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Original article

Modern Cause and Effect Model by Factors of Root Cause for Accident Prevention in Small to Medium Sized Enterprises

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ABSTRACT

Background: Factors related to root causes can cause commonly occurring accidents such as falls, slips, and jammed injuries. An important means of reducing the frequency of occupational accidents in small- to medium-sized enterprises (SMSEs) of South Korea is to perform intensity analysis of the root cause factors for accident prevention in the cause and effect model like decision models, epidemiological models, system models, human factors models, LCU (life change unit) models, and the domino theory. Especially intensity analysis in a robot system and smart technology as Industry 4.0 is very important in order to minimize the occupational accidents and fatal accident because of the complexity of accident factors.
Methods: We have developed the modern cause and effect model that includes factors of root cause through statistical testing to minimize commonly occurring accidents and fatal accidents in SMSEs of South Korea and systematically proposed educational policies for accident prevention.
Results: As a result, the consciousness factors among factors of root cause such as unconsciousness, disregard, ignorance, recklessness, and misjudgment had strong relationships with occupational accidents in South Korean SMSEs.
Conclusion: We conclude that the educational policies necessary for minimizing these consciousness factors include continuous training procedures followed by periodic hands-on experience, along with perceptual and cognitive education related to occupational health and safety.

1. Introduction

In 2018, according to a report by the Agency of Occupational Accident Prevention Compensation Policy of the Ministry of Employment and Labour in South Korea on workplace accidents, the occupational injury rate was 0.54% among workers in companies covered under the Occupational Accident Compensation Insurance Law; 102,305 workers out of 19,073,438 total reported occupational injuries required at least four days of recovery [1]. This rate was the same as in 2018 [1]. Additionally, there were 2,142 worker deaths with 971 deaths by occupational injuries. The fatality rate of occupational accidents per 10,000 people was 0.51 [1].

In analyzing occupational accidents by industry, the service industry accounts for the majority (36.7%, or 37,505 occupational injuries) of all accidents, followed by the construction industries (27.1% or 27,686 injuries) and manufacturing industries (26.8% or 27,377 injuries). These three industries accounted for 90.6% of all occupational injuries. The estimated total economic losses from occupational accidents, including direct and indirect costs, are about 25 trillion US dollars [1,2].

The results of an integrated analysis on the occupational accident and fatality rates per 10,000 people in South Korea show that the occupational accident rate was 5.09%, 9.4 times less than in 1973.

Furthermore, the occupational fatality rate per 10,000 people was 2.67, 5.2 times less than in 1973 [1,2]. These results are thought to be due to the dedication and passion for occupational accident prevention of some officials and specialists in occupational health and safety.

However, the occupational accident and fatality rates are actually higher in South Korea than in other advanced countries, and because of the limited reduction of these rates, a new safety

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paradigm needs to be established for accident prevention [1,3,4]. Additionally, about 50% of the accidents mentioned above are workers for whom the Occupational Accident Compensation Insurance Law does not apply. There are at least 1,000 worker deaths in various industries every year, and most of these result from commonly occurring accidents such as falls, slips, etc. Such accidents represent 50% of all workplace accidents in South Korea. In addition, 78.3% of such accidents occur in companies having fewer than 50 employees, which suggest fundamental and structural issues in such companies [4]. The major causes of such commonly occurring accidents are poor safety consciousness, an inability to recognize risks, and coping with those risks themselves [4–6].

On the other hand, in the view of visual ergonomics, an individual's degree of awareness about the severity of risk is often strongest for visually obvious dangers, such as harmful chemical leaks in occupational work, bridge collapses, and disasters. Indeed, most consider disaster situations to carry visible risks, whereas they do not generally perceive such risks for occupational safety-related situations. Occupational health and safety is thus a highly important field for ensuring people's safety [2,4,5].

This paper is aimed at detailing factors of root cause in the manufacturing, construction, and service industries and providing crucial information for accident prevention in these industries. More specifically, this paper aimed to develop the modern cause and effect model using factors of root cause of the accidents for SMSEs in the manufacturing, construction, and service industries, as well as systematically propose educational policies and strategies for reducing occupational accidents tailored to the South Korean worker. We provide mid-and long-term approaches to the prevention of commonly occurring accidents from occurring among SMSEs in South Korea.

2. Subjects and method

2.1. Background

A report on the basic causes of occupational accidents in South Korea, both by occurrence and by objects involved, found that fatal accidents in construction companies could be cut by more than half via the use of protective equipment, safety inspections before work, and safety supervision [7].

In a paper classifying accidents in small businesses with less than 30 employees, more accidents occurred among workers in their 20s, workers with less than one year of experience, and during work on Saturdays. Acts involving unsafe postures and motions were identified as the leading direct causes of accidents, closely followed by unsafe workplace conditions and environmental defects. The lack of safety management was cited as the most frequent indirect cause. The author proposed a number of solutions, including providing safety education for young staff, improvements in work posture, and the development of systematic safety management programs [8].

An analysis of occupational accidents using fuzzy inference noted that lack of safety consciousness, indifference, conceits regarding safety, insufficient safety management, and passive countermeasures for potential hazards were leading causes of accidents. The report concluded that accident rates were lower for companies having staff having higher safety awareness [9].

Accidents aboard fishing vessels are typically caused by worker's lack of qualifications and knowledge, insufficient safety management systems, and faults in the vessels themselves [10]. Lee and Jang's proposed solution was to use periodic education to cultivate greater awareness among ship owners and workers of the necessity of high-qualified equipment and practice. Furthermore, they recommended a safety management textbook be developed, and the safety portion of the seaman engineer's license examination improved. The report also proposed that safety management and emergency rescue systems be developed and vessel test procedures made more rigorous as methods to eliminate accident risk factors [10].

In a previous analysis on factors of the root cause of occupational accidents, occupational accidents were compared among miners and nonminers based on five standard causes: workload, inadequate training, operating procedures, lack of knowledge, and ignorance of the danger. The results showed that the causes of occupational accidents did not differ between the groups [11].

In a cause and effect analysis of the Bhopal gas leak disaster, alarm absence, potential chemical hazards, insufficient system functionality, poorly functioning equipment, misinformation, and inadequate maintenance were noted as the main causes [12]. Eckerman [12] proposed that avoiding injury and reducing risk could be achieved through a logical framework related to education, alarms, development of adequate maintenance systems, and emergency action plans.

In South Korea, the prevention of fatal accidents in SMSEs has been improved via a Korean Life Change Unit (KLCU) model that incorporates life stress factors and is adapted to Korean life [13]. They also proposed a systematic management method for this model.

Another program aiming to minimize occupational accidents and promote safety culture by using a quantifiable technique has also been developed in South Korea. This program predicts zero accident time and estimates accident rate [14]. In South Korea, little research on the prevention of occupational accidents, based on analysis of root causes, have proposed common solutions for all sizes of companies. Specifically, most existing methods for determining the causes of and means of preventing occupational accidents were developed for specific companies or characteristic facilities [6,14].

In the present study, the modern cause and effect model was developed by evaluating the factors of root cause based on a priority matrix. Our model primarily targeted workers and health and safety managers in enterprises with less than 300 employees, such as small- to medium-sized enterprises (SMSE) in the middle region of South Korea.

2.2. Procedure for the modern cause and effect model in South Korea

For minimizing occupational accidents, it is important to prioritize prevention factors and strategies that systematically provide information for establishing a useful method of accident prevention and safety management. Our procedure of creating the modern cause and effect model by prioritizing the factors of the root cause is shown in Fig. 1.

2.3. Identification of root cause factors by analysis of occupational accidents

Currently, several policies and safety systems have been implemented to prevent commonly occurring accidents in South Korea. Specifically, the strengthening of the application of the Occupational Safety and Health Act to reduce fatal occupational accidents is a notable strategy. Furthermore, a number of risk assessment techniques have been developed, which aim to create safety cultures by improving safety awareness and eliminating factors of root cause in workplaces throughout South Korea. South Korea has also consistently pursued the elimination of commonly occurring accidents among partner firms and the minimization of occupational accidents through strengthening law enforcement, particularly because of the much higher rates of occupational and deaths among partner firms than among large companies.

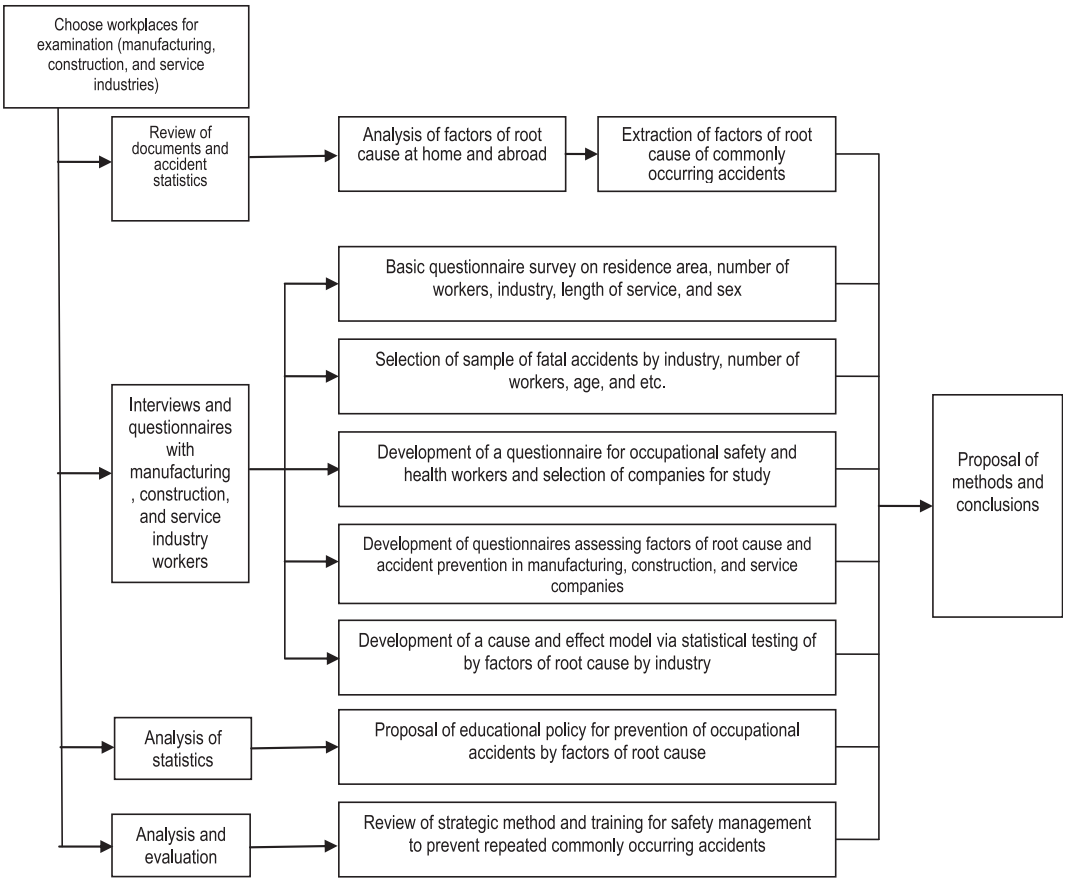

Fig. 1. Procedure for development of the modern cause and effect model by factors of root cause in SMSEs of South Korea.

"Partner firms" are defined as SMSEs that are affiliated to work between related industries in order to produce and help the final product of a large company in the field or from both the inside and outside of the firms. Also, because partner firms are managed by the company, they can regard a department of the company. Notably, the occupational accident and fatality rate per 10,000 workers appears to be unchanged in South Korea over the last few years [4,6]. Accordingly, to prevent commonly occurring accidents more efficiently, a paradigm of safety should be established and sustained via systematic strategies, policies, and implemented safety systems.

Thus, a review of domestic and overseas literature resulted in 22 root cause factors of occupational accident and fatalities [2,3,6,15,16].

In this paper, "unconsciousness" is defined as engaging in unsafe acts or working in unsafe conditions without being aware of the surrounding risks or hazards. An example of an accident caused by this factor would be injuring one's finger with a machine part after unintentionally placing it in one's pocket during maintenance and missing the pocket unconsciously.

"Disregard" is defined as not complying with safety procedures such as wearing protective equipment, lockout/tagout systems, and safety regulations. Receiving a head injury on entering a room with a low ceiling without wearing a helmet is an example.

"Ignorance" is defined as engaging in an unsafe activity, wherein one's knowledge of risk or health and safety is insufficient. An example of an accident caused by ignorance would be jammed body parts rotary parts because the worker did not read the instructions on the control unit manual.

"Recklessness" is defined as purposely engaging in unsafe activities despite sufficient knowledge of the risks. For example, a fully educated worker attempting to transfer an object that weighs more than 30kg alone can cause back injury or pain.

Finally, "stress" is defined as any negative experience that affects people in the workplace or daily life. An example of an accident caused by stress would be a jammed finger in rotary parts after hearing the news of the death of a close friend.

2.4. Scope and methodology

In South Korea, 74% of fatal accidents occur in the metropolitan and central areas.

Therefore, workers and managers in these areas were selected as subjects for investigation. The study areas included Seoul, Gyeonggi-do, and Chungcheong-do. Inclusions in the study were mainly service, manufacturing, and construction companies having less than 300 employees.

The following procedure was used to develop a model for improving educational policies in South Korea:

1. First, we analyzed existing cause and effect models and accident statistics according to factors of root cause factors found both domestically and internationally.
2. Factors of the root cause that fit the South Korean situation were extracted to devise the means of preventing these accidents.
3. A questionnaire, in which factors of root cause were randomly arranged, was created for the participating enterprises.

4. The questionnaire was administered to enterprises with less than 300 employees in the metropolitan and central areas of South Korea in the manufacturing, construction, and service industries. The questionnaire participants were both workers and health and safety managers.
5. The questionnaire was distributed to randomly selected participants.
6. A priority matrix was then used to rank factors of root cause based on the questionnaire data. The sample response rates of factors of root cause were measured using the principal diagonal of the priority matrix. Then, the ranking of each item was established [5,17,18].
7. A difference analysis was used to identify the extent of the significance in the rankings among factors of root cause. To analyze these differences, we performed intensity analysis, whether each factor was significant or not, using a significance level of 0.05 ($\alpha = 0.05$) [6,14].

The intensity analysis is very important for accidents prevention of SMSEs in South Korea. The accidents by factors of root cause in the robotic system and smart system like Industry 4.0 have more complexity than present systems. Thus, these systems should perform intensity analysis in order to minimize occupational accidents fatal accidents.

The results allow us to propose educational policies that minimize commonly occurring accidents using the cause and effect model derived from the test results.

3. Results

Participant and enterprise characteristics were obtained by distributing questionnaires to 1,750 workers and managers in companies having fewer than 300 employees. There were 1,750 questionnaires sent, and 1,391, that is, 79.5%, were returned. The recovery rate is very high because of the help of the Korea Occupational Safety and Health Agency (KOSHA). 74% of fatal accidents occurred in metropolitan and central areas in South Korea et al., [6,13]. As shown in Table 1, the sample rates in the same area the distribution of the questionnaires were reduced to 73.2%.

Additionally, occupational accidents were 94.5% [1,19] for companies with less than 300 employees in 2013. As shown in Table 1, the sample rates of these accidents were reduced to 59.3%.

Manufacturing and construction sites have had high fatality accident rates in South Korea. As shown in Table 1, the sample rates of these industries were 94.6%.

Most participants were men (94.8%) because the majority of workers in South Korean manufacturing, construction, and service companies are male. The questionnaire focused on the location and characteristics of fatal accidents. The results by age, occupation, and length of service are the same as in Table 1.

Table 2 shows the modern cause and effect model through intensity analysis by normal testing for SMSEs workers of South Korea based on our priority matrix. The main causal factors found for South Korean workers were (1) unconsciousness, (2) disregard, (3) ignorance, (4) recklessness, (5) misjudgment, (6) lack of knowledge or awareness of risk factors, (7) inadequate standards of the facility of internal work, (8) insufficient training, (9) stress (job, life, and workplace) [20], (10) insufficient safety checks in facilities, (11) poor-quality temporary construction equipment, and (12) low-bid system among partner firms.

The decision-making by consciousness factors in unforeseen interactions is more important for the prevention of occupational accidents because the advanced facility system as a smart system, robot system, information, and communication technology (ICT), etc. becomes more complex. Especially, these factors cause more and more fatal accidents.

Table 1
Participant and enterprise characteristics

No.	Variables	Frequency	Percentage (%)
	Residence area		
1	City of Seoul	164	11.8
2	Gyeonggi Province	671	48.2
3	City of Incheon	348	25.0
4	Chungcheong Province	30	2.2
5	Gyeongsang Province	54	3.9
6	Pusan	51	3.7
7	Other	73	5.2
	No. of workers		
8	Above 300	566	40.7
9	100–300	176	12.7
10	50–100	319	22.9
11	<50	330	23.7
	Industry		
12	Manufacturing	680	48.9
13	Construction	635	45.7
14	Service	76	5.5
	Length of service (years)		
15	>10	631	45.4
16	5–10	319	22.9
17	1–5	281	20.2
18	<1	160	11.5
	Sex		
19	Male	1,318	94.8
20	Female	73	5.2
	Age		
21	≥50	330	23.7
22	40s	409	29.4
23	30s	175	34.4
24	20s	177	12.7
	Occupation		
25	Worker	811	58.3
26	Health and safety manager	580	41.7
Total		1,391	100.0

As can be seen, consciousness factors (unconsciousness, disregard, ignorance, recklessness, and misjudgment) make up a large proportion of factors of the root cause and may therefore play an important role in minimizing accidents to a greater degree than any other causal factors.

In this paper, the set of null and alternative hypotheses were as follows.

H_o: $P_i = P_j$ H_a: $P_i \neq P_j$

(where i, j = 1,2, ….,22).

In Tables 2 and 3, the items with a significance level of 0.05 (α) were as follows:

- Unconsciousness and disregard
- Disregard and recklessness
- Recklessness and low-bid system among partner firms

Table 2
The Modern cause and effect model by intensity analysis for SMSEs workers in South Korea

Rank	Fundamental causal factor	Frequency	Sample response rate
1	Unconsciousness	550	0.395
2	Disregard	210	0.151
3	Ignorance	172	0.124
4	Recklessness	122	0.088
5	Misjudgment	120	0.086
6	Lack of knowledge or awareness of risk factors	118	0.085
7	Inadequate standards of facility internal work	109	0.078
8	Insufficient training	107	0.077
9	Stress (job, life, and workplace)	103	0.074
10	Insufficient safety checks in facilities	100	0.072
11	Poor-quality temporary construction equipment	99	0.071
12	Low-bid system among partner firms	77	0.055
13	Inappropriate protective devices	67	0.046
14	Insufficient safety signs	52	0.037
15	Poor work atmosphere	41	0.029
16	Owner leadership	38	0.027
17	Absence of health and safety managers	35	0.025
18	Low morale	34	0.022
19	Insufficient work safety plan	20	0.0142
20	Insufficient health and safety education for new workers	17	0.012
21	Unpleasant work environment	15	0.011
22	Shortage of health and safety managers	5	0.004

Table 3
The normal testing results with significance levels ($\alpha = 0.05$)

Item of sample rate	Test statistic	Rejection region
$P_1 = P_2$	9.27	$Z \geq \|\pm 1.96\|$
$P_2 = P_4$	3.20	$Z \geq \|\pm 1.96\|$
$P_4 = P_{15}$	2.12	$Z \geq \|\pm 1.96\|$
$P_{15} = P_{20}$	2.15	$Z \geq \|\pm 1.96\|$

Where, P_1 = Unconsciousness.
P_2 = Disregard.
P_4 = Recklessness.
P_{12} = Low-bid system among partner firms.
P_{15} = Work atmosphere.
P_{20} = Insufficient education of health and safety for new workers.

- Low-bid system among partner firms and poor work atmosphere
- Poor work atmosphere and insufficient health and safety education for new workers

However, the intensity analysis revealed that the differences in response rate for prevention factors and strategies between these items were not significant.

4. Discussions and conclusions

Recently, large companies in South Korea have been reducing occupational accidents among partner firms by improving safety consciousness and voluntary safety management practices and by developing systematic and thorough management approaches. Additionally, the Ministry of Employment and Labour in Korea developed a mobile app that encourages safety management and voluntary safety management to protect the lives and health of workers.

In particular, the government is focussing on protecting worker lives and preventing occupational deaths through stricter enforcement of the Occupational Safety and Health Act.

By adopting both medium- and long-term perspectives, and utilizing our newly developed modern cause and effect model, propose various strategies and methods for systematic safety management and education in order to minimize occupational accidents and fatalities among SMSEs, with a focus on minimizing the fatality rate per 10,000 workers.

Commonly occurring results of the priority matrix analysis using our model for workers of SMSEs showed that unconsciousness, disregard, ignorance, and recklessness had significant impacts on the occupational accident rate. In particular, the highest-ranked risk factors for occupational accidents were unconsciousness, disregard, ignorance, recklessness, misjudgment, and lack of knowledge or awareness of risk factors.

These root consciousness factors cause accidents as they represent a lack of awareness, perception, or cognition of health and safety for workers and managers. Accordingly, education of occupational health and safety in various industries should target the formulation of systematic and specific guidelines and practical methods while taking a mid- or long-term perspective to eliminate occupational accidents and fatalities resulting from these factors.

Therefore, the main conclusion and suggestion of this paper are summarized as follows:

First, we developed the modern cause and effect model in order to minimize the occupational accident and fatal accidents through intensity analysis by the priority of factors of root causes as unconsciousness, disregard, Ignorance, recklessness, ignorance, recklessness, lack of knowledge or awareness of risk factors, stress (job, life, and workplace), poor work atmosphere, low morale, unpleasant work environment, and so on.

Second, we propose a three-stage occupational safety and health education system based on a life cycle that should help cultivate better health and safety awareness and thus prevent commonly occurring accidents from occurring. The first stage of this education system would be experiential learning and periodic education of occupational health and safety; the second stage would be perceptual education; and the third stage would be cognitive education [2,5,6]. The first stage would train workers and managers in fundamental safety consciousness using experiential learning methods, as well as periodic education regarding occupational health and safety practices [2,6]. The purpose of the second stage would be to educate

workers about their workplaces using videos or training aids using actual accidents and highly hazardous factors found in their workplace on a regular basis. Such education would improve workers' perception of health and safety issues and cultivate a deep-rooted safety consciousness. Furthermore, it would help protect workers from commonly occurring accidents by encouraging their compliance with minimal safety rules. The third stage is cognitive education that aims to improve consciousness of safety and health, cultivating self-control and management by the improvement of multiple hazardous factors and the development of advanced safety culture as found in other countries. However, greater safety consciousness cannot be achieved in the short term. As such, cognitive education for health and safety does not have the same standards; instead, this education should be simple, applicable for quantitative risk assessment, and suited to the characteristics of each workplace. This education should involve identifying how to control hazard factors by oneself and should be offered on a continuous basis. Methods of promoting such education among workplaces should be discussed thoroughly, and examples include giving incentives to companies that excel in risk assessment or devising a reward system as part of a national risk assessment competition.

Third, a lockout/tagout system for important equipment should be gradually implemented to prevent basic accidents caused by the inappropriate use of protective devices. Accordingly, the government of South Korea should enforce lockout/tagout systems for important equipment in economically poor SMSEs.

Fourth, the 22 root cause factors identified provide important information for reduction of commonly occurring accidents in South Korea and provide a base for advancing the country's occupational health and safety.

Finally, our study contributes to the advancement of safety culture and ultimately will play a very decisive role in the development of a safe country and, in particular, a safe South Korea.

Future research should focus on performing an analysis among these root cause factors to determine how the presence of more than one factor influences the severity of a safety situation. The addition of female and youth workers as participants will be important to understand if the factors affect each of these groups in a different manner.

Conflicts of interest

The authors declare no conflict of interest.

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