Economic impact of safety improvement by a rotation-controllable tower-crane hook block

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Abstract

The rotation-controllable tower-crane hook block is the automated construction equipment able to rotate a steel beam in a horizontal direction. This paper estimates the economic impact of safety improvement when this equipment is deployed at construction fields. An analysis on industrial accidents shows that accidents related to steel structures make up 4.78% of total building construction accidents. This paper employed real discount rate and present worth of annuity (PWA) assessments to convert future cash flow into present worth. For this, the economic benefits were analyzed by including a reduction in the accident rate compared with manufacturing costs. The cost-benefit ratio was 1.142, demonstrating the economic feasibility of the equipment. In addition, sensitivity and qualitative benefits analyses were conducted.

Keywords: tower-crane, safety, economic feasibility, cost-benefit, sensitivity, qualitative benefits

1. Introduction

After hoisting a steel beam to a designated position of a building, workers rotate the beam horizontally for proper installation. This poses a safety problem. Accidents related to steel structure work comprise 4.78% of total building construction accidents from 2004 to 2007(Korea occupational safety & Health Agency 2005-2008). Steel structure accidents can cause economic losses, including low productivity and image deterioration, as well as expenses related to accident compensation. This paper analyzes the economic feasibility of a rotation-controllable tower-crane hook block (Kim, Jung et al. 1994) that is able to rotate in a horizontal direction. The research flow and method are shown in Figure 1.

In this paper, first, the main features of the hook block are described. Second, steel structure accidents from 2004 to 2007 are summarized. Third, the real discount rate and the present worth of annuity (PWA) analysis methods used in this paper are explained. Forth, the manufacturing costs and the economic benefits afforded by a reduction in accidents, and then the cost-benefit analysis are provided. Last, a sensitivity analysis is provided and the qualitative benefits of using the rotation-controllable hook block are described.
2. Rotation-controllable Tower-crane Hook Block

The rotation-controllable hook block is a patented item (Kim, Jung et al. 1994) that is able to rotate a steel beam by using a battery and motor inside the hook block, as shown in Figure 2. The hook block is composed of a speed reducer, a motor, and other components. The motor inside the hook block can rotate in the forward or reverse directions. The manufacturing cost of the hook block is about USD 12,500.

3. Background

3.1 Industrial steel structure accidents during building construction

Table 1 presents statistics regarding the number of steel structure casualties during building construction from 2004 to 2007 in Korea (Korea occupational safety & Health Agency 2005-2008). The casualty rate averaged 2.97%.

<table>
<thead>
<tr>
<th>year</th>
<th>The injured (person)</th>
<th>The dead (person)</th>
<th>sum (person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>27</td>
<td>27</td>
<td>54</td>
</tr>
<tr>
<td>2006</td>
<td>20</td>
<td>28</td>
<td>48</td>
</tr>
<tr>
<td>2005</td>
<td>12</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>2004</td>
<td>16</td>
<td>18</td>
<td>34</td>
</tr>
</tbody>
</table>

About 80% of squeezing accidents in steel structure accidents occurred during the horizontal manipulation of the steel according to an interview with a specialist who worked as a steel
subcontractor for more than 15 years. Table 2 provides squeezing accidents statistics from 2004 to 2007 in Korea (Korea occupational safety & Health Agency 2005-2008). One person was killed and eighteen were injured during this period.

Table 2 The squeezing accident of steel structure work

<table>
<thead>
<tr>
<th>year</th>
<th>The injured (person)</th>
<th>The dead (person)</th>
<th>sum (person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>3</td>
<td>·</td>
<td>3</td>
</tr>
<tr>
<td>2006</td>
<td>8</td>
<td>·</td>
<td>8</td>
</tr>
<tr>
<td>2005</td>
<td>3</td>
<td>·</td>
<td>3</td>
</tr>
<tr>
<td>2004</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>average</td>
<td>4.5</td>
<td>0.25</td>
<td>4.75</td>
</tr>
</tbody>
</table>

However, the actual industrial accident rate is assumed to be 32 times larger than that reported by the Ministry of Labor (Korea occupational safety & Health Agency 2008). This discrepancy is due to the fact that the Ministry’s statistics are based on data for industrial-accident compensation and many small accidents are not included in this statistics. In the next section, we analyzed the economic feasibility of the hook block on the basis of Table 2 for strict analysis.

3.2 The real discount rate

The real discount rate was applied in order to convert interest and future inflation into present worth, and is described by Eq. (1):

\[
i = \frac{(1 + i_n)}{(1 + f)} - 1,
\]

where \( i \) is the real discount rate, \( f \) is the inflation rate, and \( i_n \) is the nominal interest rate.

Here, we applied the average consumer inflation and the nominal bank interest rates from 2000 to 2007, as shown in Table 3.

Table 3 The change in inflation and nominal interest rates

<table>
<thead>
<tr>
<th>classification/year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation rate</td>
<td>2.29</td>
<td>4.00</td>
<td>2.83</td>
<td>3.41</td>
<td>3.62</td>
<td>2.77</td>
<td>2.20</td>
<td>2.54</td>
<td>2.96</td>
</tr>
<tr>
<td>Nominal interest rate</td>
<td>8.18</td>
<td>7.49</td>
<td>6.50</td>
<td>6.17</td>
<td>5.92</td>
<td>5.65</td>
<td>6.08</td>
<td>6.60</td>
<td>6.57</td>
</tr>
</tbody>
</table>

3.3 Present worth of annuity (PWA)

This paper calculates the present worth of annuity (PWA) \( P \) in order to convert future cash flow into present worth by using Eq. (2). In Eq. 2, \((P/A, i\% \text{, } n)\) is a functional symbol and is read as “find \( P \) given \( A \) at \( i\% \) interest per period for \( n \) interest periods.” \( A \) is the annual cost, including benefits, of a reduction in industrial accidents, maintenance costs, and the amount of fuel consumed. The variable \( i \) is the interest per period, including inflation and the nominal interest rate. Finally, \( n \) is the use period for the hook block.

\[
P = A(P/A, i\%, n) = A [{(1 + i)n - 1} / {i(1 + i)n}] .
\]
4. Economic Impact Analysis

4.1 Economic Impact by reduction in steel structure accidents

The casualty statistics provided in Table 1 do not include the total casualties resulting from steel structure accidents. A clear classification of casualties is difficult, hence we excluded Table 1 in our analysis of economic feasibility. The economic feasibility was performed by using the squeezing accidents statistics reported in Table 2 because a strict analysis can be performed. As mentioned in the previous section, if actual industrial accidents are 32 times higher than the statistics announced by the Ministry of Labor, using these accidents would result in a larger effect.

According to Table 2, the average number of injured persons per year is 4.5. Eight people were injured in 2006 and only three in 2005 and 2007. The one fatality was excluded because of the low sample size. Industrial accident compensation over ten years was calculated because the general life of construction equipment is considered to be about 10 years (Lee and Kim 2008). Maintenance costs are about 5% of the manufacturing cost from 1 to 5 years and 10% of the manufacturing cost from 5 to 10 years (Lee and Kim 2008).

As mentioned, the manufacturing cost of the hook block is about USD 12,500. The market cost of steel structure labor is USD 88 per day per person in Korea (The Construction Association of Korea 2009) and industrial accident compensation is 70% of the labor cost also in addition to medical costs, which were not included in our analysis. Therefore, 14 working days of 70% compensation comes to USD 833.33. The duration of medical treatment was considered to be for a minimum of 14 working days in this paper, due to the likely severity of injuries sustained by the weight of the materials at the construction site.

This paper applied 3.51% as the real discount rate by using Eq. (1) and Table 3. We also converted the maintenance cost of annuity and the reduction of industrial-accident compensation into present worth. Eq. (3) shows the calculation of manufacturing and operation costs of the hook block. Eq. (4) shows the reduction in compensation cost as a result of using the hook block. All monetary amounts in Eqs. (3) and (4) are in US dollars.

\[
\text{Manufacturing cost of the hook block + fuel consumption +} \\
\{5\% \text{ of the maintenance cost from 1 to 5 years)} \times (P/A, i\%, 10) + USD625(P/A, i\%, 5) + \{USD12,500(P/A, i\%, 10) - USD12,500(P/A, i\%, 5)} \\
= USD12,500 + USD166.67(P/A, i\%, 10) + USD625(P/A, i\%, 5) + \{USD12,500(P/A, i\%, 10) - USD12,500(P/A, i\%, 5)} \\
= USD12,500 + USD752.311 + USD2,821.11 + (USD10,390.52 - USD5,642.28) = USD20,821.72. \\
\]  

(3)

\[
\text{Reduction in compensation cost \times average of the injured \times (P/A, i\%, 10)} \\
= USD833.33 \times 4 \text{ persons} \times (P/A, i\%, 10) = 27,707.94. \\
\]  

(4)

Figure 3 shows the cost-benefit cash flow of the hook block as calculated by Eq. (3) and Eq. (4).
Eq. (5) calculates the cost-benefit analysis as 1.142. Hence economic feasibility was proved.

\[
\text{Cost-Benefit analysis} = \frac{27,707.94}{20,240.59} = 1.37. \tag{5}
\]

4.2 Sensitivity analysis

Sensitivity analysis was performed according to the changes in the number of persons injured. As analyzed in the previous section, if the number of injured persons is 8, industrial accident compensation will come to USD 55,415.88 by using Eqs. (1), (2), (3), (4) and the cost-benefit ratio will be 2.661. If the number of injured persons is 3, industrial accident compensation will be USD 20,780.95 with a cost-benefit ratio of less than 1, indicating a lack of benefit. However, in each of the ten analyzed years no few than three people were injured. The details of the sensitivity analysis are provided in Table 4.

<table>
<thead>
<tr>
<th>The injured (person)</th>
<th>Industrial accident compensation</th>
<th>Cost-benefit analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>USD 55,415.88</td>
<td>2.661</td>
</tr>
<tr>
<td>3</td>
<td>USD 20,780.95</td>
<td>0.998</td>
</tr>
</tbody>
</table>

4.3 Qualitative benefits

Qualitative benefits will be realized by the reduction of steel structure accidents. First, the image of the business will be increased by a reduction in accidents. Second, productivity will improve as a result of the increased labor stability afforded by a safer environment and a shortening of construction time. Third, delays in construction will be avoided.

5. Conclusion

The rotation-controllable hook block is the automated construction equipment able to rotate a steel beam in a horizontal direction. This paper analyzed the economic impact of expected safety improvement by the automated hook block using the real discount rate and the present worth of annuity (PWA). The total costs of the hook block amount to USD 20,821.72 and economical benefits are USD 27,707.94 through a reduction in accidents. The economic feasibility was proven by a cost-benefit ratio of 1.33 or higher for most realistic injury rate situations. Additionally, qualitative benefits
will be result. Productivity would improve through an increase in safety and by a shortening of construction time. The image of the construction company will also be improved. Delays will be avoided.

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References


