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Review

Optimal construction site layout based on risk spatial variability

M. Abune'meh [a,b,c], R. El Meouche [a,*], I. Hijaze [b], A. Mebarki [c], I. Shahrour [d]

[a] Université Paris-Est, Institut de Recherche en Constructibilité, ESTP, F-94230 Cachan, France
[b] An-Najah National University, Urban Planning Engineering Department, P.O. Box:7, West Bank, Palestine
[c] University Paris-Est, Lab. Modélisation et Simulation Multi Echelle (MSME/UMR 8208 CNRS), 5 Bd Descartes, 77454 Marne-La-Vallée, France
[d] Laboratoire de Génie Civil et géo-Environnement, Université Lille1, 59 650 Villeneuve d'Ascq, France

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ABSTRACT

The construction site layout planning is a complex and important task conducted by project managers and planners. It must able to face the occurrence of potential hazards like fire and blast waves, for instance. However, minimizing risk resulting from natural or technological hazards is still a scientific challenge.
In the present paper, a new methodology is developed in order to evaluate the risks within a construction site. It consists of:
Modeling construction site components, for instance; electric generator, fuel storage, offices, equipment and material storages, in 2D layout. These components act as hazardous sources and potential targets at the same time,
Modeling hazard interaction matrix: it shows the hazard interaction among site components and the attenuation of hazard with distance,
Modeling vulnerability interaction matrix: it represents the potential weakness of whole targets to the hazard generated from each source. In the present research, the vulnerability is expressed as function of hazard intensity,
Defining the utility function: it aims to afford an optimized site layout with minimum total risk in the construction site, finally
Performing spatial analysis technique, utilizing space syntax principle, to realize space configurations in the construction site. As the evacuation process is considered in evaluating and visualizing the risk, the actual risk is amplified by utilizing penalty factor called mean depth.
Geographic information system (GIS) is useful in visualizing the spatial variability of the risk within the site. It integrates the potential total impact of the facilities with the space configuration mean depth results. For illustration purposes, the methodology is employed in a case study consisting of several facilities acting as hazardous sources and potential targets in a 2D layout. The risk optimization considers the level of hazards at each source object, hazard attenuation and adopts conditional values for the vulnerability of the target objects. A differential evolution algorithm is adopted to minimize the global risk within the site. The results showed that the proposed methodology is efficient, due to its capability of generating site layout with safer work environment. This in turn leads to minimize work accidents, serious injuries and victims. In addition, the model is capable of highlighting the highest risk areas within a construction site.

Contents

* Corresponding author.
E-mail address: relmeouche@estp-paris.eu (R. El Meouche).

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1. Introduction

The occurrence of accidental events such as fire, blast waves and leakage of hazardous material is one main feature of the construction industry. Construction managers always aim to keep their expected consequences to a minimum level. Therefore, it is very important to adequately organize the sites in order to diminish the consequences of these hazards and provide safe work environment.

[1] stated that construction site space is one of project resources that requires management, like any other resource. In fact, the usual strategies for managing site spaces are based on the principle of "first come first served". [2] confirmed that site layout planning is unique for each construction project and depends on work areas and locations of different facilities.

Site layout planning can be defined as the accommodation of supporting temporary facilities, such as electric generator, fuel storage, offices and so on, at a suitable location within the available site space. According to [3], an efficient site layout provides superior working environments quality and safe operation for labor construction. Therefore, to consider a site layout plan as efficient, it is essential to benefit from the work areas provided to minimize hazard impact and mitigate the consequences of cascading (domino) effects.

Unfortunately, construction projects are not exempt from exposure to the occurrence of natural hazards that may lead to catastrophic consequences. [29,30] indicated that fire hazard is one kind of accidents that may occur at construction sites that may lead to construction schedule disturbance. [32] found that about 4800 construction site fires occur every year, resulting in more than $ 35 million losses in property. [31] indicated that due to rapid development in the construction industries, the fire hazard is frequently occurring at construction sites.

The current site layout planning models focus entirely on reducing the travel cost distance between facilities [4]. They overlooked the potential hazards that may lead to infeasible or non-effectual solutions. In addition to this, the parties involved in construction tend to make decisions based on their own experience. Sometimes these decisions may be incomplete and/or incorrect, which in turn leads to unsafe site layouts.

However, only a few efforts have been devoted to organizing site layout for avoiding, or at least minimizing, risk of potential hazards. [4,5] developed an optimization site layout model which aims to maximize construction safety. However, these models did not take into account the potential hazards such as fire and blast waves during optimization as they rather focus on the facilities containing hazardous materials.

Therefore, it is important to properly manage a site in order to maintain the integrity of the construction site and facilitate the evacuation process during emergency cases. Evacuation is highly significant in construction site safety planning. If any hazard occurs within a site, the workers need to be evacuated safely, through crossing areas with least risk, to minimize casualties. In the current paper, the evacuation is based on integration or segregation of each position with respect to others within the site. Relevant penalty factors are actually adopted in order to generate spatial risk map.

This research aims to enhance site layout planning by developing new models that take into account the hazard and vulnerability interactions among facilities. Furthermore, after obtaining the optimal layout of facilities, the spatial analysis technique called space syntax is utilized to analyze the influence of space configurations on spatial variability of risk within a construction site.

2. Literature review

Several studies have been conducted for construction site layout planning. There is a consensus from most researchers that site layout planning is still a challenging task [2,5,6]. [2] stated that optimizing the cost, safety and productivity of a project relies on adequate planning of the construction site layout. [5] indicated that site layout planning is a complex problem, due to the existence of several large tasks that need to be performed. [6] demonstrated that utilizing site space efficiently to locate resources and facilities over the duration of a project is a complicated dilemma.

2.1. Optimization models based on travel cost distance only

In general, most of the existing site layout planning studies consider the travel cost distance as the most significant objective function. They also apply several algorithms to optimize and accommodate construction facilities. [7] indicated that site layout models can be categorized into two classes. One is the static model, i.e. changes over time are not considered. The other is the dynamic model, i.e. changes over time are considered. [34,35] classified the algorithms used to solve facility layout problem into four categories: construction algorithms, improvement algorithms, hybrid algorithms and graph theoretic algorithms. [34] made comparison among twelve algorithms to examine their efficiency based on computation time and the accuracy of the solution. [8] noted that the meta-heuristic methods such as genetic algorithms (GAs), simulation techniques and ant colony optimization are most common algorithms used for site layout planning. [33] developed a hybrid model that integrates genetic algorithm with max-min ant system. The results of this hybrid model provide better optimal solution than utilizing traditional genetic algorithm.

[9] developed an evolution model called EvoSite. It implements a GA when searching for the optimum layout. [10] investigated the capabilities of a GA in finding the optimal solution for site layout problems. They found that when the ratio between the area of total facilities and the site area did not exceed 60%, the algorithm produces a solution that is considered very close to the optimal solution. [1] presented a model based on approximate dynamic programming (ADP) in order to optimize dynamic site layout of construction projects. [11] made a comparison between a GA model and ADP by considering two criteria: the effectiveness of optimal solution attainment and the efficiency of minimizing the computation time. They found that ADP was more efficient than the GA. However, GAs will continue to be a valuable optimization method due to their simplicity. [6] illustrated a procedure based on linear programming for dynamic site layout, by minimizing the travel distance and relocation costs among all facilities. [12] developed an innovative

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