Optimal Construction Site Layout Considering Safety and Environmental Aspects

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Optimal Construction Site Layout Considering Safety and Environmental Aspects

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Abstract: A good site layout is vital to ensure the safety of the working environment and effective and efficient operations. Site layout planning has significant impacts on productivity, costs, and duration of construction. Construction site layout planning involves identifying, sizing, and positioning temporary and permanent facilities within the boundary of the construction site. Site layout planning can be viewed as a complex optimization problem. Although construction site layout planning is a critical process, systematical analysis of this problem is always difficult because of the existence of a vast number of trades and interrelated planning constraints. The problem has been solved using two distinct approaches: Optimization techniques and heuristics methods. Mathematical optimization procedures have been developed to produce optimal solutions, but they are only applicable for small-size problems. Artificial intelligent techniques have been used practically to handle real-life problems. On the other hand, heuristic methods have been used to produce good but not optimal solutions for large problems. In this paper, an optimization model has been developed for solving the site layout planning problem considering safety and environmental issues and actual distance between facilities. Genetic algorithms are used as an optimization bed for the developed model. In order to validate the performance of the developed model, a real-life construction project was tested. The obtained results proved that satisfactory solutions were obtained.

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Introduction

In the construction industry, site planning is the most overlooked aspect by site engineers. The attitude of the engineers has been that site layout planning will be done as the project progresses. It is generally acknowledged that an efficient overall layout plays a key role in the operational efficiency, cost, and quality of construction. Site layout is routinely performed by managers on construction sites. Yet, project managers usually learn to accomplish this task by trial and error in the course of years of fieldwork.

The site layout planning problem is generally defined as the problem of identifying the number and size of temporary facilities (TFs) to be laid out, identifying constraints between facilities, and determining the relative positions of these facilities that satisfy constraints between and allow them to function efficiently (Zouein et al. 2002). TFs are those facilities that serve the construction site but are not being considered a physical part of the structure that is required to be built. Examples of TFs are material stores, fabrication yards, lay-down areas, parking lots, offices, and warehouses. In current practice, site layout planning is often done by adjusting previous plans based mainly on the project manager's experience and common sense (Cheng and O'Connor 1996).

Most construction sites involve some or all of the following items: Basic structures to be constructed, facilities that serve the whole project, obstacles such as trees or old buildings, movement (internal) routes, and site boundaries, even there are no definite barriers. Numerous techniques have been proposed to uncover solutions for site layout problems, but it is very difficult to obtain the optimal one by hand calculations. Therefore, optimization techniques are usually used to search for solutions for site layout problems.

In almost all optimization approaches for site layout planning, the layout goal to be attained is to *minimize* [*interfacilities transportation cost*]. One of the common formulas used to achieve this site layout planning goal is

$$\text{Min} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij} R_{ij} \tag{1}$$

in which n=total number of TFs; d_{ij}=travel distance between facilities i and j; and R_{ij}=parameter that represents: (1) transportation cost between facilities i and j or (2) a relative proximity weight that reflects the required closeness between facilities i and j.

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Literature Review

Many research efforts have been made toward developing a realistic model for the site layout planning problem. The problem has been solved by researchers using two distinct techniques: Mathematical optimization and heuristic methods. Mathematical optimization procedures have been designed to produce optimum solutions. Heuristic methods, on the other hand, used to produce good but not optimal solutions. Heuristic methods are based on knowledge-based expert system, and recently on artificial intelligent concepts. However, the first category cannot be adopted for large-scale projects because of the need for huge calculations and efforts. Therefore, the second category is the only practical available means for handling complex real-life projects.

Cheng and O'Connor (1996) developed an automated site layout system called *ArcSite*, which is comprised of a geographical information system integrated with a database management system. A knowledge-based expert system is used to model the spatial requirements of a TF on the construction site. A proximity index is used to determine the optimal site layout, which is calculated based on the number of trips and the attract/repel relationships between two facilities. As a notable limitation to this model, *ArcSite* can locate only a limited number of facilities.

Zouein and Tommelein (1999) developed a model for dynamic layout planning of construction facilities. They used a hybrid incremental solution method, which creates a sequence of layouts that span the entire project duration. The model is solved using linear programming to find out the optimal position so as to minimize transportation and relocation costs. The primary advantage of this method is the possibility of formulating and solving the layout problem using linear programming without undue computations. In addition, the quality of the layout based on traveling cost and relocation cost can be assessed. However, construction facilities can be represented as rectangles only. Also, they have fixed dimensions and can be positioned at 0° (or 90°) orientations only.

Li and Love (1998) introduced a genetic algorithm-based (GA-based) model to solve the facility layout problem. The objective of the model is to minimize the total traveling distance between facilities. The problem is described as allocating a set of predetermined facilities into a set of predetermined places, simultaneously satisfying layout constraints and requirements. However, it is assumed that the size of each predetermined location equals the area of the largest facility. Also, the predetermined locations are represented only as rectangles.

Hegazy and Elbeltagi (1999) developed a GA-based model for dynamic site layout planning. The model deals with any irregular user-defined site using a two-dimensional grid. Each facility is modeled as a number of grid units. The area of a single grid unit is calculated in advance for each site. The main advantages of this model are its applicability for any user-defined site shape and is not limited to rectangular or square facilities. However, the model does not consider safety considerations and environmental aspects. Also, it considers Euclidean (center-to-center) distances between facilities as a method for distance measurement.

Osman et al. (2003) developed an automated computer system called *EDSLP* (Evolutionary Dynamic Site Layout Planner). The system was used for optimally assigning TFs, simultaneously taking into consideration the dynamic nature of construction projects. *EDSLP* consists of a data input mean, a computer-aided design user interface, and an evolutionary optimization GA engine. The objective function is to minimize transportation and relocation costs. A sequence of layouts spanning the entire project duration is provided. However, the facilities are limited to rectangular shape only. Also, safety and environmental aspects are not considered.

Elbeltagi et al. (2004) introduced a model that considers both safety and productivity issues. Also, parts of the constructed space are utilized as TFs to relieve congestion on restricted sites. When a safety concern rises between two facilities, a large negative value is assigned to the closeness weight. As such, the further the distance between them, the lower the layout score (thus improving the layout). However, this method for dealing with safety considerations does not suit all requirements of projects managers regarding safety issues, as will be discussed later. Moreover, the Euclidean distance method is used in measuring distances between facilities.

In almost all models used for the site layout planning problem, safety considerations and environmental aspects have been ignored or at least not modeled in an appropriate manner. Also, distances between facilities are not measured properly. These two main limitations lead to impractical modeling of the site layout problem, and hence need modifications to suit real-life situations.

In this paper, an optimization model has been developed for solving the site layout planning problem considering safety and environmental issues. A new method for measuring distance between facilities is used, which is named "actual route distance." The developed model can also support the dynamic nature of construction projects. Because GAs are adopted here as an optimization technique, basic features of GAs will be briefly reviewed first.

Optimization by Genetic Algorithms

GAs are search algorithms that are based on the natural selection and genetics to search through decision space for optimum solutions. GAs employ a random yet directed search for locating the globally optimal solution. In addition, GAs perform an intelligent search for a solution from a nearly infinite number of possible solutions. Typically, GAs require a representation scheme to encode feasible solutions for optimization problems. Usually, a solution is represented as a linear string called chromosome whose length varies from one application to another. Some measures of fitness (objective function) are applied to construct better solutions.

Once the chromosome structure and the objective function are set, the GA evolutionary procedure takes place on a population of parent chromosomes. Three genetic operations are required: Reproduction, crossover, and mutation. Reproduction is the process by which chromosomes with better fitness values receive correspondingly better copies in the new generation. As the total number of chromosomes in each generation is kept constant, chromosomes with lower fitness values are eliminated. The second operator; crossover, is the process in which chromosomes are able to mix and match their desirable qualities in a random fashion. Crossover (marriage) is conducted by selecting two parent chromosomes, exchanging their information, and producing offsprings. The exchange of information between parent chromosomes is done through a random process. Fig. 1 shows a case of double-point crossover, but single-point crossover may also be used. As an opposite to crossover, mutation is a rare process that resembles the process of a sudden generation of an odd offspring that turns out to be genius (Goldberg 1989). The benefit of the mutation process is that it can break any stagnation in the evolutionary process, avoiding local optima.

Recently, research shows that GAs are robust and have the capability to efficiently search complex solution space. The robustness of GAs is due to their capabilities to locate the global optimal. Therefore, GAs are less likely to restrict the search to a local optimum compared with point to point movement, or gradi-

Fig. 1. Crossover operation to generate offsprings

ent descent optimization technique (Forrest 1993). However, the major drawback of GA-based applications is that they require much greater computational time than traditional methods.

Safety Considerations and Environmental Aspects

Safety is far more than craftsmen wearing hard hats on construction sites. It is a philosophy that identifies and eliminates job site hazards throughout the life cycle of a project. Accident statistics show that construction is one of the most dangerous industries in the world. However, several easily overlooked factors, such as lack of preplanning, inadequate selection of contractors, and lazy attitudes are significant contributors to these statistics (Hislop 1999). On the other hand, a safe tidy site with good safety regulations is likely to be a site with high moral, few disputes, less absenteeism and labor turnover, and better team work.

Environmental planning is considered a proven tool for reducing the impacts from any environmental risks. Typical examples of environmental hazards that occur frequently are noisy workshops and facilities that emit gases, vapors, fumes, dusts, mists, dangerous radiation, and any other harmfull substances (OSHA 1987). Both safety and environmental hazards have bad effects on human beings, and therefore their harmful effects should be prevented or at least mitigated.

Facilities of high harmful effects, which are positioned adjacent to neighbors, present actual or potential health hazards, especially when those neighbors are hospital, schools, or residential buildings. Therefore, a prespecified area adjacent to those neighbors becomes an essential requirement. These areas will be prevented from being allocated to any TF, and will be referred to as "*prohibited area*."

Another consideration is the proper "*safety zones*" around construction areas. These zones protect workers and entities from falling objects. The Uniform Building Code UBC (1985) states that: "at least 10 ft clearance from buildings or structures shall be kept clear, driveways between and around open storage yards shall be at least 15 ft wide and free from accumulation of rubbish, and material stored inside building under construction shall not be placed within 6 ft of any hoist way or inside floor opening."

The third issue regarding environmental consideration is the dangerous interaction between harmful facilities and sensitive facilities. As discussed earlier, harmful facilities are noisy workshops and those emit harmful substances. These types of facilities should be kept a far distance away from sensitive facilities, such as engineers' offices, workers facilities, and any buildings containing humans. Therefore, a "*minimum distance*" should be assigned between each two facilities having this action.

Because of the increase attention of safety and environmental considerations mentioned before, it must be considered in the site layout planning problem. The important issues, which will be considered are: Prohibited area, safety zones around constructed facilities, and minimum distance between facilities.

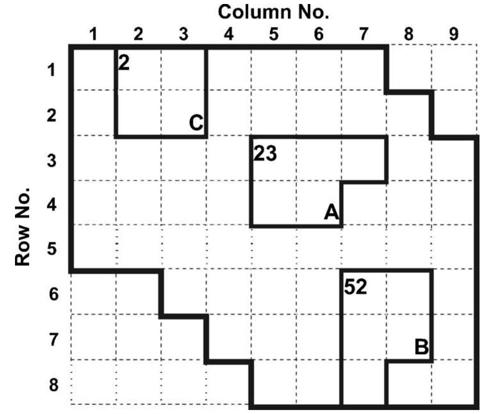

Fig. 2. Site and facilities representation

Developed Site Layout Planning Model

In developing a site layout planning model, previously discussed safety and environmental aspects are considered. Also, the distances between facilities are modeled more practically. First, representation of site and facilities are outlined, and types of facilities are presented. Safety and environmental aspects and distances between facilities are modeled in an appropriate manner. Closeness relationships between facilities are defined. Finally, coding site layout optimization in GAs format is presented.

Site and Facilities Representation

Site and facilities are modeled in the present study using a two-dimensional grid. Each grid unit is called a cell, the area of which is user-defined. Hence, any irregular shape of the site can be modeled, as shown in Fig. 2. A facility can be represented in the grid as a number of grid units, which can be calculated using

$$\text{Number of facility units} = \frac{\text{Facility area}}{\text{Cell area}} \tag{2}$$

For ease of modeling, each cell has a *location reference* that can be calculated using

$$\text{Location reference} = (\text{Row position} - 1) \, \text{Total columns} + \text{Column position} \tag{3}$$

Location reference is an expression used to define the position of any facility in the site (Elbeltagi 1999). It is formulated using the column and row boundaries of the whole site. A facility location reference is defined by the location reference of the top-most left-hand cell of the facility. For example, the location reference of Facility A in Fig. 2 is 23 $[(3-1)9+5]$. Also, location references of Facilities B and C are 52 and 2, respectively (Fig. 2).

Facilities can be placed in a site in three ways, starting from the location reference of the facility: horizontal, vertical, and rectangular. In horizontal and vertical arrangement, the user should specify the width of the facility in a number of grid units. Facility A, in Fig. 2, has an area of five cells, width of two cells, and arranged horizontally. Therefore, Facility A occupies four cells (2×2) starting from Location Reference 23 and the remaining cell (5-4) is arranged from the top-most right-hand side.

In Fig. 2, Facility B has an area of five cells and width of two cells, but arranged vertically. In this case, Facility B occupies four cells starting from Location Reference 52 and the remaining cell is arranged from the bottom-most left-hand side. In the rectangu-

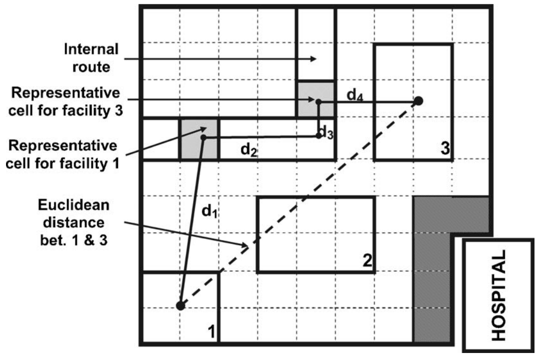

Fig. 3. Prohibited areas and shortest route distance

lar arrangement, the width of the facility is calculated as the integer of the square root of the facility area expressed in a number of cell units. Facility C in Fig. 2 has four grid units and is arranged as a rectangle starting from Location Reference 2.

Types of Facilities

In this study, the classification of facilities proposed by Elbeltagi (1999) will be adopted. Facilities are classified as temporary facilities and obstacles. Temporary facilities are those facilities that serve the site during construction. TFs may be *fixed* in place or *nonfixed*. Fixed facilities are positioned in a fixed location, such as gates, security rooms, and parking lots. On the other hand, nonfixed facilities need to be optimally located in any empty space on the site. Both fixed and nonfixed facilities are maintaining defined closeness relationships with each other. Also, structures or existing buildings will be referred to as permanent entity. Permanent entities are treated as fixed facilities because they maintain defined closeness relationships with other facilities.

Obstacles are entities that are fixed in place and not maintaining any defined closeness relationships with other facilities, such as trees or old buildings. Obstacles cannot be removed from the site, so, spaces used by obstacles in the site cannot be allocated to any other type of facility.

Modeling Safety Considerations and Environmental Aspects

As discussed before, safety considerations and environmental aspects that will be considered in this model are prohibited area, minimum distance, and safety zones. Modeling of these considerations will be discussed here.

Prohibited Areas

Fig. 3 shows a typical construction site adjacent to a hospital in the bottom right-hand side. In this case, it is important to prevent some facilities that have harmful effects (such as noise, air pollution, etc.) from being positioned adjacent or near to such sensitive entities. Therefore, a prespecified area in the job site must be prevented from being allocated to facilities with harmful effects. In Fig. 3 a prohibited area is represented by dashed cells.

Minimum Distance

If hazardous facilities have bad effects on users of other TFs, then a minimum distance between such facilities should be prespecified. The distance between such facilities should satisfy the following relationship:

$$d_{ij} \geq D_{\min ij} \tag{4}$$

where d_{ij}=Euclidean (geometric) distance between Facilities i and j and $D_{\min ij}$=minimum euclidean distance between facilities i and j. The minimum distance is user-defined and should be carefully chosen to prevent dangerous interaction between facilities.

Safety Zones

Safety zones represent an additional area added to the physical area of the facilities to protect any person who might be injured by the fall of materials, tools, or equipment being raised or lowered. Safety zones should be specified in adequacy with respect to relevant regulations, such as OSHA (1987) and UBC (1985). For example, if the actual area of the facility=50 m^2 and the appropriate safety zone=20 m^2, then the facility area=50+20=70 m^2.

Actual Route Distance between Facilities

As discussed in the literature, existing site layout models consider a Euclidean distance between facilities. A Euclidean distance between Facilities 1 and 3, in Fig. 3, is represented by the dashed line, which does not represent the actual traveling distance. To specify the actual route distance between facilities, a network of continuous internal routes in the site should be specified first. These routes are usually used for the movement of equipment and labor between facilities within the site. Internal routes are usually specified by project managers, even if these movement routes are not paved, cemented, covered, or lined. Internal routes are usually continuous to facilitate movement of facilities, and hence measuring traveling distance between them.

To specify actual route distances between any two facilities, the nearest cell from the internal routes network for each facility has to be determined first. This cell will be referred to as the *representative cell*, which acts as a representative for that facility. The shortest route distance between Facilities i and j is calculated by summing up the distance between Facility i and its representative cell, Facility j and its representative cell, and the distance between these two representative cells through the internal routes network. In Fig. 3, the shortest route distance between Facilities 1 and 3 equals the summation of d_1, d_2, d_3, and d_4.

Facilities Closeness Relationships

The interrelationships among facilities are decided by the project manager's preference and involve some degree of fuzziness and ambiguity. Interrelationships between different facilities are usually referred to as closeness relationships, which can be represented by closeness (proximity) weights. A high proximity weight between two facilities means that they share a high level of interaction and accordingly, the distance between them should be small. Evaluation of these weights can be done using either quantitative or qualitative methods.

The expertise or desirability of the project manager leads to a subjective verbal proximity relationship between any two facilities. Several attempts have been made to convert these verbal representations to numeric proximity weights between facilities. One of the popular proximity weights used in construction is given in Table 1, as suggested by Elbeltagi (1999). These proximity numbers are determined using fuzzy set theory. The proximity weights given in Table 1 express an exponential relationship with desired closeness. So, if two facilities are required to be

Table 1. Closeness Relationship Values

Proximity weight	Desired relationship
1	Undesirable
6	Unimportant
36	Ordinary
216	Important
1,296	Especially important
7,776	Absolutely important

close to each other, a high proximity weight is specified to force them to be close to each other in the optimization process, and vice versa.

Site Layout Optimization Using Genetic Algorithms

An optimization-search procedure has been developed using GAs to optimally locate nonfixed TFs on site. The procedure searches for the optimum location of each facility so that closeness relationships and actual distances between facilities are optimally maintained, simultaneously satisfying safety and environmental considerations. Implementing the GAs technique for the problem at hand involves four primary steps: (1) setting the chromosome structure; (2) deciding the chromosome evaluation criterion (objective function); (3) generating an initial population of chromosomes; and (4) selecting an offspring generation mechanism.

Chromosome structure has been set as a string of elements; each corresponds to the location of a nonfixed facility, as shown in Fig. 4. In this case, the chromosome length equals the number of nonfixed facilities (NF), which will be arranged within the site boundary. This formation is adopted in the present study.

Evaluating the total travel distance of a given site layout involves determining the centroids of all facilities, their representative cells, and then calculating the actual distances between them.

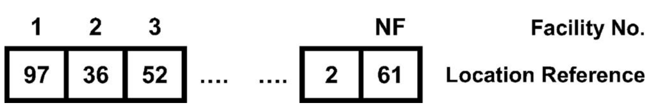

Fig. 4. Chromosome formation

Then, the total weighted travel distances (objective function) of a site layout can be determined. To evaluate the goodness of a possible layout (chromosome), Eq. (1) is used as a fitness function, in which d_{ij} represents the actual distance between Facilities i and j and R_{ij}=proximity weight between them. Once the chromosome structure and objective function are set, the genetic algorithm evolutionary procedure takes place on a population of parent chromosomes. The simplest way to generate that population is randomly. Once the population is generated, the fitness of each chromosome in this population is evaluated using Eq. (1).

The developed site layout planning model was implemented on a spreadsheet (Microsoft 2002) because of its simplicity in use and programmability features (Green et al. 2000). A computer program was coded using the macrolanguage of Microsoft *Excel* to facilitate model application (Sanad 2006). A full pseudocode for the model procedure is shown in the Appendix.

Case Study

The case study selected for the application of the developed model and automated system is "Tanta University Educational Hospital" located in Tanta City, Egypt. The project involves the construction of three multistory buildings, with perimeter fences and three gates as shown in Fig. 5. The site area is 28,500 m^2 with an irregular shape. The construction plan of the project requires six permanent facilities (three buildings and three guard houses) and eighteen TFs. These facilities and related data are given in Table 2. Note that the permanent facilities have blank entries in the last two columns.

No site layout plan was initially made to compare with. The contractor's staff depended mainly on their experience in organizing the facilities in site. Therefore, a disorganized site and material handling problems are expected during the progress of the project. Also, the contractor set aside material storage areas around each building to satisfy their individual needs. This, however, resulted in excessive material waste, extra material handling cost, and less maneuverability within the site.

The site location is critical because all adjacent buildings are sensitive to the harmful effects, such as noise and dust. These include Tanta University buildings, emergency hospitals, Al-

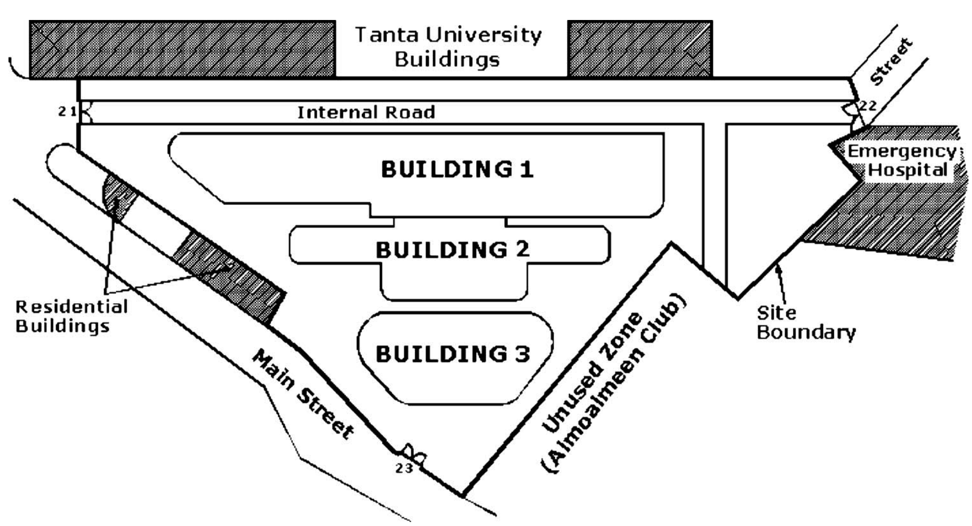

Fig. 5. General site plan for the case study project

Table 2. Facilities Data for Case Study Project

Facility number	Name	Type	Size (m^2)	Width (cells)	Arrangement
1	Building 1	Fixed	6,575	—	—
2	Building 2	Fixed	2,950	—	—
3	Building 3	Fixed	2,250	—	—
4	Batch plant (*)	Nonfixed	600	4	Vertical
5	Laydown area 1	Nonfixed	600	4	Horizontal
6	Cement warehouse	Nonfixed	400	2	Horizontal
7	Laydown area 2	Nonfixed	400	2	Horizontal
8	Labor rest area	Nonfixed	300	3	Horizontal
9	Offices	Nonfixed	300	2	Vertical
10	Scaffold storage yard	Nonfixed	300	3	Vertical
11	Carpentry shop (*)	Nonfixed	200	2	Vertical
12	Parking	Nonfixed	200	2	Vertical
13	Rebar fabrication yard	Nonfixed	200	3	Horizontal
14	Warehouses	Nonfixed	200	2	Horizontal
15	Toilets	Nonfixed	120	2	Horizontal
16	Welding shop (*)	Nonfixed	120	1	Horizontal
17	Site offices	Nonfixed	80	1	Vertical
18	First aid	Nonfixed	40	1	Vertical
19	Machine room (*)	Nonfixed	40	1	Vertical
20	Tank	Nonfixed	40	1	Vertical
21	Guard house 1	Fixed	40	—	—
22	Guard house 2	Fixed	40	—	—
23	Guard house 3	Fixed	40	—	—
24	Laboratory	Nonfixed	35	1	Vertical

Table 3. Minimum Distances between Facilities (m)

Facility number	4	8	9	11	16
8	60	—	—	—	—
9	80	—	—	—	—
11	—	60	40	—	—
16	—	60	40	—	—
17	80	—	—	60	60
18	80	—	—	60	60
21	80	—	—	80	80
22	80	—	—	80	80
23	80	—	—	80	80

moalmeen club, and some residential buildings located beside the main street.

Batch plant, carpentry shop, welding shop, and machine room are considered dangerous facilities from the safety and environment point of view and are designated by an asterisk beside the facility name in Table 2. Therefore, these facilities are prevented from being located in the prohibited area.

The minimum distances between facilities are given in Table 3. For example, the distance between batch plant and guard houses should not be less than 80 m. Also, distances between offices and welding shop should not be less than 40 m. The suggested closeness weights between facilities are given in Table 4. It is recommended to use the values given in Table 1. For example, batch plant is absolutely important to be very close to Buildings 1, 2, and 3.

The site was represented by spreadsheet cells, the area of which is chosen to be 25 m^2. Using symbols in the cells, the site can be easily drawn. Fig. 6 shows an *Excel* representation of the site elements given in Fig. 5. Also, the prohibited areas adjacent to the neighbor sensitive buildings are shown. The safety zone for each building is specified around its boundary, and fixed facilities are also located.

Having entered all the data, the optimization process can start after specifying the required scheduling data. Three milestone dates can be specified to reflect the dynamic nature of the site layout planning problem. The first period starts at the project start date and finishes August 1, 2000. Because the scheduling start date of Building 3 (Facility No. 4) is after August 1, 2000, it is not considered in the site layout optimization for that period.

The population size and number of offspring chromosomes used are 400 and 200, respectively. The optimum solution for the second period is shown in Fig. 7. The obtained results and layouts were discussed with the field engineer of the project. The discussion showed that the facilities were arranged in appropriate locations which satisfy the closeness relationships and the minimum distances between facilities. Also, these layouts maintain the safety and environmental aspects, especially with the sensitive neighbors to hazardous effects.

The case study on hand has been solved before by Elbeltagi et al. (2004) using the procedure discussed in the literature. The corresponding optimal site layout is shown in Fig. 8. Analysis of Fig. 8 shows that some drawbacks can be observed:

- Welding shop (Facility 16), which is safely dangerous, is positioned adjacent to Tanta University buildings. In the devel-

Table 4. Suggested Closeness Weights (R_{ij}) for the Case Study Project

Facility number	1	2	3	4	8	9	10	11	12	13	15	16	17
4	7,776	7,776	7,776	—	1	1	1	1	1	1	1	1	1
6	1	1	1	7,776	1	1	1	1	1	1	1	1	1
9	36	36	36	1	1	—	1	1	1	1	1	1	1
12	1	1	1	1	1	216	1	1	—	1	1	1	1
13	1,296	1,296	1,296	1	1	1	1	1	1	—	1	1	1
15	1	1	1	1	1	1,296	1	1	1	1	—	1	1
16	36	36	36	1	1	1	36	1	1	216	1	—	1
17	216	216	216	1	1	36	1	1	1	1	36	1	—
18	36	36	36	1	36	36	1	1	1	1	1	1	36
19	1	1	1	1	1	1	1	36	1	1	1	36	1
20	1	1	1	216	36	36	1	1	1	1	36	1	36
21	1	1	1	1	1	1	1	1	36	1	1	1	1
24	1	1	1	216	1	216	1	1	1	1	1	1	36

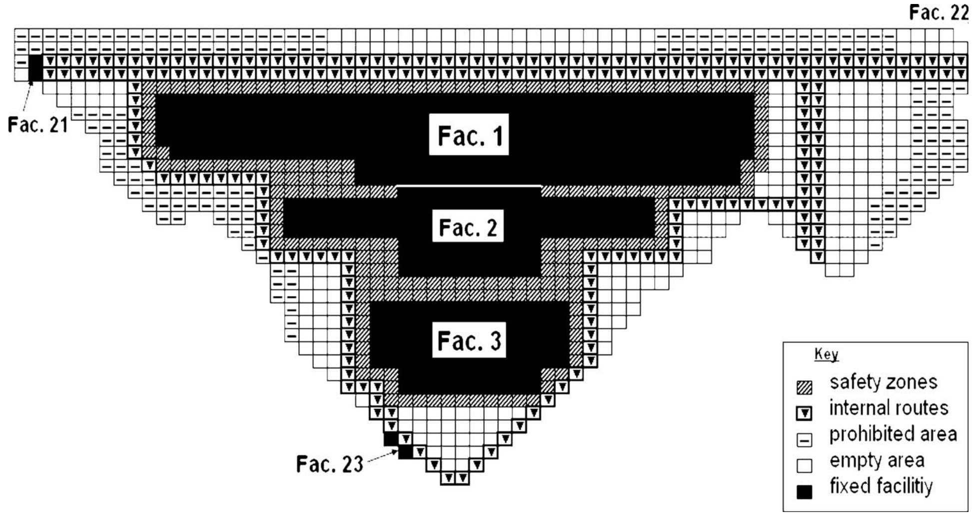

Fig. 6. Site map spreadsheet for the case study

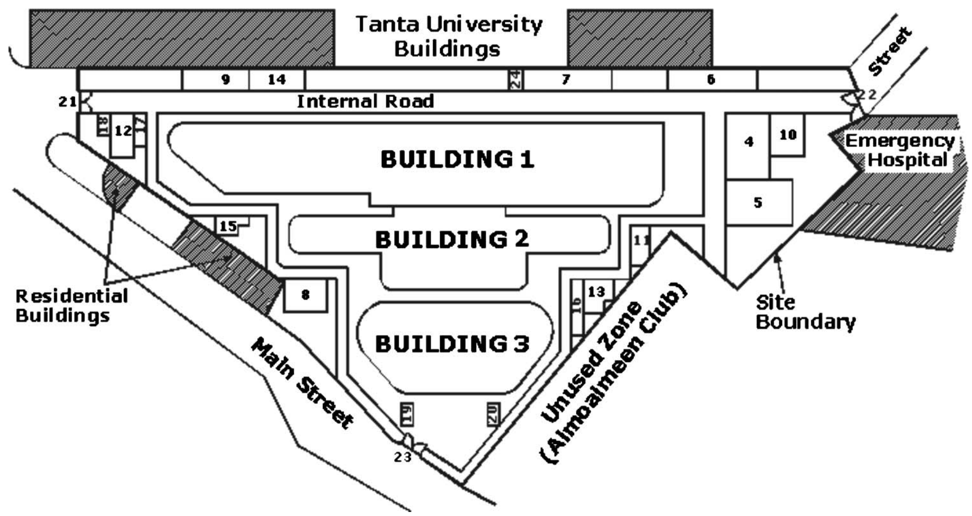

Fig. 7. Site layout for second phase of case study

oped model, this facility is prevented from being allocated in such location using the *prohibited area* concept.

- Machine room (Facility 19), which is safely dangerous, and offices (Facility 9), which are considered sensitive, are positioned adjacent to each other. In the developed model, they are positioned far from other using the *minimum distance* concept.
- No route is available to access parking (Facility 12), except if the safety zone between Building 1 and Facility 10 is used, and this is considered in violation of the main function of the safety zones. Also Facilities 8, 15, 17, 18, and 24 are located adjacent to each other and near Guard Gate 3 (Facility 23). This arrangement prevents site access from Gate 3. These two problems are solved in the developed model using the internal route concept.

Other case studies were tested using the developed model. It is observed that the well defined closeness weights for TFs among each others and with the permanent facilities greatly affect facilities positions. In addition, the integration of the schedule and layout information makes it easy for the project manager to track and update the layout of the site.

Fig. 9 shows the effect of the population size and number of generations on the convergence of the optimum solution. It is observed that the developed system performed poorly with small population sizes even when a big number of generations is used. A number of generations of 100 can be considered sufficient, as shown in Fig. 9. On the other hand, a big population size (200 or more) tends to ensure optimal solutions.

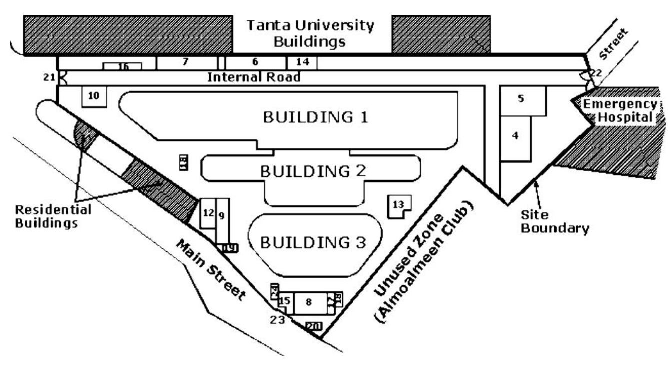

Fig. 8. Site layout in first phase for the case study (Elbeltagi et al. 2004, ASCE)

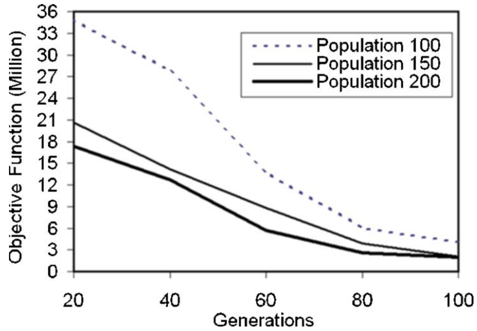

Fig. 9. Effect of population size and number of generations

Summary and Conclusions

In this paper, a developed optimization model for solving the site layout planning problem was presented. In developing the new model, two main features were introduced. Measuring distance between facilities in the site using actual route distance and incorporating safety considerations and environmental aspects are considered. The developed model was implemented on a spreadsheet (*Excel*) because of its simplicity in use and programmability features. The program was coded using the macrolanguage of Microsoft *Excel*, tested, and then experimented. Also, the dynamic nature of the site layout planning problem is considered by integrating the model with *MS Project* (Microsoft Corporation 2000). In order to validate the performance of the developed model, a real-life construction project with 28,500 m^2 site area was tested. The obtained results proved that satisfactory solutions were obtained.

Appendix: Full Pseudocode for Model Procedure

```
Begin:

Enter facilities data;
For i=1 to number of facilities;
    Enter facility code, name, and area
    Enter fixed or nonfixed
    If fixed
        Next i
    Else If nonfixed
        Enter facility width, arrangement type, and prevented or not
        prevented form being allocated to prohibited areas
    End if
Next i
Enter facilities closeness relationships;
n=number of facilities
For i=1 to n−1, j=i+1 to n
    If facilities i and j are fixed
        Next i
    Else If
        Enter closeness weight (R_ij)
    End if
Next i
Enter minimum distances between facilities;
For i=1 to n−1, j=i+1 to n
Begin:

    If facilities i and j are fixed
        Next i
    Else If
        Enter minimum distance between facilities i and j (D_min ij)
    End if
Next i
Draw site map;
Draw obstacles, internal route net, prohibited areas, safety zones and
fixed facilities
Perform GA optimization;
Input population size (P) and number of generations (G)
For each chromosome i: calculate fitness (i);
For j=1 to G
    Randomly select an operation (crossover or mutation);
    If crossover
        Select two parents at random
        Generate offsprings
    Else If mutation
        Select one chromosome at random
        Generate offspring
    End if
    Calculate fitness of offspring chromosome
    If fitness of offspring chromosome is better than the worst
    chromosome then
    Replace the worst chromosome by the offspring
Next j
Check if termination condition is reached
End
```

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