Safety Science 104 (2018) 246–259

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

A quantitative safety risk assessment model for construction site layout planning

Xin Ning[a], Jingyan Qi[a], Chunlin Wu[b,c,*]

[a] School of Investment & Construction Management, Dongbei University of Finance & Economics, Dalian, Liaoning Province 116025, China
[b] School of Economics and Management, Beihang University, Haidian District, Beijing 100191, China
[c] Beijing Key Laboratory of Emergency Support Simulation Technologies for City Operations, Beihang University, Haidian District, Beijing 100191, China

ARTICLE INFO

Keywords:
Construction site layout planning
Safety risk assessment model
Risk factor identification
Risk factor classification
Risk factor analysis
Case study

ABSTRACT

A good site layout is necessary to provide a safe construction site environment. Previous studies treated construction site layout planning as an optimization problem to achieve high safety performance. However, the optimization problem does not contain holistic risk factor analysis. Risk factors such as the dangers of falling objects, noise pollution and hazardous chemicals tend to be neglected. Moreover, when site managers face different site layout scenarios, no safety risk assessment models are currently available to help them make decisions. Therefore, this paper aims to develop a quantitative safety risk assessment model, including factor identification and classification, factor analysis, and assessment function development, to help site managers evaluate different site layout scenarios more accurately and holistically. In factor identification and classification, the interaction flows between facilities are initially considered as risk factors. Safety/environmental concerns which were not deeply probed into by previous studies are also considered. For the above two risk factor categories, safety risk assessment functions are developed according to the likelihood of accident occurrence and the linear attenuation law respectively. Finally, a case study is used to verify the proposed model. This study interprets how to implement site safety management by means of site facility layout improvement. It enriches occupational safety research by providing a systematic model for assessing site layout plans in a quantitative and more valid manner. The findings help conduct effective site safety management by proper facilities displacement during the preconstruction stage and in turn guarantee construction safety in later stages.

1. Introduction

Construction projects begin with project planning, and good planning is a foundation for delivering successful construction projects (Patrick, 2004). Decisions related to design and/or resource management made at the beginning of a project tend to be more efficient than those made at later stages (Goetsch, 2013). Site space is a type of construction resource that is as important as capital, time, material, labor and equipment (Hegazy and Elbeltagi, 1999). The construction site laying out is an important activity that is done to make good use of site space. A good site layout boosts the effectiveness and efficiency of the subsequent construction work, contributes to the reduction of cost and material travel distance (Said and El-Rayes, 2013), and increases the safety level of the construction site (Sanad et al., 2008). Thus, correct decisions must be made when choosing among different site layout scenarios via valid and systematic safety assessments, so as to improve construction site safety management in both the preconstruction and construction stages.

Malekitabar et al. (2016) revealed that 46.8% of accidents are related to the design chosen for safety and that certain risks can be avoided by making minor changes to a design. Thus, more attention must be paid to safety planning in the preconstruction stage to improve safety management more effectively. Previously, safety researchers tended to conduct safety management during the construction stage and emphasized the important roles that risk factors play in safety performance improvement. These researchers discovered that most accidents are related to inadequate hazard recognition or appraisal and thus are rarely mitigated (Albert et al., 2017, 2014; Haslam et al., 2005; Smith and Carter, 2006). Safety can be improved by finding causations among safety risk factors (Albert et al., 2017; Li et al., 2017; Raviv et al., 2017a,b) and then monitoring and preventing accidents (Isaac and Edrei, 2016; Li et al., 2015). Because of the importance of human factors in construction safety (Cañamares et al., 2017), an increasing number of studies have focused on human-related safety antecedents, such as safety psychology (Pinion et al., 2017), safety climate (Fogarty et al., 2017; Leitão and Greiner, 2017; Zarei et al., 2016), and safety

* Corresponding author at: School of Economics and Management, Beihang University, Haidian District, Beijing 100191, China.
E-mail address: wuchunlin@buaa.edu.cn (C. Wu).

https://doi.org/10.1016/j.ssci.2018.01.016
Received 30 July 2017; Received in revised form 24 October 2017; Accepted 23 January 2018

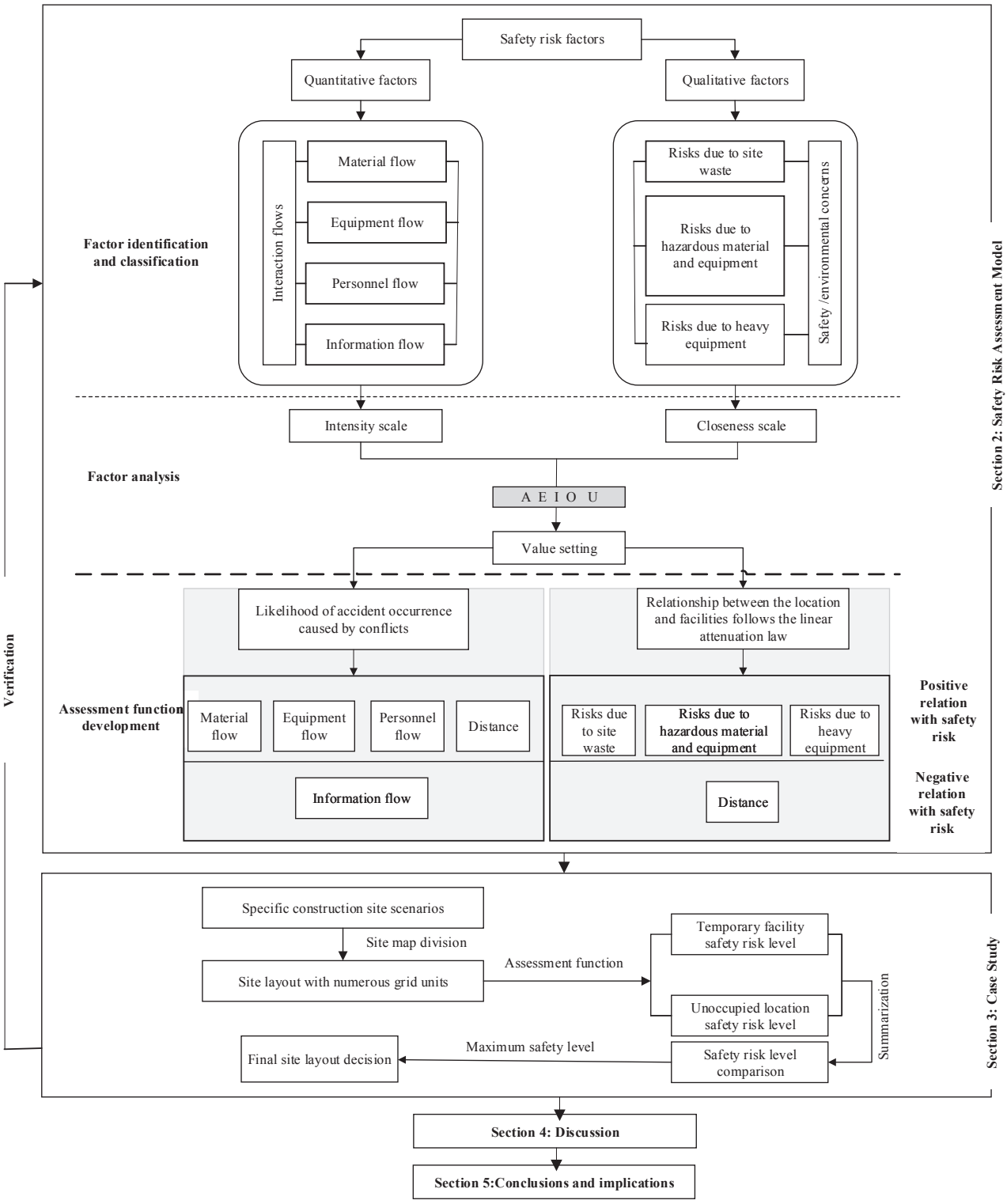

Fig. 1. Research flowchart of the paper.

leadership (Wu et al., 2015; Wu et al., 2017). Their goals have been to probe the relationships between human factors and safety performance, construct safe environments and thus avoid accidents. Based on these studies, this paper considers the design of construction site layouts containing higher safety levels via a systematic safety risk factor identification, classification and analysis and focuses on analyzing the relationship between risk factors and safety level in construction site layouts to build a safety risk assessment model that can assist site managers during the decision-making process.

A construction site layout is developed during the project planning phase, i.e. the preconstruction stage. Similar to a manufacturing plant, a construction site is used to produce an engineering product (e.g., buildings, roads, bridges, and railways). The laborers, machinery, materials and other resources are all located at the construction site. Site layout planning is critical to construction safety performance, as the disorderly placement of construction resources increases the likelihood of accidents. The highly frequent transportation of materials and laborers between facilities, such as fabrication shops, material laydown