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Productivity and CO_2 emission analysis for tower crane utilization on high-rise building projects

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A B S T R A C T

Cranes maintain a central role in construction projects, and tower cranes are one of the major equipment used in the construction of high-rise buildings. As the scale of construction projects increases, selecting a proper crane becomes more important for the successful completion of projects, especially in regards to taller buildings. To provide lift engineers with a planning tool, this paper presents a crane selection methodology for high-rise building construction projects based on crane productivity performance, carbon footprint impact and simulation process. The crane productivity analysis considers a tower crane with two jibs that operates using propellers mounted at the end of each jib to improve the performance of crane operations. This paper presents a methodology to quantify and assess the environmental footprint (CO_2 emissions) associated with the tower crane swing operation. A case study is presented to demonstrate the effectiveness of crane productivity and CO_2 emission analysis for building construction projects.

1. Introduction

The use of machinery in the construction industry has always been a major cost element, and cranes are among the most expensive types of construction equipment. Crane operations in construction projects are complex, as erection of a typical high-rise building involves lifting a number of heavy prefabricated objects. Efficient crane operation can have a significant impact on the overall scheduling, cost, and safety of these projects. It is therefore important to analyze the capacity and capability of key resources to improve the productivity of on-site operations. Thomas and Yiakoumis [1] separated factors affecting productivity into four categories: environmental, site, management, and design. The construction industry has also become increasingly aware of the sector's contribution to climate change. The construction industry's energy use causes significant environmental impacts [2]. Carbon footprint quantification, analysis, and reduction cannot be ignored. Cranes maintain a central role in construction projects, and tower cranes in particular have dominated high-rise building projects. Construction cranes consume great amounts of energy and emit significant volumes of CO_2 on site. Since 2006, the Government of Canada has been introducing regulations to reduce emissions from key sources [3]. Cranes were listed in the U.S. Environmental Protection Agency's (EPA) non-road vehicles and equipment category as one of the main sources of emissions [4]. Due to the large amount of diesel used on site, the U.S. EPA published a Non-road Diesel Program to advance emission control technologies for engines used in non-road equipment [5]. However, the NONROAD model data were only intended to predict average emissions for a fleet of vehicles. Similar data are needed to quantify the CO_2 emission generated by on-site crane engines. At a time when the environment is of utmost importance, every opportunity to minimize a project's carbon footprint is vital. Minimizing crane operations on construction sites will lead to faster construction and eliminate unnecessary CO_2 emissions.

Current research in the domain of construction cranes focuses primarily on developing tools to assist practitioners in the crane selection process and visualization of their operations. A basic 4D Computer Aided Design (CAD) simulation model allows users to visualize the expected evolution of building structures during a given period of construction based on the schedule of activities. Specifically, these drawings show where cranes are expected to be located at different periods of time during the construction process [6]. 3D visualization is helpful in the verification and validation of crane operations [7] and can be a useful tool to improve the productivity of crane operation. However, measuring the productivity of construction machinery remains difficult. Park et al. [8] introduced a standard construction productivity metrics system (CPMS). The proposed CPMS is a standard construction productivity data collection tool and provides a framework to report industry norms to benchmark construction productivity. Crane productivity analysis does not

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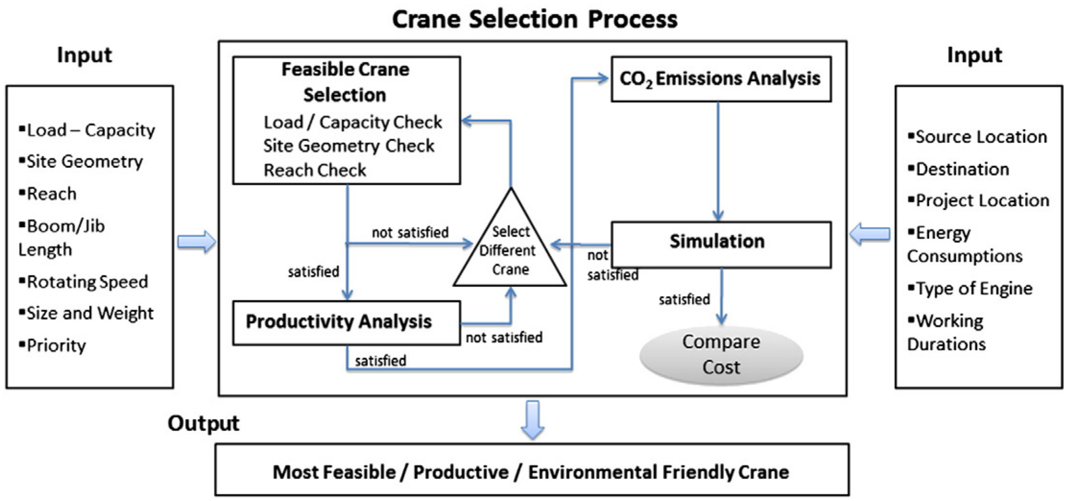

Fig. 1. Crane selection methodology.

receive much attention by practitioners. Lee et al. [9] proposed a wireless technology to improve the productivity of the traditional tower crane. In practice, planning for crane operations is performed mostly intuitively and informally. The construction industry is seeking innovative approaches to improve the productivity and minimize the carbon footprint of crane operations.

This paper presents a methodology that focuses on the selection of cranes for high-rise building construction projects based on crane productivity performance and carbon footprint impact. This paper also presents a comparison analysis between the use of a single-jib tower crane and a new type of tower crane that operates using two jibs, referred to in this paper as a "double-jib" tower crane [10]. The proposed methodology is tested on a case study that involves the construction of a 34-story building in Brooklyn, NY. The building is constructed using modular construction technology. It consists of over 950 modules, and the cranes involved in lifting the components of the shear wall will make over 150 additional lifts.

2. Crane selection methodology

Lift planning and crane selection are receiving considerable attention from practitioners and academics who wish to ensure safety and economy within the workplace. Rodriguez-Ramos and Francis [11] proposed a mathematical prescriptive model to establish the optimal location for a crane in a construction site. Alkass et al. [12] described a methodology for crane selection for construction projects. The methodology is incorporated into an integrated computer system capable of advising users on the selection of appropriate cranes for their construction projects. A fuzzy logic approach to selecting the best crane type for a construction task from a list of selected crane types has also been established by Hanna and Lotfallah [13]. Kamat and Martinez [14] demonstrated that process-based simulation could be used to analyze crane operations by modeling the dynamic movement of cranes as well as the interaction between the crane and the lifted material during a given operation. Sawhney and Mund [15] developed a prototype

Fig. 2. A double-jib crane operation.