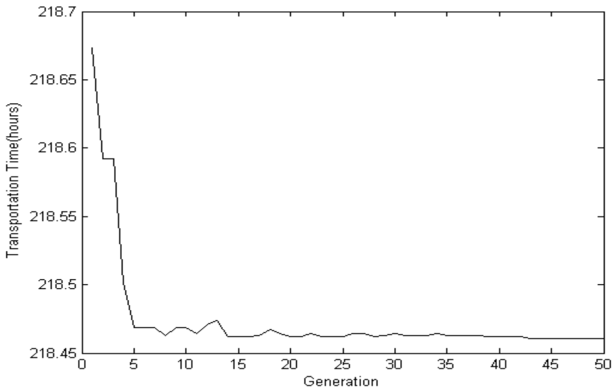

Fig. 3. Relationship between hoisting time and generation number.

The results of rounds of example with different times are shown in fig 3. It shows hoisting time at all generation for radius 42 m.

Table 4 shows the model output, which is the minimum time for different radius from 221.78 to 218.34 hours. From the model results, it is shown that increasing the radius from 42 to 64 m gets decreasing in time values 221.78 to 218.34 and shows that the time decrease from 221.78 to 218.33 hours as when the radius increase from 42 to 52 m. The time values are constant 218.35 hours as the radius values increase from 54 to 60m. The time value increases to 218.37 hours when the radius increases to 62 m. The time value becomes 218.34 hours when the radius takes the value 64 m. The first working radius value which realizing constant time value can be selected from GA generation. The selected radius satisfies the optimum crane location which minimizing the total hoisting time.

Table 4.
Result of illustrative example for different radius

Radius (m)	X (m)	Y (m)	Hoisting time (hours)
42	31.8	30	221.78
44	31.6	30.4	221.61
46	32.7	31.9	219.44
48	33.2	34.4	218.46
50	36.8	32.3	218.36
52	37.4	31.9	218.33
54	372	32.1	218.35
56	37.2	32.1	218.35
58	37.2	32	218.35
60	37.3	31.9	218.35
62	37.2	32.2	218.37
64	37.4	32	218.34

8. Conclusions

The proposed GA model gives an objective, quantitative, and scientific way to evaluate the effectiveness of site facility layout. Experimental result indicates that the model performs satisfactorily. As revealed from the application illustrative example, if site planners just randomly allocate the tower crane location, the hoisting time will be 2.5% lower than the optimum solution as shown in table 4 for radius 42m. This fact implies that a systematic approach in site facility planning is important to improve the site production efficiency. A 2.5% saving in crane traveling time can generate a substantial improvement in site productivity and savings in time of construction. The model offers the following superiority over traditional approaches. (1) Possible tower crane positions are obtained realistically according to the site conditions and geometrical layout of the permanent structures. The model cane thus generates a more realistic solution. (2) Unlike the 2D layout approach of traditional methods, the model developed cane handle 3D coordinates of all supply, demand, and tower crane location. (3) Site facility layout is a nondeterministic polynomial problem that is difficult to solve by other polynomial algorithms. GA is an effective tool in handling this kind of nondeterministic polynomial optimization.

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