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Feasibility of beam erection with a motorized hook-block

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ABSTRACT

On average, approximately 90 workers are injured or killed every year while lifting and installing steel beams in South Korea. Rotation-controllable tower-crane hook-blocks (RTH) remotely rotate beams horizontally to the target position, thus helping to prevent accidents related to steel beam installation. In this study, the expected safety improvements and economic effects of the RTH were analyzed. the real discount rate, and operation and maintenance costs in accordance with the general cash flow analysis practice as well as the CO_2 offset price. The results of the analysis showed that when the effects of the RTH were at their maximum and average levels, the break-even points occurred in the first year and the second year, respectively. Although the RTH might not be profitable in the minimum case, this study demonstrated that using it would generally contribute to economic efficiency, and more importantly to worker safety.

1. Introduction

Approximately 90 people are injured and die annually during the installation of steel beams at construction sites [1]. The accidents are mostly attributed to the current method of rotating and installing a beam on site. For example, after lifting a steel beam in order to rotate the beam to the target position, a worker who hangs from a column pulls the ropes that are tied to both ends of the steel beam. Depending on the position of the beam, sometimes the worker cannot reach the beam without help from other workers on the ground. This method results in accidents and increased work time. To solve this problem, a rotation-controllable tower-crane hook-block (RTH) is proposed to automate the horizontal rotations of a hook [2–6]. However, this hook-block has not been commercialized or deployed on actual construction sites, and has remained mostly a patented idea because actual construction sites require automated equipment that has been verified not only for safety but also for productivity and economic efficiency.

This paper qualitatively discusses the expected safety improvement and quantitatively analyzes the economic feasibility of the RTH by developing a working prototype. Given the fact that the economic loss due to accidents in the construction industry in Korea is USD every year [7], the findings of this study can contribute to the economic success of the construction industry by encouraging construction sites to utilize automated equipment. This paper is organized in the following manner.

First, the qualitative analysis of the expected safety improvements is composed of three steps. 1) The existing steel beam installation methods are explained. 2) The status and risk of industrial accidents that are closely associated with the horizontal rotations of steel beams are explained. 3) The major characteristics of the developed RTH are explained for improved safety during the installation of steel beams.

Second, the quantitative analysis of the economic feasibility is composed of three steps. 1) The measured efficiency of an RTH in terms of the work time is analyzed. 2) The costs incurred by developing and applying RTH and the obtainable benefits are analyzed. 3) The economic feasibility is analyzed based on the input and output variables explained in the section.

2. Literature review

Quite a few studies have been conducted regarding feasibility analyses of automated equipment [8–14]. Some of them have focused on the analysis method itself [8–10]. For example, Kangari and Gregory [8] analyzed a telerobotic and autonomous system based on socio-economic, technological, and operational factors. Slaughter [9] suggested an analysis method using automation and robotics based on adoption opportunity, perceived benefits, adoption complexity, and complementary changes. Hastak [10] suggested factors based on need-based, technological, economic, project-specific, and safety and risk criteria when automated equipment was substituted for the manual method. The other studies focused on feasibility analyses of automated operations or equipment [11–14] rather than on the analysis method itself. For example, Hastak and Skibniewski [11] evaluated the potential of automating pipe laying operations. They suggested hazards, productivity, quality, design standardization, repetitiveness, union resistance, and technological feasibility as the evaluation factors. However, the economic feasibility was not analyzed. Instead, the technical feasibility was analyzed based on a productivity analysis. Warszawski and Rosenfeld [12] developed the Technion autonomous multipurpose interior robot for an economic

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feasibility analysis in relation to painting, plastering, tiling, and masonry. Haas [13] analyzed the economic feasibility of a developed crack sealer from the perspectives of an introduction object, the design stage, and a market analysis. Song et al. [14] analyzed the technological feasibility of a radio frequency identifier (RFID) for pipe tracking. Their study did not quantitatively analyze the productivity and economic feasibility, but rather explained the effect of having accurate material information, information delay, and error reduction in terms of reducing the work time and work planning. Some previous studies, such as those of Warszawski and Rosenfeld [12] and Haas [13], analyzed the feasibility by comparing the economic effects of the manual and automated methods, considering only the labor costs and ignoring other operation costs.

Several previous studies of automation equipment analyzed the economic feasibility based on cost and benefit factors [15–17]. Rosenfeld and Shapira [15] developed a semi-automatic navigation system that is part of a crane, and analyzed its productivity and economic feasibility. Lee et al. [16] analyzed the productivity and economic feasibility of tele-operated pipe laying equipment that they developed. The labor costs, equipment rental costs, and labor productivity in that work were calculated without considering the discounted rate of cash flow. Kim et al. [17] analyzed the productivity and economic feasibility of a hume-concrete pipe manipulator that they developed.

This study takes a similar approach to previous studies. However, additional factors are considered to make the analysis result as acceptable as possible to potential users by following the standard practice in terms of the cash flow analysis and by considering the other maintenance cost factors and the CO_2 offset price. The next section discusses the additional variables that we consider in more detail.

3. Analysis method

Although this study generally follows the analysis framework used in previous studies, there are several differences. First, in addition to the labor cost, we consider the operation and maintenance cost factors such as the rental cost of the construction equipment, the electricity cost, and the fuel cost. The fuel cost is calculated based on the number of fuel replacements. This number also takes into account the CO_2 offset price, which has become one of the standard factors considered in a cost–benefit analysis these days.

Second, we adopt a standard practice used in the cash flow analysis and apply 'real discount rates' rather than nominal interest rates or the discount rate based on the minimum attractive rate of return used in previous studies [15,17]. In addition, the inflation rate is applied to various cost factors, and the analysis considers a consumer price inflation rate, a labor cost inflation rate, a rental cost inflation rate of construction equipment, an electricity cost inflation rate, and a CO_2 offset price inflation rate. When a tower crane is leased, the lease charge of the machine, including the machine's depreciation costs and the labor cost of the operator, are included.

Third, the analysis is conducted based on Korean construction statistics because the first target market of the RTH is Korea. Rosenfeld and Shapira [15] applied 1800 h as the time for using a crane, while 2000 h are applied in this study, as suggested by the Korea Institute of Construction Technology [18]. In addition, we apply 5% of the purchasing costs for 5 years from the year of manufacture and 10% from 6 years to 10 years after the year of manufacture as the maintenance cost rates, following the Korean standard practice [19], whereas Rosenfeld and Shapira applied 9% [15].

Forth, as for productivity, while only the effect of the reduced number of workers resulting from the shortened work time was analyzed, this study also considers the effects of the reduced number of days of using tower cranes.

The factors of this study were divided into costs and benefits. Table 1 summarizes a list of the cost and benefit factors used in this study. The assumptions used for calculating the costs and benefits are also listed. The cost factors are the purchasing costs, annual maintenance costs, and fuel costs. The benefit factors from the shortened work time can be subdivided into reduced labor cost, tower-crane rental cost, energy consumption cost, and CO_2 offset price resulting from the reduced use time.

In the following sections, we first introduce any safety issues that may occur during the conventional beam installation process and RTH use, and qualitatively discuss the expected safety improvements. We then quantitatively analyze the economic feasibility of the RTH.

4. Expected safety improvement

4.1. Conventional installation method

In general, for horizontal steel beam installation methods, two workers adjust the horizontal location of a steel beam at both sides of the steel beam, as shown in Fig. 1. To adjust the location, the workers may hold onto the steel beam directly or may hold a rope that is hanging from the steel beam. The steps for this method, which are shown in Fig. 1, are as follows. First, one of the two workers standing on the ground holds the rope surrounding the steel beam to roughly adjust the horizontal location of the steel beam ((1), (2), and (3) of Fig. 1). Next, the worker goes up to the position for installing the steel beam ((4) and (5) of Fig. 1). Meanwhile, the other worker on the opposite side holds the steel beam to maintain the roughly determined horizontal location. Finally, both of the workers precisely adjust the horizontal location at the steel beam installation location ((6) of Fig. 1).

For cases in which the weight and/or size of the steel beam to be installed are large, and thus the horizontal adjustment work is difficult. In these cases, a worker may be additionally assigned to adjust the location of the steel beam from the ground by using a rope, or a worker may be added to either side of the steel beam installation location.

4.2. Status and risk of industrial accidents related to steel frame installation

Existing working methods require many movements and trips up and down in order to manipulate heavy steel beams in narrow and high positions, as shown in Fig. 1. The number of casualties per year related to steel beam installation is approximately 90 people [1]. The Korean Occupational Safety and Health Agency [20] conjectures that its statistics are assumed to be about 32 times lower than the actual number of accidents, because only accidents that are related to insurance compensation are reported. Table 2 shows a detailed classification of accidents by cause during steel construction. Among industrial accidents, falls occur most frequently. The mean of the number of casualties due to falls was approximately 51, which was at least five times higher than that of the other causes of casualties. The next highest rate of casualties was due to drops, which was followed in order by overturns, collision/contact, squeezing, and collapses. The definitions of the accident types are as follows:

- Fall: an accident in which a worker falls down while working in a high place.
- Overturn: an accident that occurs because a steel frame overturns during working.
- Collision/contact: an accident that occurs because of a collision between a steel beam and a worker.
- Drop: an accident that occurs as a steel beam is dropped down.
- Squeezing: an accident that occurs as a worker is caught between a steel beam and another structure or steel beam while the steel beam is being installed.
- Collapse: an accident that occurs as the place of the steel beam work collapses.

Fig. 2 shows the average recuperation period [1] of the injured parties in industrial accidents that occurred from 2004 through 2011.