타워크레인의 정량적 위험성 평가기법에 관한 연구(FMEA 기법 위주)

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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 installation 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.

초 록 : 본 연구는 건설현장에서 사용하고 있는 타워크레인에 대한 검사기관의 검사결과를 토대로 위험성과 중요도를 미리 검토하고 분석하여, 상호간의 검사 기준에 대한 판정기준을 정립하고 검사능력을 UP-Grade 시킬 수 있는 기회로 활용하기 위한 방안으로, 적절한 평가방법을 도입하여 객관적인 평가 모델을 제시하는데 목적이 있다. 타워크레인은 건축물 또는 구조물 등, 건설현장에 설치되어 짧게는 2~3개월부터 2년 남짓 동안 지상에서 20~150M 이상 높은 곳으로 건설자재와 중량물 등을 실어 나르는 기계장치로, 건설 현장에서는 없어서는 안될 중요한 설비이다. 그러나 설치해서 사용하는 기간이 짧고, 건설 현장의 기술자들이 타워크레인에 대한 전문 기술력이 부족하여 체계적이고 정량적인 안전관리가 이루어지지 않고 있다. 이러한 문제점을 해결하기 위해서 전문가들의 지식과 경험을 바탕을 한 지식기반기법과 타워크레인에 적용 가능한 RBI절차 연구의 일환으로 정량적 위험우선순위를 FMEA기법을 활용하여 RPN을 적용시켜 보았다. 일반적인 RBI 80/20 Rule을 적용시켜 보았을 때, 위험도가 높은 부분은 와이어로프, 권과방지장치 및 브레이크와 권상감속기 등으로 나타났다. 하지만, 아직 타워크레인에 대한 위험분석이 제대로 이루어지지 않아 미흡한 부분이 많지만, 본 연구를 시작으로 좀 더 경험과 지식이 풍부한 전문가들이 나서서 중요 정보를 공유하고 data base화 하여, 타워크레인에 대한 활발한 RBI 기법의 보완과 지속적인 연구개발이 필요하다.

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

1. 서 론

Article 27(self inspection) of the law on industrial

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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.

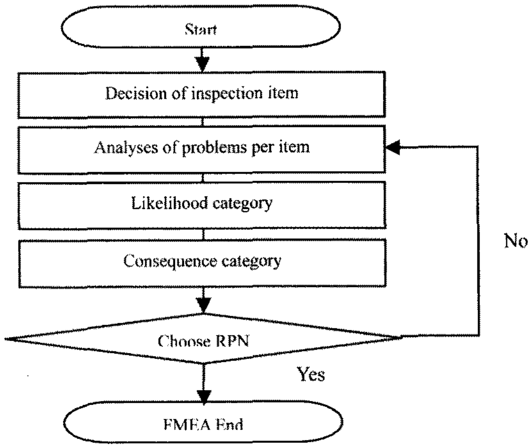

Fig. 1. Procedure of FMEA.

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.

$$(Risk)s = (LoF)s \times (CoF)s \tag{1}$$

In here, S is a scenario factor, LoF is Likelihood of Failure, and CoF is Consequence of Failure[3].

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

Category	Average	1999	2000	2001	2002	2003	2004	2005	2006	2007
Disaster ratio	0.75	0.60	0.61	0.69	0.72	0.86	0.94	0.75	0.70	0.66
Persons killed	659	583	614	659	667	762	779	609	631	630
Ten thousands ratio of the death	2.82	3.22	2.75	2.70	2.41	2.89	3.88	2.86	2.48	2.18

Table 2. Status of occurrence of disasters per year

Category	Average	1999	2000	2001	2002	2003	2004	2005	2006	2007
Number of occurrence of disasters	4.43	4	6	2	3	7	4	5	-	-
Persons killed (People)	6.89	6	1	3	2	8	4	6	11	21
Persons wounded (People)	6.57	4	6	4	4	20	1	7	-	-
Total number of people of disasters	10.86	10	7	7	6	28	5	13	-	-

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

Category	Average	2001	2002	2003	2004	2005	2006	2007	2008
Number of sets of inspection	3,062	2,104	2,951	3,330	2,985	3,278	3,013	3,470	3,409

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[2].

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(Detection)[8] to disaster occurrence ratio(Occurrence) and level of damages of disasters(Severity)[9]. Evaluating RPN is like the following equation.

$$RPN = Occurrence \times Severity \times Detection \quad (2)$$

In this study, status of failure as results of regular inspection of tower cranes(Year 1999~2004)[10] 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)

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

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

Category	Total	1997	1998	1999	2000	2001	2002	2003	2004
Number of sets of inspection	28	0	0	2	0	6	4	2	14

Table 6. Inspection status per year (KIT)

Category	Number of sets of inspection per year (Unit: year, set)						
	Total	2003	2004	2005	2006	2007	2008
Tower Crane	1,324	124	145	219	356	89	391

Table 5 has analyzed[10] 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 analyses[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

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

Table 8. Status of comparison of problems per inspection items of KOSHA vs. KIT

Inspection items	KOSHA (28sets / 41 case) 1.46cases	KIT (1,324sets / 2,025case) 1.54cases	Revision conversion factor
Structural part(Status of external appearance installation)	31.7 / 4.9	24.84	30.72
Coiling machinery device (Machinery device)	14.6	29.73	22.17
Revolution device (Operation status)	4.9	5.28	5.09
Safety device	26.8	8.20	17.50
Load test and etc.	0	0.15	0.07
Electricity related	17.1	15.06	16.08
Other	0	16.74	8.37
Subtotal	100 %	100 %	100 %

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[8], 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

Category	Classification	Scope (%)
1	Occurrence is impossible	Less than 0~5
2	Almost no occurrence	Less than 5~11
3	Occurrence at times	Less than 11~17
4	Occur often	Less than 17~23
5	Very frequent	Over 23

Table 10. Level of damages of disaster (Severity)

Category	Human damages	Material damages
1	Treatment period under 4days	No impacts
2	Treatment period under 4~14days	Property damages under 1 million won
3	Treatment period under 14~30days	Property damages of 1 million~ less than 10 million won
4	Treatment period under 30~84days	Property damages less than 10 million~100 million won
5	Treatment period over 84days and death	Property damages over 100 million won

Table 11. Level of Detection

Category	Level of skill and years of working of operators	Implementation of safety education	Level of obsoleteness of facility	Safety device	Inspection frequency	Scope	Level of revision detection
1	Over 10 years	Once per one week	Less than 2 years	Use well	One time per month	1-2	1
						3-8	2
2	5 years~less than 10 years	Once per 1 month	Less than 2~5 years	Use some	One time per three months	9-16	3
						17-32	4
3	1 year~less than 5 years	Once per 2 months	Less than 5~10 years	No use	One time per six months	33-64	5
						65-128	6
4	6months~less than 1 year	Once per 3 months	Less than 10~15 years	Some breakdowns	One time per year	129-256	7
						257-512	8
5	Less than 6 months	No education	Over 15 years	No attachment	No implementation	513-1024	9
						Over 1025	10

Table 12. A simple sheet with application of FMEA

Category	Inspection items		Potential Failure Mode	Occurrence	Severity	Detection							RPN	Ranking
	Item	Contents				Operator	Education	Level of Obsoletenes	Safety device	Inspection frequency	Total	Grade		
1	Structural part	Mast and jib	Changes of mast and jib	5	3	3	2	3	1	2	36	5	75	5
		Fixed bolt and fixed pin	Detachment of division pins and loose of nuts	5	1	3	2	3	1	2	36	5	25	10
2	Coiling machine device	Wire rope	Breaks of ropes	4	5	3	2	2	1	2	24	4	80	3
		Sieve	Abrasion and break of sieve	4	3	3	2	2	1	2	24	4	48	7
		Twist prevention device	No revolution of twist prevention device	4	1	3	2	2	1	2	24	4	16	13
		Coiling decelerator	Damages of decelerator	4	5	3	2	2	1	2	24	4	80	3
3	Revolution device	Main body of operation room	Fire	2	1	3	2	3	1	2	36	5	10	14
		Revolution device	Damages of revolution motor	2	3	3	2	3	1	2	36	5	30	9
4	Safety device	Prevention device of coiling	Collision of prevention device of coiling	4	5	3	2	2	3	2	72	6	120	1
		Prevention device of excessive load	No operation of safety device	4	4	3	2	2	3	2	72	6	96	2
		Load device	No operation of safety device	4	1	3	2	2	3	2	72	6	24	12
5	Load test	Brake capability	Brake damages	1	5	3	2	3	1	2	36	5	25	10
6	Electricity related	Distribution board and control panel	Before measuring load	3	3	3	2	2	2	2	48	5	45	8
		Wiring	Damages of sheathing and electric shock	3	5	3	2	2	2	2	48	5	75	5
7	Other	Other		2	1	3	2	2	1	2	24	4	8	15

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.

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