A Quantitative Risk Analysis of Related to Tower Crane Using the FMEA

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Abstract: The purpose of this study is to suggest objective evaluation model as a plan to utilize as opportunity in establishing judgment standard of mutual inspection criteria and to upgrade inspection ability by reviewing and analyzing level of danger and importance in advance based on inspection results of inspection institutions regarding tower cranes used in construction fields. Tower crane is a mechanical device transporting construction supplies and heavy materials to places over 20-150M high from the ground for the period ranging from a short time of 2-3 months to two years after being installed in construction sites in vicinity of buildings or structures and is an important facility indispensable for construction sites. However, since use period after installment is short and professional technical ability of technicians working on-site about of tower crane is poor, systematic and quantitative safety management is not carried out. As a part of researches on procedure of RBI(Risk Based Inspection) possible to apply to Knowledge Based System based on knowledge and experiences of experts as well as to tower cranes for solving these problems, quantitative RPN(Risk Priority Number) was applied to RPN utilizing technique of FMEA(Failure Mode and Effect Analyses). When general RBI 80/20 Rule was applied, parts with high level of risks were found out as wire rope, hoist up/down safety device, reduction gear, and etc. However, since there are still many insufficient parts as risk analyses of tower crane were not established, it is necessary for experts with sufficient experiences and knowledge to supplement active RBI techniques and continuous researches on tower cranes by sharing and setting up data base of important information with this study as a starting point.

Key Words: tower crane, RBI, safety inspection, FMEA, knowledge based system, risk

References:

1. Article 27(self inspection) of the law on industrial
safety and health enacted and announced on December 31, 1981 (Law no. 3532) had provided legal ground for the start of the first self inspection of dangerous machinery devices in Korea.

After that, as the whole text was revised on January 13, 1990 (Law no. 4220), it was classified into article 34 (Inspection of harmful or dangerous machinery device and facility) and article 36 (Self inspection) and manufacturing standard and manufacturing standard regarding stability of facility and safety standard were decided and in recently revised industrial safety and health law (Law no. 9319, December 31, 2008), article 34 and article 36 of the existing law was merged into safety inspection\(^1\) and use of terminology of self inspection became suspended.

In this study, evaluation standard regarding mutual inspection standard was established with the objects of results of inspection of tower cranes in construction fields and quantitative evaluation was carried out as a plan to utilize as an opportunity to upgrade inspection capability one step higher. And by suggesting universal evaluation model of dangers, it was intended to use as an objective measurement scale.

2. Main text

2.1. Scope and method of the study

The purpose of this study is to review dangers of tower cranes under use at construction fields in advance and to suggest objective evaluation model by introducing proper evaluation method. In order to secure objective basic data, over two HQs of companies were designated in multiple number among inspection institutions designated by Ministry of Labor out of domestic construction companies and self inspection was carried out regularly once per each three months and this study was progressed with result\(^2\) of analyses of self inspection data (January 2003–December 2008) conducted for six years with the objects of three companies.

Reliability technique has lots of similarity but FMEA is an inductive analyses method to systematically find out all types of breakdowns possible to occur at affiliated facility in detail and to confirm consequent damages on systems\(^3\). In this study, FMEA technique, which can review potential danger in more efficient and relatively faster time in advance than other techniques, was introduced and ranking of danger necessary for carrying out RBI of tower cranes was evaluated quantitatively by calculating level of importance from results of analyses.

2.2. Analyses of tower crane related statistics

It is reality that tower cranes are used a lot almost as much as impossible to find out construction fields without tower cranes except a small scale but it is in a state that evaluation of dangers regarding tower cranes is not almost carried out.

Since it is general from installation to dismantling tower cranes in one construction field that it does not elapse over two years even it takes a long time while it takes just 2–3 months in case of a short period, it is difficult to have systematic management and also it is impossible in reality to evaluate facilities which have occurrences of problems with technical capability only on field. For solving these problems, in this study, knowledge-based technique\(^4\) (knowledge based system) based on experiences and knowledge of experts was introduced.

\[
(Risk) = (LoF) \times (CoF)
\]

In here, S is a scenario factor, LoF is Likelihood of Failure, and CoF is Consequence of Failure\(^5\).

RBI is a technique to secure efficient stability and to pursue economy of maintenance and management
Table 1. Disaster ratio and ten thousands ratio of the death\(^7\) of construction industry per year

<table>
<thead>
<tr>
<th>Category</th>
<th>Average</th>
<th>1999</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>
</tr>
</thead>
<tbody>
<tr>
<td>Disaster ratio</td>
<td>0.75</td>
<td>0.60</td>
<td>0.61</td>
<td>0.69</td>
<td>0.72</td>
<td>0.86</td>
<td>0.94</td>
<td>0.75</td>
<td>0.70</td>
<td>0.66</td>
</tr>
<tr>
<td>Persons killed</td>
<td>659</td>
<td>583</td>
<td>614</td>
<td>659</td>
<td>667</td>
<td>762</td>
<td>779</td>
<td>609</td>
<td>631</td>
<td>630</td>
</tr>
<tr>
<td>Ten thousands ratio</td>
<td>2.82</td>
<td>3.22</td>
<td>2.75</td>
<td>2.70</td>
<td>2.41</td>
<td>2.89</td>
<td>3.88</td>
<td>2.86</td>
<td>2.48</td>
<td>2.18</td>
</tr>
</tbody>
</table>

Table 2. Status of occurrence of disasters per year

<table>
<thead>
<tr>
<th>Category</th>
<th>Average</th>
<th>1999</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>
</tr>
</thead>
<tbody>
<tr>
<td>Number of occurrence</td>
<td>4.43</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Persons killed (People)</td>
<td>6.89</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Persons wounded (People)</td>
<td>6.57</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>20</td>
<td>1</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total number of people</td>
<td>10.86</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>28</td>
<td>5</td>
<td>13</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3. Status of inspection of completion of tower cranes (Unit: Year, set)

<table>
<thead>
<tr>
<th>Category</th>
<th>Average</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sets of inspection</td>
<td>3,062</td>
<td>2,104</td>
<td>2,951</td>
<td>3,330</td>
<td>2,985</td>
<td>3,278</td>
<td>3,013</td>
<td>3,470</td>
<td>3,409</td>
</tr>
</tbody>
</table>

by qualitatively or quantitatively evaluating level of dangers from the equation (1) concurrently to find out problems(Principle of 80/20\(^5\)) within around 20%, which take majority of dangers of the entire plants and by inputting human and material resources intensively in the most optimum method for this\(^6\). And statistical distribution regarding tower cranes before analyzing potential dangers of tower crane through FMEA evaluation of quantitative analyses and before calculating level of importance from that result is as below.

Table 3 is status of inspection of completion of domestic tower cranes during the most recent eight years\(^5\).

2.3. Plan to utilize FMEA through analyses of results of the inspection

In deciding RPN of tower crane, it can decide more accurate level of dangers if we evaluate by adding(De\(^9\)tection)\(^8\)) to disaster occurrence ratio(Occurrence) and level of damages of disasters(Severity)\(^9\). Evaluating RPN is like the following equation.

\[
RPN = \text{Occurrence} \times \text{Severity} \times \text{Detection} \quad (2)
\]

In this study, status of failure as results of regular inspection of tower cranes\(^{2\text{nd}}\) conducted by KOSHA(Korea Occupational Safety & Health Agency) for enhancing objectivity of results of analyses and result data of self inspection(January 2003–December 2008) conducted by an inspection institution KIT(Korea Inspection Technology) designated by Ministry of Labor were analyzed and RPN was calculated using FMEA technique for deciding evaluation index per each evaluation factor.

Table 4 shows status of failure of regular inspection.

Table 5. Status of failure per items of regular inspection (Year 1999~2004)

<table>
<thead>
<tr>
<th>Inspection items</th>
<th>Problems (Case)</th>
<th>Remarks (Percentage, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status of external appearance and installation</td>
<td>13</td>
<td>31.7</td>
</tr>
<tr>
<td>Structural part</td>
<td>2</td>
<td>4.9</td>
</tr>
<tr>
<td>Machinery device</td>
<td>6</td>
<td>14.6</td>
</tr>
<tr>
<td>Safety device</td>
<td>11</td>
<td>26.8</td>
</tr>
<tr>
<td>Operation status (Load and etc.)</td>
<td>2</td>
<td>4.9</td>
</tr>
<tr>
<td>Electric device</td>
<td>7</td>
<td>17.1</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>41</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4. Status of failure of regular inspection of tower cranes per year (Unit: Year, set) (KOSHA)

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sets of inspection</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>14</td>
</tr>
</tbody>
</table>

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Table 6. Inspection status per year (KIT)

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of sets of inspection per year (Unit: year, set)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Tower Crane</td>
<td>1,324</td>
</tr>
</tbody>
</table>

Table 5 has analyzed\(^{(0)}\) status of a total of 28 sets failed in regular inspection of KOSHA per inspection items.

Table 6 is overall inspection status\(^{(2)}\) of self-inspection conducted by an inspection institution (KIT) designated by the Ministry of Labor.

Table 7 is an analysis\(^{(2)}\) of a status of occurrence of problem per inspection items of results of self-inspection of three companies, which was conducted for about six years from January 2003 to December 2008 once per three months after signing contract between KIT and headquarters of construction companies, just like a status of failure per regular inspection items of KOSHA.

Table 7. Status of occurrence of problems per inspection items

<table>
<thead>
<tr>
<th>Inspection items</th>
<th>Problems (Case)</th>
<th>Remarks (Percentage, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural part</td>
<td>503</td>
<td>24.84</td>
</tr>
<tr>
<td>Coiling machinery device</td>
<td>602</td>
<td>29.73</td>
</tr>
<tr>
<td>Revolution device</td>
<td>107</td>
<td>5.28</td>
</tr>
<tr>
<td>Safety device</td>
<td>166</td>
<td>8.20</td>
</tr>
<tr>
<td>Load test and etc.</td>
<td>3</td>
<td>0.15</td>
</tr>
<tr>
<td>Electricity related</td>
<td>305</td>
<td>15.06</td>
</tr>
<tr>
<td>Other</td>
<td>339</td>
<td>16.74</td>
</tr>
<tr>
<td>Subtotal</td>
<td>2,025</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 8 has obtained a conversion factor which was revised by converting percentage of each institution in an absolute value after comparing and reviewing per inspection items.

The occurrence of a problem was analyzed as 1.46 cases and 1.54 cases on average and the deviation between them was only 0.07 cases. So, it analyzed that the fairness and the objectivity has been kept.

2.4. Measurement scale of evaluation

Since objective index necessary for deciding RPN was obtained but there is no standardized criteria for scope of grade\(^{(3)}\), in this study, we use scope of 1~5.

For calculating RPN value, it was evaluated in three categories of frequency of occurrence of breakdown mode, level of damages of disasters(Severity) and detection during occurrences of breakdowns and Table 9~11 indicate frequency of occurrence, severity and grade of detection.

Level of detection can have various different variables per each item but in this study, it was set by referring to only few(Five) among items judged to make a significant contribution to prevention of accidents of tower crane and it was presumed that it is impossible to detect in advance as the measurement scale is higher.

Table 9. Occurrence by revision conversion factor

<table>
<thead>
<tr>
<th>Category</th>
<th>Classification</th>
<th>Scope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Occurrence is impossible</td>
<td>Less than 0~5</td>
</tr>
<tr>
<td>2</td>
<td>Almost no occurrence</td>
<td>Less than 5~11</td>
</tr>
<tr>
<td>3</td>
<td>Occurrence at times</td>
<td>Less than 11~17</td>
</tr>
<tr>
<td>4</td>
<td>Occur often</td>
<td>Less than 17~23</td>
</tr>
<tr>
<td>5</td>
<td>Very frequent</td>
<td>Over 23</td>
</tr>
</tbody>
</table>

Table 10. Level of damages of disaster (Severity)

<table>
<thead>
<tr>
<th>Category</th>
<th>Human damages</th>
<th>Material damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Treatment period under 6 days</td>
<td>No impacts</td>
</tr>
<tr>
<td>2</td>
<td>Treatment period under 4~14 days</td>
<td>Property damages under 1 million won</td>
</tr>
<tr>
<td>3</td>
<td>Treatment period under 14~30 days</td>
<td>Property damages of 1 million~less than 10 million won</td>
</tr>
<tr>
<td>4</td>
<td>Treatment period under 30~84 days</td>
<td>Property damages less than 10 million~100 million won</td>
</tr>
<tr>
<td>5</td>
<td>Treatment period over 84 days and death</td>
<td>Property damages over 100 million won</td>
</tr>
</tbody>
</table>
2.5. Analyses of evaluation

Using evaluation measurement scale reviewed in the previous, a simple FMEA sheet was prepared and using frequency of occurrence by revision conversion factor, strength of damages and detection, RPN was calculated like Table 12. Looking at the results of analyses, prevention device of excessive coiling appeared as the highest RPN in 120 points and the next, it appeared in a sequent order of power distribution related items such as prevention device of excessive load, wire rope, coiling decelerator, and power distribution panel. Bigger RPN value means it is an object of the priority management in safety accidents.
3. Conclusion

This study reviewed, in advance, dangers of tower cranes used in construction fields and applied grades of dangers using FMEA technique for qualitative danger order as a part of research on RBI procedure possible to apply to tower facilities. Parts with high level of danger appeared in coiling prevention device, prevention device of excessive load, wire rope, and coiling decelerator. There are still lots of lacking parts because danger analyses with regard to tower cranes are not carried out properly but with a start of this study, it is necessary for experts with more abundant experiences to continue supplementation of RBI techniques and steady research & development(R & D) by preparing data base of information of tower cranes such as detailed frequency of occurrence and level of damages per each item.

Reference

2) Shim kyu-hyung, A Study on the improvement of safety devices by execution the self inspection on Tower Crane, Safety Engineering, University of Incheon, pp. 5~21. 2006.
7) Korea Occupational Safety & Health Agency(KOSHA), www.kosha.or.kr/Statistics of industrial disaster/Status of industrial disasters (Per year)