CONSTRUCTION SAFETY MANAGEMENT USING FMEA TECHNIQUE: FOCUSING ON THE CASES OF STEEL FRAME WORK

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As buildings become higher and larger, the possibility of accident also increases, and recurrent accidents and serious accidents are also increasing. However, it is not possible to control all the hazardous activities in construction site. Therefore, hazardous activities with higher possibility should be identified and prioritized in advance so engineers and managers can control the activities in safe manner. For this purpose, this research adopts FMEA technique, which has been widely utilized in manufacturing industry. In order to apply FMEA technique in construction safety management, the process of construction work is divided into sub-processes or activities. Then FMEA technique is applied to quantitatively analyze the importance of each activity from the safety perspective. This research applies FMEA technique to structural steel erection work and analyzes the safety of each activity. Moreover, the quantitative analysis results from FMEA process are compared with the previous accident data so as to verify the analysis results.

Keywords: accident, FMEA, priority order, safe management, structural steel work.

INTRODUCTION

The Overview and Purpose

The recent trend in the construction sites is that the buildings are becoming more skyscraperalized, complicated and large in scale; the risks of accidents in construction sites are increasing as well. Compared to general industrial accident, construction accidents are relatively more frequent, as it composes the second largest reason for industrial accidents. However, according to 2005 statistics in Korea, in the manufacturing industry, 26% of the 3,053,542 workers lose their lives in industrial accidents, yet 24.43% of the 2,127,454 workers in the construction industry[2], indicating relatively high ratio of accident likeliness. To prevent such accidents, various efforts are needed and it should be handled at the national level.

Although the construction industry has been attempting to find reasonable and efficient safety supervision system, the system in reality lacks comprehensiveness and technical preventive measure against accident and management. The safety supervision system at professional construction companies that are in charge of the actual constructions is insufficient; the construction sites are always exposed to accident risks and such risks are hard to manage by the supervisors alone. Therefore, it is necessary to prioritize these risk factors and manage the factors accordingly.

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[2] Korea Occupational Safety & Health Agency, 2005, Industrial Accident Report

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For prioritization based on the risk factors, first the method for the prioritization will be established then management plan, more realistic and reliable, will be presented based on such prioritization.

Method and Area of Study

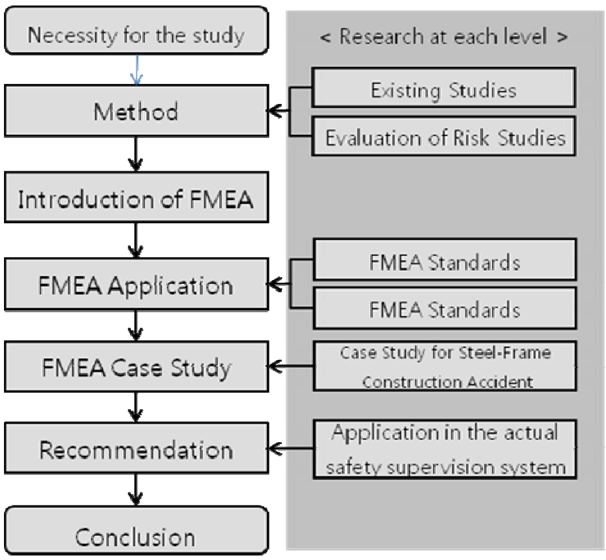


Figure 1 Flow of study

This study focuses on the efficiency of the management strategy in the safety supervision system. To extract the itemized list of safety measures, first the study must choose appropriate FMEA by comparing existing studies and evaluation methods and present new management system.

PRELIMINARY STUDY

Study of Existing Safety Supervision System

Previous investigation on the safety supervision system have tried to prevent accident on sites. The types of study can be divided into two major groups: 1) categorization and development of checklists based on case studies, and 2) development of safety supervision protocol and system. The existing studies in Korea are as following:

Table 1: Categorization and Development of Checklists Based On Case Studies

Researcher	Contents
Chung, J.Y.(1996)	Studies safety measures and accident reduction
Kim, D.C (2001)	Presents standards of case study analysis
Ju, H.G. (2003)	Develops a checklist for risk recognition by improving existing standards
Yang. Y.C. (2004)	Shows a checklist and connection to comprehensive process in construction
Hong, H.S. (2004)	Investigates safety supervision in steel-frame construction
Han, D.I. (2005)	Researches current safety situation and improvement methods
Han, B.S (2007)	Develops a checklist for evaluating the risk factors in the blueprint, by applying “Design for Safety” doctrine.

Although many studies were done on the checklist and categorization through case study, these checklists were mostly for risk recognition. Actual application of the categorization or checklists is insufficient.

Table 2: Studies on Safety Supervision Protocols and System

Researcher	Contents
Son, C.B. (2002)	Comprehensive evaluation and analysis on the system at major construction company.
Lee, J.B. (2003)	Evaluation standards and ratings by analyzing safety level and its problems
Choi, H.H. (2004)	Suggests a model for safety evaluation base on basic concepts and analysis
Hong, J.S (2005)	Presents safety supervision protocol and the necessary improvement by studying successful case analysis
Ko, S.S (2005)	Develops a safety management system, applying previous cases and risk values
Song, H. (2006)	Quantitative analysis on causes of accidents by using Fault Tree Analysis (FTA).

The studies done on safety supervision protocols and system development are difficult to understand by laymen without professional background in construction, resulting in ineffective use. They also lack reliability needed for practical application for they merely suggest simple solutions.

Development of existing studies

The existing studies consist of he categorization or checklist system and concentrates on the improvement. This research suggests ways to improve efficiency in safety management though itemizing safety measures. Before the safety measures are itemized, evaluation method for risk factors must be chosen, appropriately. Table 4 shows various risk factor evaluations.

Table 3: Risk Factor Evaluations

Methods	Contents
Checklist Method	To confirm general risk factors or standards of process. Generally, the person with the most experience writes the checklist for everyone else to follow.
Preliminary Hazard Analysis	Applied to risk factors when a new construction project lacks experience in safety measures, to identify the risks in the beginning.
What-If Analysis	To combine all irregularities at design, construction, operation, and modification levels; to verify potential risks and to reduce the likelihood of accidents.
Hazard and Operability	To extract risk factors as well as problems in efficiency.
Failure Modes Effects and Analysis	To make a table, visualizing severity of the risks and failure modes. The time spent to analyze similar systems is saved due to its repetitive nature.
Fault Tree Analysis	By deductive reasoning, to guess the causes of the accidents from studying the consequences. This method is useful in identifying the causes and the relationships among the factors. Logical and mathematical analysis may become more complicated in some examples.
Event Tree Analysis	By inductive reasoning, to guess the result from studying the causes. This method uses a event tree diagram to visualize the types of consequences caused by a certain phenomenon.

The method must be able to prioritize the consequences by project and its danger level. It should also consider the repetitive nature of such accidents. This research will use FMEA (Failure Modes Effects and Analysis) for the prioritization of safety management.

FMEA Overview

FMEA measures severity or the influence on the entire system when the process of the system fails (Stamatis, 1997). FMEA evaluates potential risks by its occurrence, severity and detection then uses the multiplication of the three factors for RPN (Risk Priority Number).

By concentrating management strategies on the higher RPN, FMEA prevents failure and marginalizes the consequences (Pyzdek, 2003).

Such advantages can be expected in using FMEA for safety management. It is quite common that similar accidents occur repetitively; to think of accidents as failures, application of the process is useful. If a certain process has an issue that may almost certainly increase the likelihood of accident. Thus, identifying risk factors and issues using FMEA could reduce possibility of accidents on construction sites. Safety management could also prevent accidents more efficiently rather than simply using a checklist.

Trend in FMEA Application in Construction Industry

Studies with FMEA in construction industry are at their first step compared to the application of FMEA in manufacturing industry. Application of FMEA is also limited to reliability and influence of the types of constructions. Table 5 shows trends in FMEA studies in Korea construction industry.

Table 4: Trends in FMEA Studies in Construction Industry

Researcher	Contents
Kim, Y.S (2002)	Studies of application of FMEA that increases reliability of quality, and of standards using Life Cycle Analysis, Risk Analysis, etc
Hong, Y.T. (2003)	Studies of application of FMEA that increases reliability of quality, and of standards using Life Cycle Analysis, Risk Analysis, etc
Kim, K.G (2006)	To estimate the factors that influence resources by using FMEA, for realistic and systematic resources management.

The current studies have so far suggested many ways to reduce likelihood of accidents at the planning process. This research will also use FMEA and suggest other ways to reduce probability of accidents at the planning level.

EVALUATION METHOD AND STANDARD

Evaluation standard

Because the frequency, intensity, severity of FMEA is generally unsuitable for this study. This research adopts frequency of accidents, intensity of accidents, severity.

Standard of frequency of accidents, intensity of accidents, severity are applied according to Korean Ministry of Labor's danger of Construction, types of business danger estimate method consults calculation and Evaluation method. Specific standard about danger of construction that it is propose in this research is as following.

- **Frequency of Accidents**

Frequency of accidents is measured by possibility of the potential risk. Standard of frequency is as shown in Table 5.

Table 5: Frequency of Accidents

Frequency division	Frequency level	Contents
Negligible	1	Once in 10 years
Low Possibility	2	Once in 3 years
Possibility	3	Once a year
High possibility	4	Once a month
frequent	5	Once a day

- **Intensity of Accidents**

Intensity of accidents is to measure the anticipated casualty. Most of the construction accidents are deadly. Therefore, casualty should be considered beyond monetary damage. The classification standard of casualty is based on the numerical value of KOSHA[3]. Standard of intensity is shown in Table 6.

Table 6: Intensity of Accidents

Intensity division	Intensity level	Contents
Negligible Effect	1	No casualty
Labor damage by accident	2	Medical treatment for a week
Labor damage by accident	3	Medical treatment for 8 day ~ 28 day
Labor damage by calamity	4	Medical treatment is necessity within 29 day ~ 180 day
Labor damage by calamity	5	Medical treatment for more than 6 months
Labor damage by calamity	6	The case which is a fatal disaster which brings a death or labor loss

- **Degree of Severity**

The severity is the degree of influence of accidents on the construction progress. Even if intensity of accidents is low, the entire process can be influenced by the accident. Standard of severity is shown in Table 7.

Table 7: Severity

Severity division	Severity level	Contents
Marginal	1	Continuation work possible as planned
Considerable Danger	2	If there is not danger, it continues a work, with damage control
No Possibility	3	Must suspend a work immediately

- **RPN (Risk Priority Number)**

RPN is the prioritized risk measured by the multiplication of frequency, intensity, and severity. According to degree of RPN value, countermeasure to reduce dormant danger is needed. A RPN value can establish the reliability of the management as well as quantify potential risks.

Evaluation method

Safety check-up is a protocol that prevents accident before the construction begins. Accident prevention must estimate potential danger and establish countermeasure to reduce danger before the construction begins. Accidents can happen even if you recognize them beforehand. Therefore, if supervisor does not establish enough counter measure beforehand, accidents can result in a big damage in construction progress.

Safety supervisor measures RPN value by frequency of accidents, intensity of accidents, and severity on construction activity. Each RPN value is showing each activity's numerical value of dangerousness. The safety supervisor can effectively manage according to high level of RPN value.

THE EVALUATION PROCESS

Figure 2 shows how FMEA is applied. The purpose of applying FMEA is to evaluate the effect to the disaster and to verify the reliability of the evaluation.

[3] Korea Occupational Safety & Health Agency (www.kosha.or.kr)

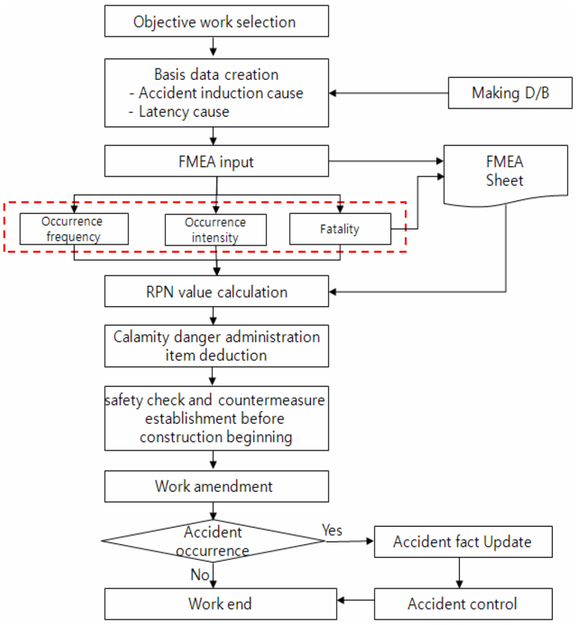


Figure 2: Administration process to inflect FMEA

(1) The safety supervisor selects the activity before work.

(2) The safety supervisor draws cause of accident and potential danger. If the user has existing D/B, the supervisor can use it for extract the factor easily.

(3) The safety supervisor makes FMEA sheet based on the information.

(4) The safety supervisor evaluates the each disaster from work about frequency of accidents, intensity of accidents and severity.

(5) After extracting important safety supervision categories, supervisor takes preventive measures against factors of accidents.

(6) When work is completed, the updated data can be used in similar kind of work.

FMEA APPLICATION EXAMPLE IN STEEL-FRAME WORK

Steel-frame work is one of constructions that serious accidents frequently occur. Therefore, this research analyzes the data by Steel-frame work at KOSHA[4] for the practical application of FMEA. The result of steel frame project data at KOSHA by construction location, the beam construction recorded 29.3% (46 cases). The next, data shows the construction equipment at 19.1% (24 cases), pillar 12.1% (19 cases), roof 10.8% (15 cases). Sorted beam work can be categorized into three types: leveraging, lifting. And, application data is based on the statistics during beam lifting work.

EXAMPLE OF FMEA SHHET FOR STEEL-FRAME WORK

Figure 3 is the example of FMEA sheet with EXCEL. The procedure of number ①-⑥ detail in Figure.3 is as follows.

Divide steel frame work into process work with the existing case study of KOSHA, and explained with the case of beam lifting work.

[4] Korea Occupational Safety & Health Agency (www.kosha.or.kr)

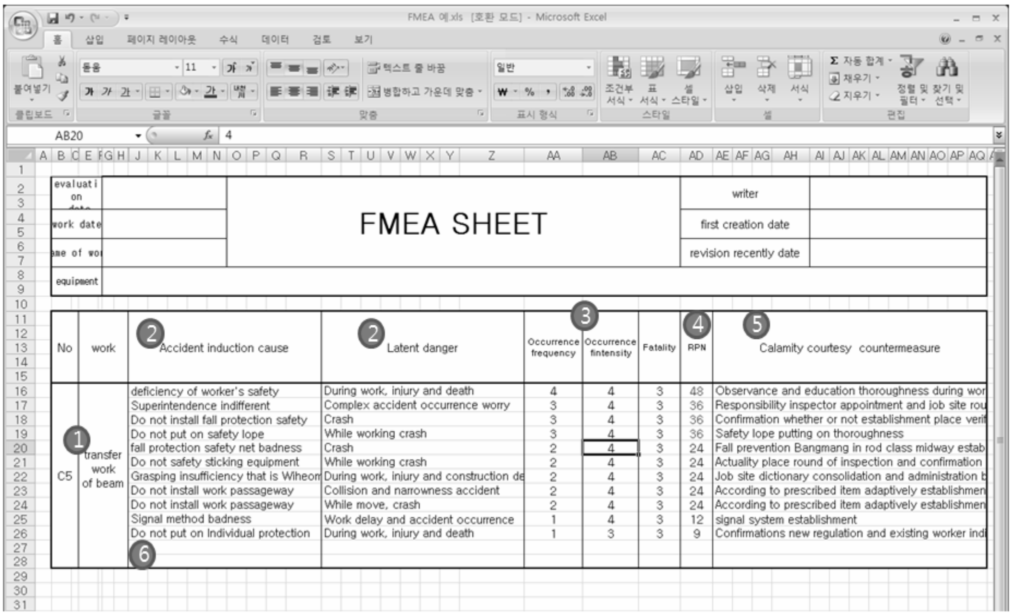
Understanding the cause of accidents in beam lifting work, and derive potential risk factors, and make out about the cause of accidents and potential risk factor.

Estimate each value of frequency of accidents, intensity of accidents, and severity with the standards in (1) and (2)

Multiply frequency of accidents, intensity of accidents, severity, and calculate the value of RPN, and arrange them in order of the value, figure out the key risk factor which is preponderantly managed in beam lifting work.

Make out prevention measure of each risk factor, and carry out safety supervision activity. The management should concentrate on the high level of RPN risk factor to prevent safety accident.

After completion of work, apply the existing sheets to new cause of accident and potential risk, and manage them, and calculate the new value of RPN with the estimation of frequency of accidents, intensity of accidents, and severity numerical value. New item is recorded and renewed to apply in the future.



No	work	Accident induction cause	Latent danger	Occurrence frequency	Occurrence fintensity	Fatality	RPN	Calamity courtesy countermeasure
C5	transfer work of beam	deficiency of worker's safety	During work, injury and death	4	4	3	48	Observance and education thoroughness during wor
		Superintendence indifferent	Complex accident occurrence worry	3	4	3	36	Responsibility inspector appointment and job site rou
		Do not install fall protection safety	Crash	3	4	3	36	Confirmation whether or not establishment place verif
		Do not put on safety lope	While working crash	3	4	3	36	Safety lope putting on thoroughness
		fall protection safety net badness	Crash	2	4	3	24	Fall prevention Bangmang in rod class midway estab
		Do not safety sticking equipment	While working crash	2	4	3	24	Actuality place round of inspection and confirmation
		Grasping insufficiency that is Wiheom	During work, injury and construction de	2	4	3	24	Job site dictionary consolidation and administration b
		Do not install work passageway	Collision and narrowness accident	2	4	3	24	According to prescribed item adaptively establishmen
		Do not install work passageway	While move, crash	2	4	3	24	According to prescribed item adaptively establishmen
		Signal method badness	Work delay and accident occurrence	1	4	3	12	signal system establishment
		Do not put on Individual protection	During work, injury and death	1	3	3	9	Confirmations new regulation and existing worker indi

Figure 3: Example of FMEA sheet for steel-frame work

The above example is the data based on a serious accident case of KOSHA. But, the example is for the serious casualty such as death, therefore frequency of accidents, intensity of accidents, severity show high numerical value, which is why RPN numerical value is high. If not only serious accident case but also general accident case is applied, various RPN numerical values will be derived.

ANALYSIS RESULT OF BEAM LIFTING WORK

As a result of analyzing causes of accidents and potential risk factors during lifting work of beams, the highest value of RPN is deficiency of worker's safety that it is appeared to the biggest hazardous factor by 48, and ignorant supervision, failure to install fall protection safety net, and safety lope appeared by 36. Above four items need to be managed in priority because 4 item’s value of RPN is higher than other items.

CONCLUSION

The construction industry has more possibility of accident than any other industries, and when the accident occurs, it can cause serious and deadly damage. The serious accident is repetitive, occurring at same progress of work. Therefore, it is necessary that formulated system which prevents and manages the accident in advance, and it requires scientific and formulated safety management system, beyond a simple checklist.

Following conclusions are deduced through the analysis of essential fact and standard of the accident and the research with FMEA

(1) The result of analysis of steel-frame work among 2740 important accidents examples, provided by KOSHA, shows that construction accident is repetitive and specific. Therefore, the case study is important subject at safety supervision.

(2) Many of Safety data on construction industry exists. But, the data is individualized and not integrated. The data was integrated for practical use of the FMEA.

(3) As a result of using FMEA sheet, RPN values differ from work element to work element. High level of RPN value needs to be concentrated by the management.

(4) Using the safety supervision system based on FMEA during the process, the research estimated checking item and reliability. With this result, the research presents an active and expansive administration system than limited existing activities.

This research established a system for the safety management of steel-frame work, applying FMEA sheet based on the analysis of precedents. The construction accident includes not only at some special work, but also many dangerous essential parts at construction industry as a whole. Therefore, the research about total safety management system based on FMEA is required at all process of work, not only steel-frame work.

REFERENCES

Choi, H. H. (2004). Risk-based Safety Impact Assessment for Construction Project. Proceedings of KICEM Annual Conference, 5, p.504-509.

Chung, J.Y. (1996). A Study on Measures to Counter the Decline of Safety and Accident Control in Construction. Proceedings of AIK Annual Conference, **16**(1), p. 181-185.

Go, S. S. (2005). Development of the Safety Information Management System according to the Risk Index for the Building Construction Work. Architectural Institute of Korea. 21(6), p. 113-121.

Ju, H.G. (2003). A Development of the Risk Identification Checklist through the RE-establishment of Risk Breakdown Structure of Construction Project. Korean Journal of Construction Engineering and Management, **4**(2), p. 109-117.

Han, B.S. (2007). Occupational Health and Safety Risk Assessment Checklist for Preventing Accidents during Building Design Phase. Korean Journal of Construction Engineering and Management, 8(2), p. 68-74.

Han, D.I. (2005). An Investigation on the Current Safety Management System and Suggested Guidelines. The Korean Institute of Building Construction, **5**(2), p121-126. .

Hong, H. S. (2004). A Study on the Development of Checklist for Safety Management of Frequently occurred Accident Process in Steel Structural Work. Proceedings of KICEM Annual Conference, 5, p.552-555.

Hong, J. S. (2005). A Safety Management Activity Improvement in Construction Sites through Analysis of Success Factors. Korean Journal of Construction Engineering and Management, 6(5), p. 148-157.

Hong, Y. T. (2004). Evaluation of Time-Affecting Factors in High-Rise Building Construction Using FMEA. Architectural Institute of Korea, **20**(10), p. 183-193.

Kim, D. C. (2001). A Plan the Accident Classification System for the Analysis of Disaster Information in Construction project. Architectural Institute of Korea, **17**(11), p. 139-146.

Kim, K.G. (2006). Developing an Assessment Model for Major Cost-Increasing Factor in Skyscraper Construction Using FMEA. . Proceedings of KICEM Annual Conference, 6, p. 507-511.

Kim, Y. S. (2002). Approach to Method of Process Failure Mode and Effect Analysis for Construction Industry. Proceedings of KICEM Annual Conference, 3, p. 271-275.

KOREA OCCUPATIONAL SAFETY and HEALTH AGENCY (KOSHA). (1992-2006). Construction importance calamity, instance and countermeasure.

Lee, J. B. (2003). A Study on the Evaluation Index of the Safety Management Level in Construction Site. Architectural Institute of Korea, **19**(3), p. 171-178.

Lee, S. Y. (2005). Reliability engineering. Publishing company of Hyungseul.

Pyzdek, T. (2003). The Six Sigma Handbook, pp590-600, McGraw-Hill. .

Song, H. (2006). A Study on the Analysis of Accident Cause of Form Work Using FTA(Fault Tree Analysis) System. Architectural Institute of Korea, **22**(6), p. 119-127.

Stamatis, D. H. (1997). TQM Engineering Handbook, pp 247-263, Marcel Dekker, Inc. .

Yang, Y. C. (2004). A Study of Methods on Safety Checklist Improvement and Integrated Operation with Schedule for Construction Accident Prevention. Korean Journal of Construction Engineering and Management, **5**(2), p. 123-136.