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# Bilevel and multi-objective dynamic construction site layout and security planning

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ABSTRACT

The joint problem of dynamic construction site layout and security planning is fundamental to any construction project. However, it is still largely unexplored. Few research studies investigated the implementation of security measures during the construction phase. This paper proposes a bilevel multi-objective model for the dynamic construction site layout and security planning problem. Specifically, the upper-level programming denotes that the project manager must first choose the construction site layout and security strategies to minimize the layout costs and consequences of a potential attack. The lower-level programming denotes that the attacker will destroy a subset of the facilities to inflict the maximum economic consequence on the construction facilities system. Thereafter, a bilevel multi-objective Particle Swarm Optimization Algorithm (MOBLPSO) is designed to solve this model. Finally, the approach is carried out in the Xiajiang hydropower large-scale construction project to illustrate the effectiveness of the proposed model and algorithm.



## 1. Introduction

Construction site layout and security planning are both important to any successful project and have a significant impact on both finances and safety. Construction site layout problems can be broadly divided into two categories: static and dynamic. The static construction site layout assumes the facilities serviced in the different construction phases in accordance with the requirements of the construction work during the whole progress are the same [1]. However, this is only the case in small-scale construction projects or short planning horizons, in which the material flows are fairly constant [2]. As for the large-scale construction project, the construction site layout planning with the consideration of changing site facilities and site space in different time intervals is termed as dynamic. Therefore, there is a need to consider the possibility of site space reuse to accommodate different resources at different times, the relocation of resources and the varying resource space needs over time [3]. Driven by practical necessity, an increasing number of studies focus on solving dynamic construction site layout problems. For example, Andayesh and Sadeghpour [4,5] adopted the Minimum Total Potential Energy principle from physics to develop a dynamic construction site layout planning model. They further provided a comparative analysis of the three approaches of static, phased, and dynamic site layout planning [6]. Ning et al. [3] used a continuous dynamic searching scheme to guide the max–min ant system algorithm to solve the dynamic construction site layout planning problem, and they then developed a computational decision-making system to solve the dynamic, multi-objective and unequal area construction site layout planning problem [7]. Xu and Li [8] proposed a multi-objective dynamic construction site layout planning model in a fuzzy random environment. Huang and Wong [9] optimized the construction site facility layout for multiple construction stages with safety considerations and requirements.

Dynamic construction site layout planning leads to dynamic security planning of a construction site, because the security strategy decision is facility-level based. Dynamic construction site security planning is crucial because the lack of early security arrangements can increase the vulnerability of a construction project [10,11]. Vulnerability of construction facilities due to man-made threats or various types of attacks is one of the major threats to the construction industry. The potential attacks refer to theft, vandalism, deliberate damage, and terrorism. The attackers are perpetrators who conduct such attack behavior at construction sites. Construction sites are easy targets for the opportunist thief, because the high value of plants and equipments can lead to quick and easy profit for the successful thief. Vandalism is also common and terrorism can potentially be an issue as well [12,13]. These dangerous attacks are not only monetary, but put the construction behind schedule [14]. There are some critical questions that project

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managers face: (1) Is it worthy to restore the security countermeasures when a facility is moved? (2) Should a facility be secured by different countermeasures over different periods? Research shows that the construction site layout affects many spatial aspects of the site security system and significantly impacts the performance of implemented countermeasures [10,14]. However, few research studies investigated the implementation of security measures during the construction phase [10].

There is a need to support current construction security standards by studying and modeling the mutual impacts between site space design and the effectiveness of the implemented security measures. The joint problem of dynamic construction site layout and security planning is bilevel in nature because it can be described as a leader–follower or a Stackelberg game [15]. The leader is the project manager who must first make the construction site layout decision and then decides how each facility should be secured in different periods. The follower is the potential attacker who then has the opportunity to attack a subset of the facilities. The attacker's strategies will in turn affect the project manager's strategies. A bilevel fortification/interdiction median model has already been adopted as an efficient tool for assessing network vulnerabilities to linkage or node disruptions in supply chain, critical infrastructure protection planning, and homeland security improvements, etc. [16–18]. Church and Scaparra [16] demonstrated that protecting the most vulnerable facilities or predictable targets is not necessarily the most cost-effective way of confronting threats; fortification patterns, which take into account the interdependency among the system components and the effect of multiple, simultaneous losses, can produce better and more resilient protection plans. This theory also can be applied in construction site planning. The problem is also multi-objective and uncertain in nature. We illustrate the multi-objective problem and the rationale of adopting twofold random variables in Section 2.

Bilevel programming problem falls into the class of NP-hard problems and many scholars have tried to find effective ways to solve this type of problem [19,20]. Among the different kinds of evolutionary algorithms, Particle Swarm Optimization Algorithm (PSO) has shown a fast convergence rate [21]. Research shows that PSO is also a competitive method for solving general bilevel programming problems [22,23]. Therefore, this paper proposes a modified PSO method — the multi-objective bilevel Particle Swarm Optimization Algorithm (MOBLPSO) — to solve the dynamic construction site layout and security planning model.

The development of analytical approaches and mathematical modeling, as well as algorithms which are able to solve the bilevel and multi-objective dynamic construction site layout and security planning problem are still largely unexplored. The purpose of this paper is to describe the problem clearly, provide a bilevel multi-objective model, and design an effective algorithm to solve it.

## 2. Key problem statement

The construction site layout and security planning problem firstly deals with the assignment of appropriate site locations for temporary facilities such as warehouses, site offices, workshops, and batch plants. Construction sites include many targets that can be vulnerable to potential security breaches. Therefore, project managers have to develop detailed security strategies. For example, in Fig. 1, there are three construction periods and the construction site layout is different in each period according to the construction schedule and the demand of the facilities. Given the large area and multiple facilities in the large-scale construction project, security countermeasures cannot be applied to all the facilities. In Fig. 1, the white rectangles inside of the site fence represent unsecured facilities, and the gray ones represent secured facilities. In construction period 1, among the secured facilities, facility 1 is secured by area lighting, response force, and natural surveillance. At the same time, facility 2 is secured by facility fence, intrusion detection, and fence lighting. The attacker can attack both the unsecured and the secured facilities. The attacker attacks three facilities in Fig. 1, which leads to various economic and efficiency consequences.

A good layout and security plan demands the fulfillment of several competing and often conflicting design objectives [24]. In this paper, the project manager has to balance the trade-offs between the two critical objectives of minimizing the efficiency consequence and

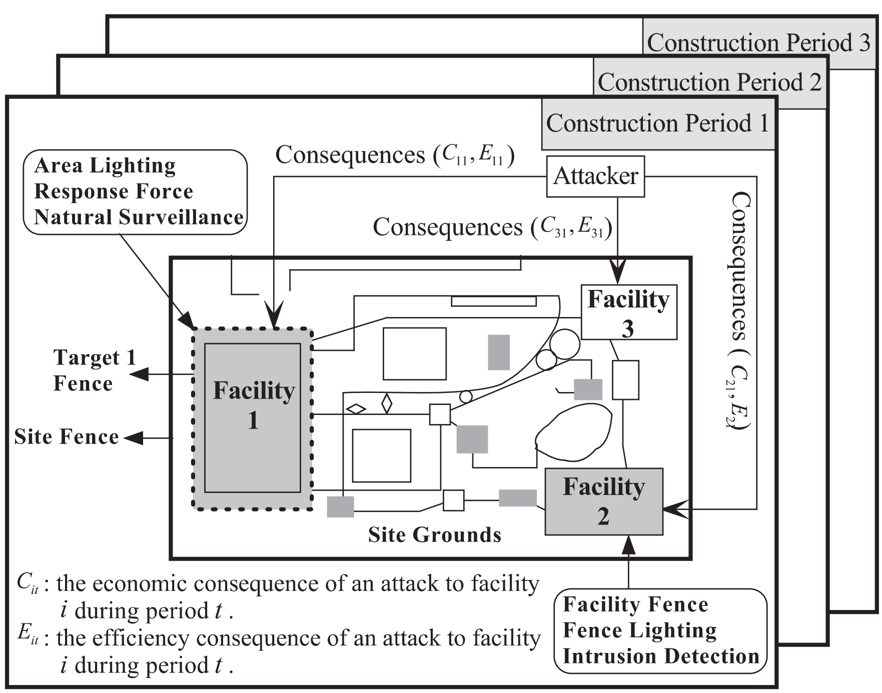


**Fig. 1.** Problem statement of the dynamic construction site layout and security planning.