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Enhancing the safety of construction crew by accounting for brain resource requirements of activities in job assignment

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ABSTRACT

Safety management is regarded traditionally as an aggregate attribute for Human Resources (HR) in which the focus is placed on safety of construction crew by assuming same behaviour, capabilities and thus level of exposure to risk for all workers in the crew. In line with this, a team-based approach is generally adopted for task assignment to workers in construction operations. However, this approach tends to disregard the differences between skill level, experience, capabilities, learning rates and fatigue rates of different individual workers forming the team. In particular, due to differences in visual, auditory, cognitive and psychomotor capabilities of different workers and brain resource demands of different activities, the traditional approach may result in inconsistent workloads and uneven fatigue rates within a crew, affecting the workers' and crew's safety negatively. This paper proposes a novel framework for task assignment to construction workers in which safety of individual workers and thus the crew is ensured through optimizing workload distributions within a crew. The framework computes visual, auditory, cognitive, and psychomotor requirements of the jobs assigned to a worker and minimizes the identified workload imbalances through collaborative execution of shared tasks. The application of the proposed framework is examined on a pipe spool fabrication operation of a refinery project in a simulation environment.

1. Introduction

Despite the efforts made in improving safety practices, the health and safety performance of construction industry is still far from acceptable; with a significant number of fatalities and injuries reported every year [1]. Over the past decade, the industry has been consistently ranked among top three sectors with the highest rate of accidents, based on the statistics reported by safe work authorities in different countries [1–4]. A wide range of accidents with different occurrence frequencies and mechanisms in terms of affected occupations, and types of affected workers and their experience and age, occur regularly in the construction industry [1,5,6]. However, the traditional safety management approaches tend to disregard the differences between the impacts of different accidents on different affected personnel, by applying a similar safety management approach to the entire construction crew.

The existing crew-based safety management approaches have two main drawbacks. First, they provide common safety trainings within a crew formed by workers of different skill levels, capabilities, and ages, through disregarding the differences in the nature and level of exposure to risks within a crew due to the differences in the type of the tasks assigned to individuals and differences in capabilities and thus response of individuals to safety risk events [7–9]. Second, the existing crew-based safety management approaches are predominantly focused on elimination of hazards associated with physical substances such as chemicals, and particular site conditions (e.g.: unprotected trench and heights, and congested and confined spaces), as well as hazards associated with equipment (e.g.: electrocution and operation hazards), which have been generally identified as high risk based on historical accident records [1,10–12]. Such risk assessment practices, however, tend to overlook or inadequately account for human-related risk factors.

Human-related risk factors are defined as unsafe behaviour or actions of employees [13] and, account for > 80% of workplace accidents in different countries, as revealed by previous studies since the 1960s [14,15]. Human-related risk factors may stem from either self-caused behaviours of workers or working conditions imposed on them. The self-caused behaviours can be exemplified by ignorance, defiance, and forgetfulness which are typically long-term issues with psychological

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substance resulted from a combination of internal and out-of-workplace factors [13,21]. Such issues are difficult to be proactively detected and hence, cannot be readily accounted for in the near-term planning of projects [21]. Imposed conditions such as work pressure, stress, and on-the-job training are, on the other hand, predictable and thus the management is kept responsible to prevent their consequent hazard-prone human behaviours. Among various managerial decisions affecting the workers, job assignment to workers is perhaps the most influential decision which directly affects the imposed work conditions and thus unsafe human actions [9,18]. Availability of modern methods for planning job assignments provides an opportunity to minimize the human related risk factors in a project. This however requires systematic scrutiny to maximize compatibility between job demands and human capabilities.

The safety performance of the construction crew may be affected significantly by the type and quantity of works assigned and the experience and capability of crew in performing the assigned tasks [7,9]. A simple approach proposed to account for safety in the task assignment process in construction projects involves dividing the planned tasks into physically and mentally demanding, which are then assigned to groups of physical and skilled workers, respectively [16,17]. However, this method has two main shortcomings. First, physically and mentally demanding tasks are identified in a subjective manner [18] and a systematic methodology for categorization of tasks and their physical and mental resource requirements is lacking. Second, the differences between individual members of a crew, particularly in terms of experience, capabilities, and learning rates, are overlooked in task assignment [19]. Such shortcomings may in turn lead to mismatches between human resource requirements of a particular task and capabilities of allocated workers and thereby an uneven workload distribution among workers in a construction crew. Uneven workload distribution places extra loads on unknown team members, thereby increasing the likelihood of unsafe behaviours and errors, putting the crew's safety at risk [13,21,22].

Safety management is a delicate domain which requires considerate attention at micro level as a minor failure can lead to disastrous consequences. With increasing attention to safety of construction personnel as an important social factor, a growing number of studies have been directed recently towards deployment of technologies and tools customized to protect individuals against a specific type of safety hazard such as moving machinery [12]. The methods in these studies mainly target human-machine interactions on the construction site while the focus is placed on the machinery side of such interactions [12,23]. Despite its importance, the human side has not been adequately scrutinized to systematically diagnose reasons behind human actions/reactions. An analytical approach towards investigating the compatibility between workers' capabilities and assigned tasks at micro level can complement the recent advances in safe operation of machinery to develop a more holistic approach for dealing with safety risks in construction.

The main objective of this paper is to integrate personalized safety factors into workforce planning of construction operations. Accordingly, a novel framework is proposed for task assignment to construction workers in which safety of individual workers and thus the crew is ensured through optimizing the workload distribution within a crew. The proposed framework provides a uniform basis for microscopic analysis of a construction operation through which visual, auditory, cognitive, and psychomotor requirements of jobs assigned to a worker are computed and workload imbalances are identified. To minimize load inconsistencies within a crew, the framework establishes different safety management strategies, each aiming to protect different workers against a specific safety issue, while meeting the technical constraints of the operation. The application of this framework is demonstrated by assignment of jobs to workers in a medium-size pipe spool fabrication operation using a spreadsheet platform and MS Solver 2010 and the proposed solutions are examined in Discrete Event Simulation (DES) environment of Simphony.Net 4.

2. Research background

In traditional crew-level safety management approach, paramount emphasis is placed on enforcement of safety culture in the workplace [24]. To enforce safety culture, particular focus is placed on safety beliefs, values, and attitudes of employees as facilitators for improved health and safety [7]. Accordingly, teams are trained to raise awareness about the safety rules and regulations, common hazards, and clarification of responsibilities and safety citizenship [11,25]. In this setting, the personalized safety training is limited to emotional briefing on impacts of safety risks on workmates, particularly with the objective of influencing safety behaviour of individuals [26].

In addition to training and preventive dimension of safety management, safety behaviour models have been developed to improve understanding of the reactive and supportive dimension, where communication plays a central role during the real course of jobs [27,28]. Breakdowns in communication have been found to contribute more significantly to accidents than technical competencies [29]. A number of different approaches to enhance communication on the construction site have been proposed as means to improve safe behaviour [27,30,31]. The verbal exchange is generally highlighted as the most effective mode of communication, while communication between leaders and subordinates is emphasized as the most widely promoted line of exchange [27,32]. In line with this, a coaching role is assigned to foremen and supervisors whose behaviour and safety awareness have been shown strongly affect the risk recognition and awareness of workers in a real-time manner [33,34]. Nevertheless, this has been proved to be a challenging job due to the dynamic and transient nature of construction operations and workforces [33,35]. While a great deal of effort have been made in developing methods for persistent intervention of superintendents under such circumstances, the proposed solutions are rather qualitative and lack a systematic pre-planning and implementation scheme that can be followed in practice [33,36,37].

The safety literature has widely investigated occupational risks and accidents in order to identify factors contributing to unsafe behaviour in construction projects [38]. However, despite novelty and diversity of methods used, the outcomes are commonly presented in an aggregate manner in which merely a general reference is made to determinants of safety climate including organizational policy, regulatory compliance, self-awareness, safety knowledge and motivation, and production pressure [13,28,39,40]. Accordingly, a number of different theoretical frameworks have been proposed for predicting safety behaviour, assessing effectiveness of safety management systems, or rule-based safety inspection and auditing [11,38,40]. In such frameworks, the features concerned with personalized safety management are generally related to individuals with leading role in the team and the soft skills they need to acquire [7]. Nevertheless, a strong step has been taken to individualize application of such frameworks through embedding human error analysis systems [13,28]. Therefore, a new causal analysis methodology has been proposed in which focus of workers is scrutinized at activity/event level, leading to provision of relevant safety trainings [13].

Construction scholars have targeted a zero error atmosphere in order to prevent accidents in construction operations and processes [41]. To address this issue, a number of studies have targeted fatigue minimizations due to its evident impact on human error. Thus, fatigue management strategies have been studied widely as a means to reduce the likelihood of occurrence and number of errors [13,42]. Widely accepted strategies in management of fatigue are focused on planning of shift time, overtime hours, and rest time. The primary goal in fatigue management is, however, to improve productivity through minimizing errors rather than minimize accidents [18,43]. This perspective induces an approach in which workers' fatigue is basically either physical or mental, depending on the category of physical or mental jobs assigned