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INCORPORATING SAFETY INTO CONSTRUCTION SITE MANAGEMENT

Emad Elbeltagi
Post-Doctoral Fellow, Civil Engineering Department, University of Waterloo, Waterloo, Ontario, Canada

Tarek Hegazy
Associate Professor, Civil Engineering Department, University of Waterloo, Waterloo, Ontario, Canada

ABSTRACT
The construction industry involves many operations that can be risky, dangerous, and unhealthy. The number of injuries, accidents, and work related illnesses reported on construction sites exceed that of the manufacturing industry, thus contributing to additional costs and delays on projects. To ensure that a construction site is safe for operations, proper site management procedures have to be put in place, considering safety into account. This paper presents an effort to provide a quantitative approach that will help in maintaining safe and productive construction sites. First, safety issues on construction sites are discussed and the factors that contribute to unsafe sites are outlined. Three aspects are then considered during site planning to improve safety: (1) Defining the necessary temporary facilities needed for safety reasons on construction sites; (2) Defining proper safety zones around the construction space; and (3) Considering safety in the process of determining the optimum placement of facilities within the site. These considerations will lead to a safe site and accordingly increase productivity. A case study is presented to demonstrate the benefits of the three safety measures proposed and future extensions are outlined.

KEYWORDS
Safety, Site Layout, Construction Management, Environment, Accidents

1. INTRODUCTION

Site layout planning is an important construction activity involves identifying the facilities needed to support construction operations, determining their size and shape, defining the relationship among these facilities, and positioning them within the boundaries of the available on-site or remote areas (Tommelein et al, 1992). These temporary facilities range from warehouses, job offices, and workshops, to batch plant(s). The basic consideration in an effective site layout planning is the smooth and low-cost flow of materials, labor, and equipment within the site, in addition to satisfying various work constraints and safety requirements (Elbeltagi and Hegazy, 2001).

Health and safety issues are often ignored in most previous studies on site layout planning and organization (Anumba and Bishop, 1997). This is despite of the need for preventing, or minimizing construction accidents through proper site layout planning. Among the few researchers addressed the problem of integrating health and safety issues during a site layout planning are Farrel and Hover (1989) and Anumba and Bishop (1997). Farrel and Hover (1989) addressed the problem of site safety layout by developing a computer program to assist in selecting and positioning of 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, then provided guidelines for the required integration. Other construction site layout planning models that are important but not necessarily consider safety issue are Popescu (1981), Handa and lang (1987), Hamiani and Popescu (1988), Tommelein (1989), Cheng and O'Connor (1996).

Isolated from the site layout problem, previous efforts on construction site health and safety have tended to concentrate on studies related to 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 costing 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 factors affecting safety performance on construction sites (e.g., Sawacha et al, 1999). One interesting study has also attempted to incorporate health and safety into critical path scheduling method (CPM) through a knowledge base system (Kartam, 1997) to introduce heath and safety considerations earlier in the planning and scheduling phase.

This paper presents an effort to provide a quantitative approach that will help in maintaining safety and productivity on construction sites. Safety issues on construction sites are discussed and the factors that contribute to unsafe sites outlined. A systematic approach for defining and optimally placing temporary facilities is then presented, taking into account safety-related issues to define proper safe zones around the construction space.

2. CONSTRUCTION SITE SAFETY

In addition to respecting deadlines and providing high-quality work, workers' safety is of central 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, including workers' compensation insurance, indirect costs of injuries, and the increased chance of liability suits. Every year, a considerable amount of time is lost as a result of work-related health problems and various degrees of site accidents (Anumba and Bishop, 1997).

The U.S. Department of Labor, Bureau of Labor Statistics, reports an average of one death and 167 injuries per $100,000,000 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). The construction industry is statistically one of the most hazardous industries and ranks low in safety. One out of every six construction workers can expect to be injured every year, at an average cost of $18,000. This staggering number translates to 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 five most common categories of accidents defined by The Occupational Safety and Health Administration (OSHA) are: falls, struck-by, caught in/between, electric shock, and other (Hinze et al, 1998). OSHA examined the construction fatalities occurring from 1985-1989 in the five categories (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. In analysis of these accidents, various factors were found to contribute to accidents. These include: severe weather, hazardous substances used or generated during construction, site conditions, unsafe practices (methods, equipment, etc.), inadequate training, poor supervision and monitoring, lack of health and safety facilities, and human errors (Anumba and Bishop, 1997).

There are numerous reports of construction site accidents, which could have avoided if adequate consideration had been given to health and safety issues during the early stages of site layout planning (Anumba and Bishop, 1997). This may be due to inadequate understanding of the extent to which proper site layout planning influence construction safety. However, there is some researchers realize that proper site management is vital for reducing hazards and accidents on construction site (Anumba and Bishop, 1997; Stokdyk, 1994). Accordingly, several of the 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. Proper site layout planning, therefore, is a good opportunity for managers to address several health and safety issues early in the construction planning phase.

3. INCORPORATING SAFETY INTO SITE LAYOUT PLANNING

A Properly planned site is likely to be a safe site with high morale, few disputes, and good maneuverability. Such conditions mean time saving, lower cost, and higher quality. To improve safety on construction sites, three aspects will be included in the present site layout planning model: defining the temporary facilities needed for safety reasons and to support the construction operations; defining proper safety zones around construction spaces; and considering safety in determining the optimum placement of facilities within the site.

3.1 Defining Temporary Facilities

The temporary facilities are needed to support construction operations and to provide services for the workers on site. Good facilities can have a positive benefit on health and well being and can help prevent dermatitis. Necessary temporary facilities and services range from access roads, laydown areas, warehouses, and batch plant, to first aid office, toilet on site, and labor rest area. Construction workers need adequate toilet and washing facilities, a place to warm up and eat their food, and somewhere to store their clothing. The size and number of these facilities should reflect the site size, nature of the work, and numbers 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. pouring concrete), more washing facilities are needed. Important facilities and services are listed below.

Site access
Easy site accessibility will keep the morale of the equipment and vehicle drivers high, minimize the chance of accidents, and save time in maneuvering to access and leave the project. In large projects, proper planning is required for the roads leading to the nearest highway, internal roads, and parking lots (if enough space is available).

Site offices
Site offices should be close together, close to the construction space, and in a safe area. Their location should provide a good view with less noise from construction operations. In addition to the job office, offices should be provided for the general contractor, sub-contractors, and consultants.

Welfare facilities
Minimum welfare facilities should be provided on construction sites to comply with the construction health and safety regulations. Welfare facilities may include: toilets, washing, changing, personal storage, and rest areas. Such facilities (more than one of each type if necessary) should be easily accessible and have adequate heating, lighting, and ventilation.

First aid
First aid services and provisions for medical care shall be made available.

Housekeeping
During the course of construction, formwork and scrap lumber with protruding nails, and all other debris, shall be kept cleared from work areas, passageways, stairs, buildings, or other structures. Debris shall be removed at regular intervals during the course of construction with safe means. Containers shall be provided for the collection and separation of waste, trash, oil, and other refuse.

Workshops
Workshops are used where materials and equipment are fabricated on site. This includes electrical, mechanical, carpentry, and paint shops. Also, testing shops used to house the necessary testing equipment and personnel.

Material storage and handling
It is necessary to plan and reserve storage areas for materials so that multiple movement of material is avoided. Laydown areas, staging areas, and warehouses are used for material storage and they are generally located as close to work as possible. One third or more of all construction operations can be classified as material handling. The use of proper equipment for material handling, and advanced planning for minimizing multiple handling will result in direct cost and time savings.

3.2 Construction Safety Zones

As described earlier, falls represent the major cause of accidents in construction site (33% of the construction fatalities). In order to reduce accidents, proper safety zones around construction areas should be provided to prevent harm from falling objects. Some of the regulations were described by the uniform building code (UBC 1985), including: at least 10 feet clearance from buildings or structures shall be kept clear from using, driveways between and around open yard storage shall be at least 15 feet wide and free from accumulation of rubbish, and materials stored inside buildings under construction shall not be placed within 6 feet of any hoist way or inside floor opening.

Accordingly, a proper site layout planning model should allow the use of safety zones around construction areas, hoists, cranes, and laydown (storage) areas.

3.3 Optimal Positioning of Temporary Facilities

Effective placement of facilities within a site improves the movement of resources, decreases the hazards and accidents and increases the safety or basically the interactions among the facilities. Such interactions are referred to as the closeness relationships among the facilities and represent the desirability of having the facilities close or apart from each other. Due to the vagueness and ambiguity associated with such relationships (e.g., facility A should be "as far as possible" from facility B) especially for large and congested sites, determining crisp values for these relationships is a problem that lends itself well to fuzzy set applications (Elbeltagi and Hegazy, 2000).

The factors used in this study to determine the closeness weights among facilities are: 1) the level of work flow (WF) between each two facilities; 2) the level of safety/environmental (SE) hazard; and 3) the user's preference (UP). The work flow between two facilities encompasses the total flow of material, equipment, personnel, and information between the two facilities. The level of safety/environmental hazard also represents any concerns that may arise when the two facilities are close to each other. The third factor "user's preference" represents the project manager's desirability of having the facilities close or apart from each other (Elbeltagi and Hegazy, 2000).

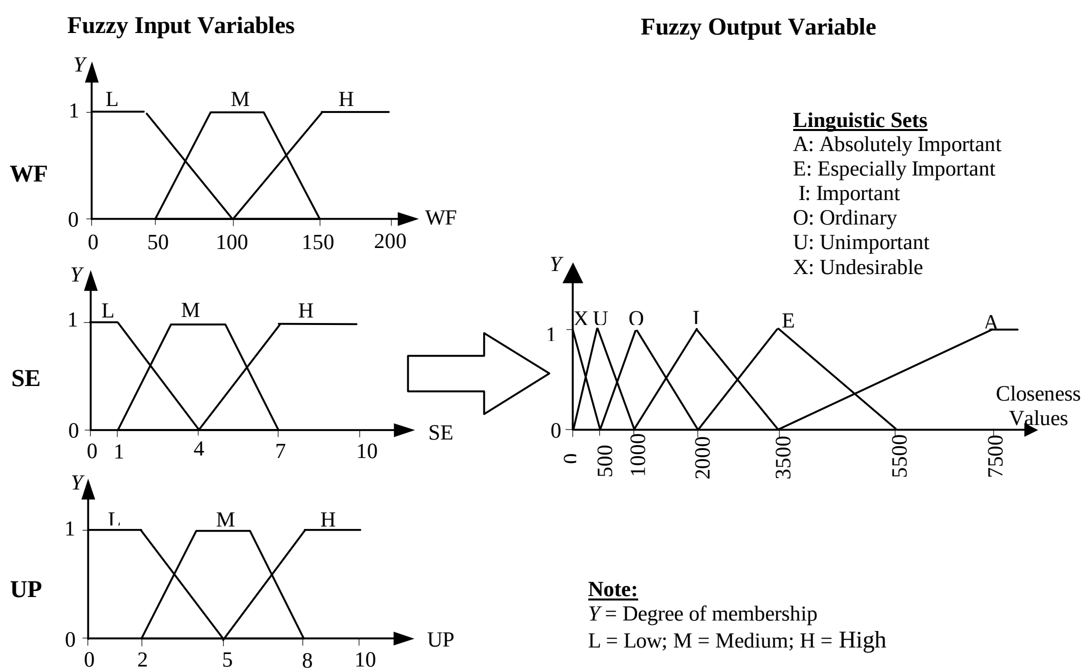

Figure 1: Fuzzy Sets of the Input and the Output Variables

The three factors are used as fuzzy input variables: "WF"; "SE"; and "UP". These three variables affect the fuzzy output variable "Closeness Weight". Each input variable is assumed to have three membership functions "Low" (L), "Medium" (M), and "High" (H), while the output variable has six membership functions (Fig. 1). Using the fuzzy rule-based inferencing process described in (Elbeltagi and Hegazy, 2000), single crisp value for the closeness weight can be calculated between each two facilities based on user inputs of “WP”, “SE”, and “UP” values. Accordingly, the closeness weights among facilities can be used as an important step needed for determining the proper site layout plan.

To evaluate the goodness of a possible layout, an objective function was constructed by multiplying the closeness weight between two facilities by the actual distance between them, and summing up for all facilities. The objective function, as such, represents the total travel distance associated with a given site layout. Accordingly, minimizing this objective function is required in order to arrive at the optimum layout that brings the least travel distance. A representative score for the total travel distance associated with a layout is calculated based on the d_{ij} distances among the facilities, as follows:

$$\text{Objective function} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij} R_{ij} \quad (1)$$

where, R_{ij} is the closeness weight value between facilities *i* and *j*, and n is the total number of facilities. Using this objective function (Eq. 1), it is possible to change the location of facilities on the site plan and accordingly calculate the site score. The layout plan gives the smallest score becomes the optimum site layout plan. For site layout optimization, the approach of Elbeltagi and Hegazy (2001) can be used in this case with few modifications to respect the safety zones described in section 3.2.

4. CASE STUDY

A case study of a water treatment plant constructed in Mansoura, Egypt is used to demonstrate the concepts presented in this paper. The project (constructed on a 53,000 m^2 site) involved the construction of reservoirs, basins, pump station, operation building, workshop, and fences/gates with attached utilities. Originally, no formal site layout plan was made for the site, and the consultant depended mainly on the general contractor’s experience in organizing the site.

Based on the project information obtained from the consultant and the contractor, the research team independently generated a site layout plan considering safety and health issues. The site plan was then presented to the contractor and the consultant for verification and comments. First, necessary temporary facilities and services and their required space were identified as shown in Table 1. The closeness weights between each two facilities were then determined using the fuzzy logic procedure described earlier, based on user input of estimated work flow, safety concerns, and user preference.

Table 1: Temporary Facilities and Services

No.	Temporary Facility	Area (m^2)
1	Offices	540
2	First-aid	60
3	Information and gurad	40
4	Toilet on site	80
5	Labors rest area	160
6	Maintenance shop	300
7	Rebar fabrication/storage yard	1060
8	Batchplant	500
9	Sampling/testing lab	80
10	Piping yard	1040
11	Parking lot	400
12	Tank	60
13	Long term laydown yard	2400
14	Machine room	50
15	Material warehouse	280
16	Scaffold storage yard	240

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. Afterwards, the identified temporary facilities were optimally placed on the remaining space on site using the calculated closeness weights and the optimization procedure of Elbeltagi and Hegazy (2001). The resulting layout (Fig. 2) exhibits the minimum (or close to minimum) travel distance as calculated by Eq. 1.

As shown in Fig. 2, the hatched areas represent the temporary facilities on the site. Notice the location of site offices near the entrance, on an access road with good view of the construction area, and far from the noise and dust from the batchplant. The access road, also, covers the whole site to enhance site access with easy maneuvering. Safety zones around construction spaces were kept clear from locating any temporary facilities.

The resulted site layout plan was shown to the contractor and the consultant, and favorable comments were received. Discussing this resulting layout with the project manger and site field engineers showed that the temporary facilities were arranged in appropriate locations. The flexibility of the proposed approach and the consideration of heath and safety in defining the temporary facilities and determining their closeness weights were major points of appeal.

5. SUMMARY AND CONCLUDING REMARKS

Safety and freedom of health-related concerns are key factors for a productive construction site. In this article, 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 to account for site layout planning: (1) defining the temporary facilities and services needed on site for health and safety reasons; (2) defining proper safety zones around the construction space to minimize or prevent accidents; and (3) using a fuzzy logic approach to quantify facilities closeness relationships based on safety considerations and accordingly optimize the placement of facilities on site. A practical case study is then presented to demonstrate the proposed approach.

An on-going extension of the proposed approach is a comprehensive testing on various construction sites to quantify its impact on site productivity. This is, however, a difficult and long-term task that requires a large number of projects and performing various statistics on number of accidents and site productivity measurements. This article, however, has identified key aspects and guidelines of construction site layout which need to be addressed if health and safety considerations are to be integrated to generate a proper site plan at the early stages of a construction project.

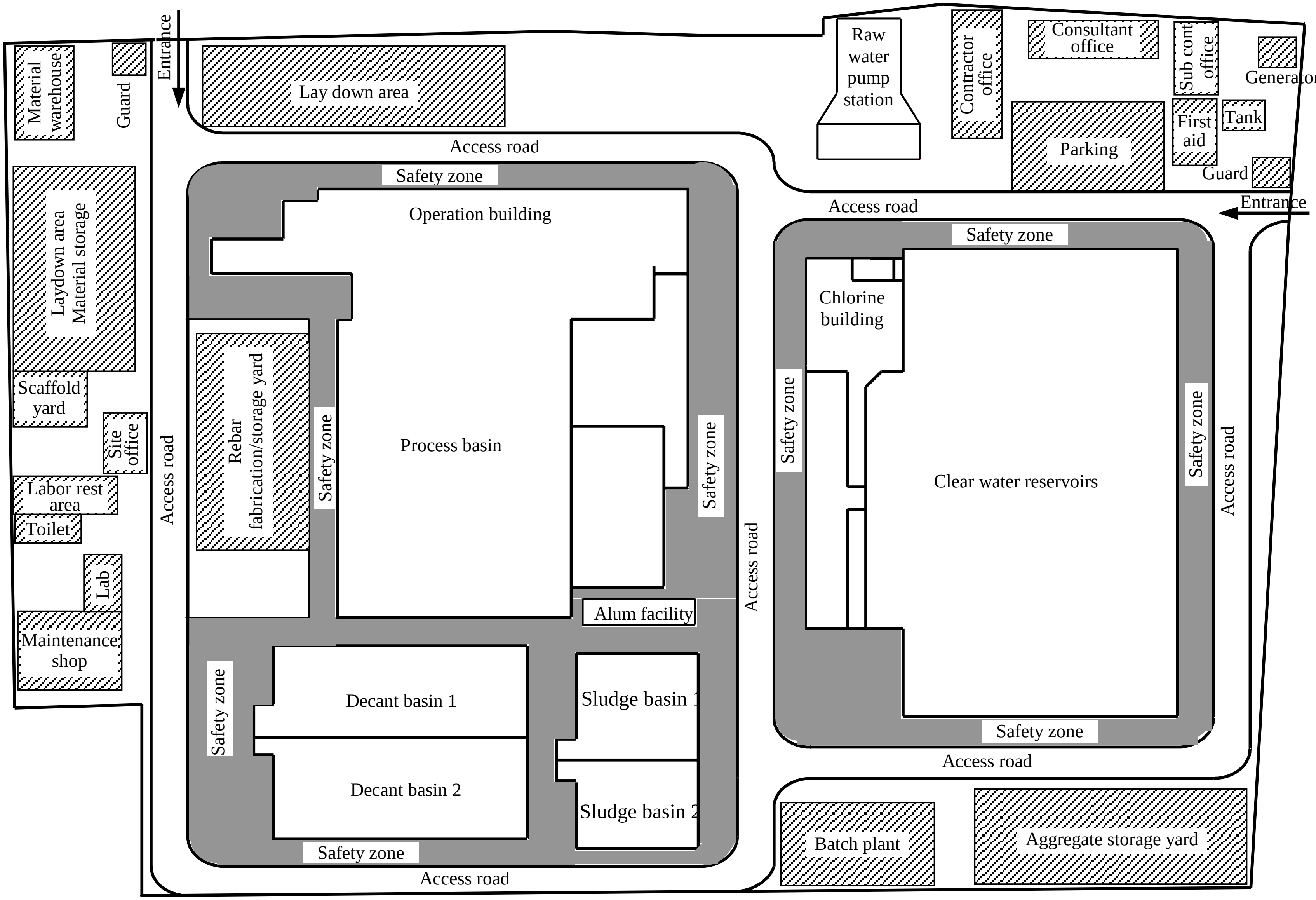

Figure 2: Site Layout Considering Safety Issues

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