Dynamic Layout of Construction Temporary Facilities Considering Safety

Emad Elbeltagi, M.ASCE[1]; Tarek Hegazy, M.ASCE[2]; and Adel Eldosouky[3]

Abstract: The layout of a construction site plays a major role in the safety and productivity of operations, particularly when site space is restricted. 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. Four aspects are considered during site-layout planning: (1) defining the safety-related temporary facilities needed on construction sites; (2) defining proper safety zones around the construction space; (3) considering safety in determining the optimum placement of temporary facilities on the site; and (4) utilizing parts of the constructed space as temporary facilities to relieve congestion on restricted sites. A case study is presented on a prototype system to demonstrate the benefits of the proposed approach.

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Introduction

Site layout planning is an important task that involves identifying the temporary facilities (TFs) needed to support construction operations, determining their size and shape, and appropriately positioning them within the boundaries of a construction site (Tommelein et al. 1992). Such TFs include warehouses, job offices, workshops, batch plant(s), and equipment (e.g., cranes). The primary consideration in effective site layout planning is safety, in addition to the smooth and low-cost flow of materials, labor, and equipment within the site.

Health and safety issues were often ignored in most previous studies on site layout planning and organization (Anumba and Bishop 1997). This is despite the need for preventing or minimizing construction accidents through proper site layout planning. Among the few researchers who addressed the problem of integrating health and safety issues during site layout planning are Farrel and Hover (1989) and Anumba and Bishop (1997). Farrel and Hover (1989) developed a computer program to assist in selecting and positioning cranes on construction sites, with the objective of preventing crane accidents through proper planning. Anumba and Bishop (1997), on the other hand, examined the need to integrate safety into site layout and organization, and provided guidelines for the required integration. Other construction site layout planning models that are important but do not explicitly consider safety issues are Hamiani and Popescu (1988); Tommelein et al. (1992); Cheng and O'Connor (1996); and Zouein et al. (2002).

The models that deal with dynamic layout planning in construction are limited. Cheng (1992) developed a system called ArcSite that is comprised of a knowledge based system, integrated with a geographic information system (GIS) to locate the TFs on construction sites. The resulting layout of facilities may not arrive at the optimal solution. Using a different approach, Tommelein and Zouein (1993) and Zouein and Tommelein (1999) developed a dynamic layout planning system. Similar to traditional resource allocation, their models try to modify the schedule at various intervals so that the site space is not overallocated. The latter model used linear programming to dynamically allocate space to resources one-by-one, so that total cost is minimized.

Isolated from the site layout problem, previous efforts on construction site health and safety have concentrated on the analysis of accidents, psychological factors in accidents, legal and legislative aspects, and general safety planning [e.g., International Labor Office (ILO) 1992; Shechan 1992]. Other studies have focused on the cost of accidents (e.g., Everett and Frank 1996); causal analysis of accidents (e.g., OSHA 1990; Hinze et al. 1998); analysis of safety indicators (e.g., De la Garza et al. 1998); identification of the level of site hazards (Carter and Smith 2000); and safety performance on construction sites (e.g., Sawacha et al. 1999). One interesting study (Kartam 1997) has also attempted to incorporate construction project health and safety into the critical path method (CPM) through a knowledge based system.

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. The proposed model determines the schedule-dependent site needs of TFs. Accordingly, it optimizes the site plans needed at various intervals along the construction process. Safety issues on construction sites are discussed and the factors that contribute to unsafe sites are outlined. A systematic approach

[1]Assistant Professor, Structural Engineering Dept., Mansoura Univ., Mansoura, Egypt. E-mail: eelbelta@engmail.uwaterloo.ca

[2]Associate Professor, Civil Engineering Dept., Univ. of Waterloo, Waterloo ON, Canada N2L 3G1. E-mail: tarek@uwaterloo.ca

[3]Professor, Structural Engineering Dept., Tanta Univ., Tanta, Egypt.

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for defining and optimally placing TFs is then presented, which incorporates safety-related issues. Details of the dynamic model are described and a practical case study is then used to demonstrate its capabilities.

Construction Site Safety

In addition to respecting deadlines and providing high-quality work, workers' safety must be of first importance. In the past decade, the need for safety awareness among construction companies has greatly increased (Wilson and Koehn 2000). This is due, in part, to the high cost associated with work-related injuries, workers' compensation insurance, indirect costs of injuries, and the increased chance of litigation.

Every year, a considerable amount of time is lost as a result of work-related health problems and site accidents (Anumba and Bishop 1997). The U.S. Bureau of Labor Statistics reports an average of one death and 167 injuries per \$100 million of annual construction spending. The total cost of these accidents reached \$8.9 billion or 6.5% of the \$137 billion spent annually on industrial, utility, and commercial construction (Kartam 1997). One out of every six construction workers can expect to be injured, at an average cost of \$18,000. This staggering number translates into more than 2,000 deaths and 200,000 disabling injuries each year (Hinze 1993).

There are numerous factors responsible for health problems and construction site accidents. The Occupational Safety and Health Administration (OSHA) examined the causes of construction fatalities occurring from 1985 to 1989 (OSHA 1990). The results showed that 33% of the fatalities in construction were caused by falls, 22% were struck-by incidents, 18% were caught in/between incidents, 17% were electrocutions, and 10% were caused by other conditions.

Various researchers have reported that proper site management is vital for reducing hazards and accidents on construction sites (Stokdyk 1994; Anumba and Bishop 1997). Several causes of construction site accidents and health hazards (such as falls, falling objects, site transportation, site layout, and hazardous substances) can be controlled through creating an efficient site layout plan.

Dynamic Layout Planning

In this paper, dynamic site layout planning (DSLP) can be defined as the reorganization of the location and/or areas of the needed TFs on site at various schedule intervals, along project duration to suit the activities' dynamic need of TFs.

In the proposed DSLP, its dynamic nature stems from the fact that the needed TFs on site change as the schedule and its underlying operations evolve. To determine the needed TFs on site in any time interval (between any two schedule dates), a five-step approach is used: (1) necessary TFs must be identified and sized; (2) a schedule of the construction process must be assembled; (3) the activities' requirements of the TFs are defined, similar to the requirements of labor, equipment, and other site-specific resources. In this sense, the selected TFs are dealt with as resources that are assigned to activities; (4) the service times for each temporary facility (TF) are then determined from the schedule [service time is the time from facility start time (FST) to facility finish time (FFT)]; and (5) the TFs that serve any time interval can be defined and considered as the needed TFs on site in this interval.

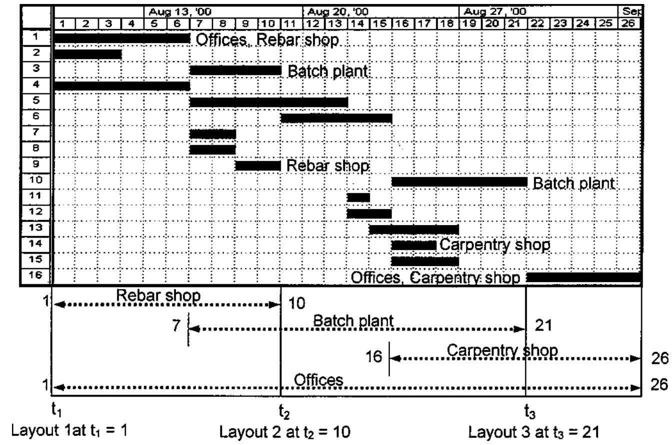

Fig. 1. Needed temporary facilities at different schedule intervals

This process of defining the site needs of TFs is illustrated in Fig. 1. In this figure, a list of TFs (offices, rebar shop, batch plant, and carpentry shop) is considered as resources assigned to activities. For example, the "batch plant" is assigned to activities 3 and 10. Accordingly, the service time of the batch plant on the site is between the start date of activity 3 and the finish date of activity 10. Similarly, the service times for the four facilities are shown in Fig. 1.

Knowing the FST and FFT of each TF, it is possible to decide on the facilities that should be considered for any intermediate layout. The start time of a layout j is t_j and the layout interval spans from t_j to t_{j+1}, (start of next layout). Thus, for a layout to service the project between times t_j and t_{j+1}, a facility i will be considered to be placed on the site if it satisfies the following:

$$(a) \quad t_j \leqslant \mathrm{FST}_i < t_{j+1}$$

(i.e., the facility starts sometime within the layout interval) or

$$(b) \quad \mathrm{FST}_i < t_j \quad \text{and} \quad \mathrm{FFT}_i > t_j$$

(i.e., the facility exists on site and is still needed for this layout interval) (1)

For example, "batch plant," "offices," and "carpentry shop" facilities (Fig. 1) will be considered for layout 2 that serves the project between times t_2 (day 10) and t_3 (day 21). One important consideration here is that frequent changes and reorganization of the site layout can be very costly. Therefore, in the DSLP, a simple process is used to minimize the cost of reallocating TFs in order to minimize work disruption. Therefore a TF that was placed on the site in a previous layout and it is still needed for the new layout will not change its location. To do that, a TF that is needed in subsequent layouts will be considered to have a fixed location (called fixed facility). As such, for any layout j, the facilities that need to be converted into fixed facilities are the ones that satisfy condition (b) of Eq. (1). Facility "batch plant," for example, is used in layout 1 and will be considered as a fixed facility in layout 2 (Fig. 1).

Incorporating Safety into Site Layout Planning

A properly planned site is likely to be safe, with high morale, and good maneuverability. Such conditions translate into time savings

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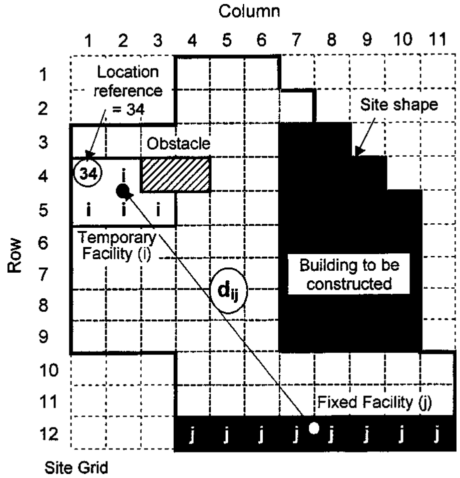

Fig. 2. Site and facilities representation

and lower costs of operations. To incorporate both safety and productivity aspects into site layout planning, the proposed DSLP model involves four aspects: defining the temporary facilities needed for safety reasons and to support construction operations; defining proper safety zones around construction spaces; considering safety in determining the optimum placement of facilities within the site; and dynamically changing the TFs uses and also using parts of the completed permanent space as TFs, to alleviate site congestion.

Safety-Related Temporary Facilities

The TFs are needed to support construction operations and to provide services for the workers on site. The inclusion of all necessary construction facilities, in addition to properly positioning them on site can have a positive benefit on health and well being of site personnel. The TFs that have an impact on health and safety issues include access roads, laydown areas, warehouses, and welfare facilities which include: first aid station toilet on site, labor rest area, washing facilities, and cafeteria. The size and number of these facilities should reflect the site size, nature of the work, and the number of people who will use them. If a large number of people are working on site or the work being carried out is particularly dirty or involves a health risk (e.g., batching/placing concrete), more hand washing facilities are needed.

It is also necessary to carefully plan and reserve storage areas for both equipment and temporary materials so that excessive movement of material is avoided. The use of proper equipment for material handling and advanced planning for minimizing multiple handling will result in direct cost and time savings. Accordingly, among the important TFs and services that should be included in the construction sites are: site access; site offices; welfare facilities; workshops; material delivery and storage; and material fabrication and assembly.

Each TF is allocated a site area, before being placed on site, as shown in Fig. 2. For flexibility, each facility is represented as a number of small grid units that can take irregular shapes. The area of each grid unit is calculated as the greatest common divisor (GCD), i.e., the largest integer that divides without remainder, of all facilities' areas. For example, if three facilities have areas of 50, 120, and 90 m^2, then the GCD is 10 m^2. Accordingly, the site is divided into a grid with unit area of 10 m^2. With the site grid known, each cell gets a location reference that is calculated as

$$\text{cell location reference} = (\text{cell row} - 1) \times \text{site columns} + \text{cell column} \tag{2}$$

For example, a cell in the fourth row and first column on site has a location reference of $(4-1)\times 11+1=34$. Using this location reference, a TF can be placed on the site grid, either horizontally or vertically, by assigning any location reference to its top left position. For example, facility i in Fig. 2 is placed horizontally starting at location reference 34.

Construction Safety Zones

As described earlier, falls and struck by falling objects represent two major causes of accidents on construction sites (33% and 22% of the construction fatalities, respectively). In order to reduce accidents, proper safety zones around construction areas should be provided to prevent harm from falling objects. One useful regulation in this regard is the Uniform Building Code (UBC 1985) that includes, for example, the following: at least 10 ft clearance from buildings or structures shall be kept clear, driveways between and around open yard storage shall be at least 15 ft wide and free from accumulation of rubbish, and materials stored inside buildings under construction shall not be placed within 6 ft of any hoist way or inside floor opening. Also, OSHA has issued many standards for health and safety on construction sites that can be consulted to determine the required safety zones for different construction operations (OSHA 1998). Accordingly, a proper site layout planning model should allow the use of safety zones around construction areas, hoists, cranes, equipment, and storage areas.

Optimal Positioning of Temporary Facilities

Having defined the required facilities, their areas, and their service times, it is possible to optimize the generation of the various layouts at user-defined intervals throughout construction. The optimization process involves the following steps: (1) identifying layout intervals and the TFs needed for each interval, as discussed earlier; (2) identifying facilities' closeness relationships upon which the optimization process will take place; and (3) optimizing the positioning of the selected list of facilities in each interval.

Facilities Closeness Relationships

Effective placement of TFs within the site improves safety and facilitates the movement of resources, or basically the interactions among facilities. Such interactions are referred to as the closeness relationships (weights) among the facilities and represent the desirability of having the facilities close or apart from each other (Hegazy and Elbeltagi 1999). Traditionally, closeness relationships have represented aspects that relate only to productivity and could be set as the actual amount of material moved between facilities or the actual transportation cost. In the literature (e.g., Malakooti 1987), six closeness relationships are usually set in advance, and the user can give desired weight values associated with each category as shown in Table 1.

Using the closeness weight values in Table 1, the traditional measure used to evaluate a specific layout is a weighted sum of all travel distances as follows:

$$\text{layout evaluation measure} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij} R_{ij} \tag{3}$$

where d_{ij} = distance between facilities i and j (Fig. 2); R_{ij} = closeness weight value between facilities i and j; and n

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Table 1. Traditional Closeness Relationship Weights

Desired closeness relationship	Weight
Absolutely necessary (A)	10^5
Especially important (E)	10^4
Important (I)	10^3
Ordinary closeness (O)	10^2
Unimportant (U)	10^1
Undesirable (X)	10^0

=number of facilities. In this formulation, the all positive values of the weights in Table 1 make the layout measure [Eq. (3)] a direct function of only facility distances. The smaller the distances (minimum travel distance), the better the layout. As such, the above formulation may not be suitable in terms of safety potential because, in some cases, having two facilities close to each other (short distance) can mean a potential safety hazard. Positive weights values, therefore, are unsuitable in terms of safety.

To consider safety in the proposed DSLP, changes are made to the closeness weights (with some positive and some negative values) as shown in Table 2. The formulation of the layout evaluation measure (layout score) in Eq. (3) remains valid but rather than indicating travel distances, it becomes a numerical score of the match between facilities' locations and their desired interrelationships. Using the values of Table 2, 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). It is noted that the use of Table 2 is subjective and the values to be assigned between two facilities must reflect both the expected work flow and any potential safety/environmental hazard between them.

Optimization Process

The process of placing TFs on site uses the genetic algorithms (GAs) technique as a nontraditional optimization procedure. Researchers have reported the robustness of GAs and their ability to solve several engineering and construction management problems (e.g., Zouein et al. 2002). The procedure searches for the optimum location reference of each nonfixed facility so that closeness weights are optimally maintained. Typically, GAs require a representation scheme to encode feasible solutions to the optimization problem. Usually this is done in the form of a string called a gene. Each gene represents one member (i.e., one solution) that is better or worse than other members in a population. As shown in Fig. 3, the gene formation has been set as a string of elements. Each corresponds to the location reference of a nonfixed facility and the gene length equals the number of nonfixed facilities to be placed on the site.

Table 2. Proposed Closeness Relationship Weights

Desired closeness relationship	Weight
Necessary to be close	10^3
Better to be close	10^2
May be close	10^1
Indifferent	0
May be apart	-10^1
Better to be apart	-10^2
Necessary to be apart	-10^3

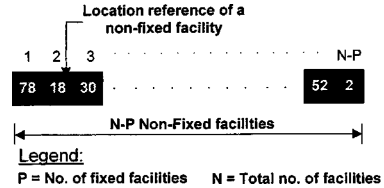

Fig. 3. Gene formation

During the generation of a gene in the population, each nonfixed facility is placed, in turn, by selecting its location reference as a random number from 1 to n, where n=total number of site units (columns×rows). Then, the facility is placed at this location reference using its required method of placement (horizontal or vertical). In case this is not possible (i.e., all adjacent cells are filled by other facilities or the location reference chosen is close to the site edge or a site corner), a new location reference is generated in an attempt to place the facility. This procedure continues until all facilities are placed on the site. When facilities are placed on site, distances to other facilities can be easily measured (Fig. 2) (Hegazy and Elbeltagi 1999).

To evaluate a specific layout, the objective function becomes the layout score calculated using Eq. (3). Accordingly, minimizing this objective function is required in order to arrive at the optimum layout that brings the least layout score and at the same time satisfies the desirability of having the facilities close or apart from each other. Using this objective function [Eq. (3)], it is possible to change the location of facilities on the site plan and accordingly calculate the layout score. The layout plan that gives the smallest layout score becomes the optimum site layout.

Consideration for Restricted Sites

The layout planning of site space on restricted sites, such as downtown areas, becomes more important than any other resource. In many situations, construction managers use part of the constructed facility (e.g., some floors in a high rise building) for storage purposes or other uses. The present model incorporates this important feature to its formulation. At any time interval, the user can select which part of the constructed space can be used to place a TF. Two conditions must be satisfied in this situation: (1) the constructed space has to be available (i.e., its finish date is earlier than the service start date of the needed TF); and (2) the constructed space area has to be large enough to accommodate the TF.

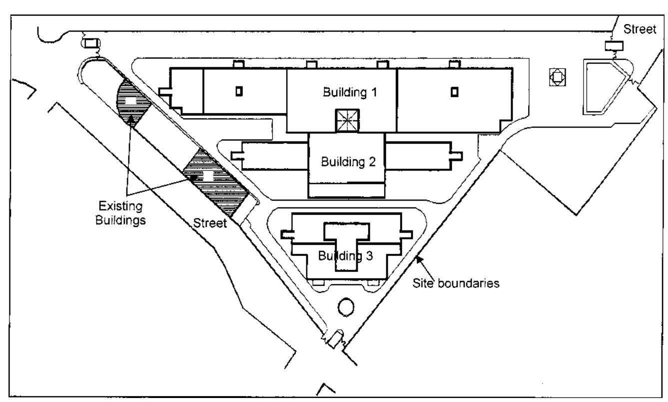

Fig. 4. General layout of case study

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Table 3. Case Study Data

Item	Value
Number of staff/engineers	20
Number of owner representatives	6
Number of subcontractor staff/engineers	20
Number of labors	366
Number of mechanics	30
Peak daily usage of reinforcing steel (ton)	10
Peak daily usage of cement (ton)	95
Buildings frame construction	Reinforced concrete
Foundation	Piles
Scaffold type	Metallic

Also, for increasing construction efficiency and cost savings, a facility can be placed at the location of another one that is no longer needed at the present schedule time. In this manner, the space on site can be allocated to accommodate different temporary facilities at different times. For example, assuming that three layouts are sufficient for the simple project shown in Fig. 1, the rebar shop will not be needed for layout 2 or 3. Accordingly, the space on site can be dynamically reallocated to accommodate other facilities at different times.

Implementation and Case Study

The proposed DSLP model was implemented on a commercial spreadsheet program where macroprograms were used to automate the system. Other macroprograms were also used to link the proposed system with a widely used scheduling software, thus establishing a direct link to the project schedule. After implementation, testing was carried out on various hypothetical examples. Afterwards, actual case study projects were then tried on the system to test its wide applicability. One case study is presented in this paper to demonstrate the system capabilities.

This case study deals with a project constructed in Tanta, Egypt, ‘‘Tanta University Educational Hospitals.’’ The project has a 28,500 m^2 site area and involved the construction of three multistory buildings, with perimeter fences and gates. Fig. 4 shows the general site plan with a layout of the buildings to be constructed. Also, some other data that is related to the case study is given in Table 3.

Originally, no site layout plan was made for the site, and the contractor's staff depended mainly on their experience in organizing the site. At the time of applying the developed system to this project, construction was about 60% complete. The project at the time was experiencing some difficulties related to a disorganized site and material handling problems. Also, the contractor set aside material storage areas around each building presumably to satisfy their individual needs. This however, resulted in excessive material waste, extra material handling costs, and less maneuverability within the site. In addition, the contractor located one of the tower cranes in the right wing of building 2, which delayed the construction in this part of the building. Other problems were also experienced related to the movement of crews and safety conditions.

Table 4. List of Facilities (Fixed and Nonfixed)

Number	Name	Size (m^2)	Units[a]	Maximum units per width	Arrange[b]	Fixed (Fix=1, Non=0)	Start date[c]	Finish date[c]
1	Building 1	6,575	263			1	1 April 1999	30 June 2001
2	Building 2	2,950	118			1	15 December 1999	15 September 2001
3	Building 3	2,250	90			1	1 September 2000	30 December 2001
4	Road 1	2,650	106			1	1 April 1999	30 December 2001
5	Road 2	675	27			1	1 April 1999	30 December 2001
6	Road 3	600	24			1	1 April 1999	30 December 2001
7	Guard house 1	40	2			1	1 April 1999	30 December 2001
8	Guard house 2	40	2			1	1 April 1999	30 December 2001
9	Batch plant	600	24	4	1	0	1 April 1999	15 March 2001
10	Laydown area 1	600	24	4	0	0	1 April 1999	30 December 2001
11	Laydown area 2	400	16	2	0	0	1 April 1999	18 July 2001
12	Cement warehouse	400	16	2	0	0	1 April 1999	30 December 2001
13	Labors rest area	300	12	3	0	0	1 April 1999	30 December 2001
14	Offices	300	12	2	1	0	1 April 1999	30 December 2001
15	Scaffold storage yard	300	12	3	1	0	10 November 1999	30 December 2001
16	Carpentry shop	200	8	2	1	0	1 September 1900	30 December 2001
17	Warehouses	200	8	2	0	0	1 April 1999	30 December 2001
18	Parking	200	8	2	1	0	1 April 1999	30 December 2001
19	Rebar fabrication yard	200	8	3	0	0	1 April 1999	15 June 2001
20	Toilet on site	120	5	2	0	0	1 April 1999	30 December 2001
21	Welding shops	120	5	1	0	0	1 April 1999	15 August 2000
22	Site office	80	3	1	1	0	1 April 1999	30 December 2001
23	First aid	40	2	1	1	0	1 April 1999	30 December 2001
24	Machine room	40	2	1	1	0	1 April 1999	30 December 2001
25	Tank	40	2	1	1	0	1 April 1999	30 December 2001
26	Sampling lab	35	2	1	1	0	1 April 1999	15 March 2001

[a]Number of units = facility size/25 (unit size).

[b]0 = horizontal arrangement, 1 = vertical arrangement.

[c]Facilities' service time.

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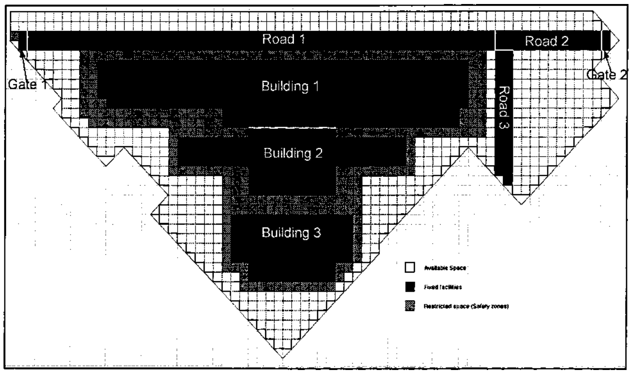

Fig. 5. Case study site representation on spreadsheet

Based on the project information obtained from the contractor, the research team independently generated a site layout plan. The site plan was then presented to the contractor and the consultant for verification and comments. First, necessary TFs and services and their required space needed to support construction operations and provide welfare for the workers were identified (Table 4). Then, the prototype automatically activated the schedule in order to assign the identified TFs to the various activities using the software features. Once this was done, a list of the facilities and their expected service times (''Start date'' and ''Finish date'' of Table 4) on the project became available.

The next step was to map the irregular site shape on the prototype. Given a grid unit area of 25 m^2, the site was represented by spreadsheet cells, each cell representing one grid unit. Using colored cells, the site was easily drawn on the spreadsheet as shown in Fig. 5. To facilitate this process, a computer-aided design drawing of the site was put as a background on *Excel* to be used in tracing the site using spreadsheet cells. Fig. 5 shows the fixed locations of the buildings that will be constructed on the site, the access roads, and the site gates. Also, to define proper safety zones around the buildings to be constructed, local codes and regulations were consulted and appropriate clear spaces were kept from allocating other facilities as shown in Fig. 5. The irregular shapes demonstrate the DSLP flexibility to model any site shape and facilities.

Having defined the service time for each TF, a choice was made of having two layout intervals, each covers one-half of the construction period, as shown in Fig. 6. Accordingly, the prototype automatically provided a list of the facilities that will be used in each layout interval [using Eq. (1)]. The facilities needed for the first layout are shown in Fig. 7. Then, the facilities' closeness weights were set as numeric values, as shown in Table 2, based on work flow and safety concerns between each of the two facilities.

Afterwards, the identified TFs were optimally placed on the remaining space on site (excluding the area needed for the buildings to be constructed, the access roads, and the safety zones) using GAs (Hegazy and Elbeltagi 1999). Accordingly, the prototype came up with the site layout for the first layout interval as shown in Fig. 8, given a layout score of 540,639. This layout satisfies the closeness weights used, for example, a high closeness weight (1,000) was set between facilities ''Laydown area 1'' and ''Access roads 5 and 6'' and thus resulted in locating facility ''Laydoen area 1'' adjacent to the ''Access roads 5 and 6.'' Also, a very low closeness weight (−1,000) was set between facilities ''Offices'' and ''Batch plant'' for safety reasons, and thus resulted in locating them far from each other. In this layout, it is noticed that the construction offices were located near the main street

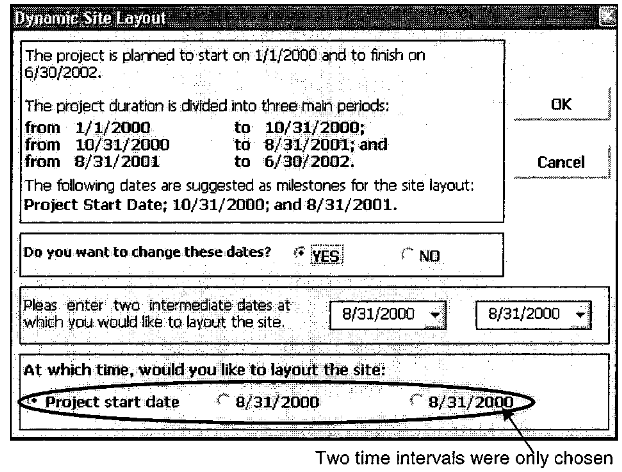

Fig. 6. Defining layout intervals

with separate entrances and good views of the construction area, and far from the noise and dust from the batch plant. The service roads, also, cover the whole site to enhance site access with easy maneuvering. Safety zones around construction spaces were kept in locating any TFs.

In the second scheduling period, facilities that finished in the previous interval were removed and their site areas became clear to accommodate other TFs. Also, existing TFs that are continuing to be utilized in the new layout interval were considered as fixed so that to maintain their locations. The full list of facilities for the second layout interval is shown in Fig. 9. With ''Building 1'' being completed in the first layout interval, its space could be used to accommodate a new TF. Accordingly, part of the constructed space was utilized to accommodate the ''Carpentry

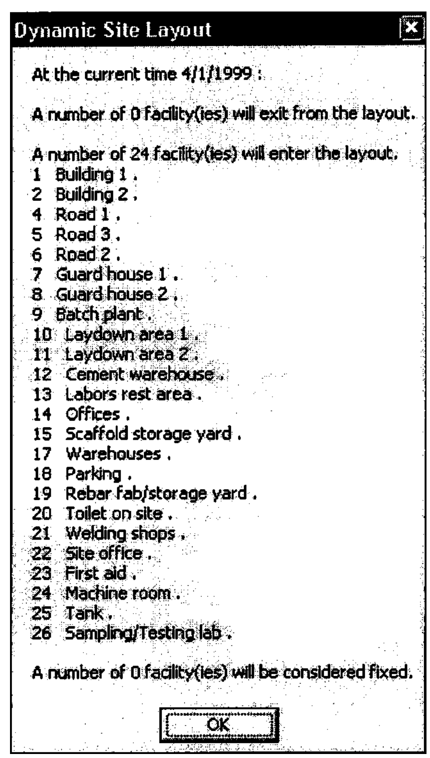

Fig. 7. List of facilities for first layout interval

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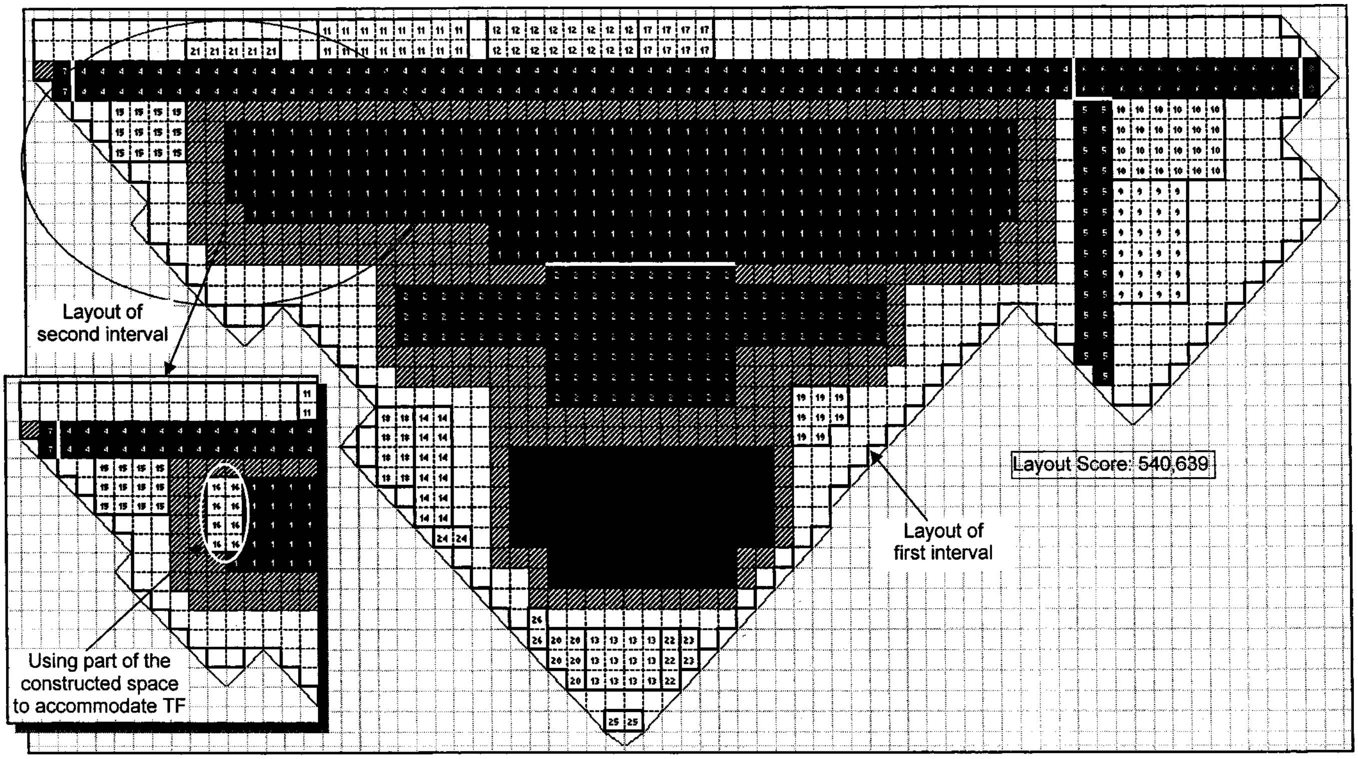

Fig. 8. Optimum layout plans

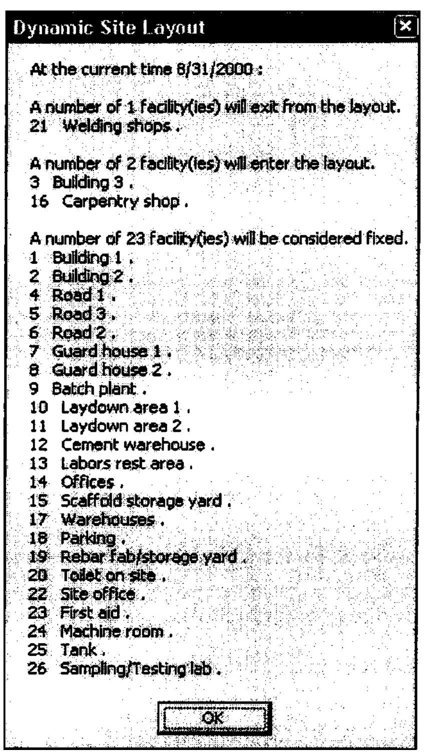

Fig. 9. List of facilities for second layout interval

shop," as shown in the second layout of Fig. 8. This future is very useful in sites with restricted space.

Comments on System Performance

Discussing the results of the two site layouts made along project duration with the consultant, the contractor, project mangers, and site engineers proved that the TFs were arranged in appropriate locations. Using the proposed system, the processing time to obtain the optimum or near-optimum site layout was about 185 min on a Pentium 900 Mhz personal computer. It is noted that the DSLP model for site planning presented in this paper is simple and practical. Yet, it can be expanded to consider the actual profile of material use within the construction activities. It can also be linked to a Geographic Information System to automate the mapping of the site and the identification of site characteristics.

An on-going extension of the proposed approach is a comprehensive testing on various construction sites to quantify its impact on site safety and productivity. This is, however, a difficult and long-term task that requires a large number of projects and performing various statistics on the number of accidents and site productivity measurements.

Summary and Conclusions

Safety and freedom of hazards concerns are key factors for a productive construction site. In this paper, the factors that contribute to unsafe construction sites are discussed and the need for health and safety considerations to be integrated into site layout planning emphasized. Three aspects were considered for site layout planning: (1) defining the temporary facilities and services needed on site for health and safety reasons; (2) defining proper

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safety zones around the construction space to minimize or prevent accidents; and (3) defining facilities closeness weights based on safety considerations and accordingly optimizing the placement of facilities on site. A practical case study is then presented to demonstrate the applicability of the proposed approach.

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