◈ Application Papers

Identification and Structuring of the Workplace Risk Factors Regarding Power Press Machines

Kuk Kang Hur*
Donghyun Park*

Abstract

Industrial accidents have been consistently increased in terms of medical costs, lost work days, and incidence rates every year in Korea. Since the infrastructure of the industry changed shifts rapidly from 1980s in the developing countries such as South Korea, the nature and magnitude of the industrial accidents have also undergone a major shift. The situation is especially severe in small-to-medium sized industry(SMI). This article reports the development of a systematic evaluation system of risk factors specifically for the SMIs. The new approach introduced by this article is geared to the systematic identification and evaluation of the injuries from power press machines using the Analytic Hierarchy Process with the key evaluation data generated and evaluated by the employees on site.

A total of 21 companies was studied and surveyed using the hierarchical structures of the cause-effect relationship of the mechanical injuries and their countermeasures. For the relative weighting of each risk factor, separate questionnaire survey was conducted for the selected workers from each company who had worked for more than 10 years in press work. Most participants (48 out of 62) replied that human attributes were the most significant factors for mechanical injuries followed by administration, machine, and work environment factors. The result also showed that the self-motivated risk assessment and safety enhancement activities would be an effective and efficient way of managing the risk factors in the SMIs.

1. Introduction

One of the major problems of the risk management in terms of industrial safety is the systematic evaluation. Although comprehensive evaluation is regarded as important, actually conducting the evaluation in the context of risk management activity is rare for a variety of reasons. Authorities in the risk management, either government or the public institutes, often does not have time or resources to do more than the quick review of the 'case progress' after the case has occurred. For political or administrative reasons, the responsible parties sometimes are not informed of the detailed account of the accident cases [3].

However, with the public pressure during the process of the democratization of the labor policies, newly industrialized countries such as South Korea are pushing toward the new initiative so that the regulating agencies can often take more innovative approaches for achieving the enhanced level of accident risk management than the advanced countries do. This paper reports the development of a systematic evaluation system of risk factors specifically for the SMIs.

Since the infrastructure of the industry has been changed rapidly from 1980s, the number and

*) Department of Industrial Engineering, Inha University

functions of SMIs have been drastically increased. The nature and magnitude of the industrial accidents in the SMIs also have undergone a major shift. In Korea, there is a trend of industrial accident becoming larger in scale, and more severe in fatality with the expansion of the industrial capacity. From the 70s, industrial machines such as power press have been appointed as the Hazardous Machine by the government and been continuously supported through safety enhancement program, financial support, safety devices, training and education. Even with these efforts, so-called powered machine accident did not improve especially in SMIs.

In general, the major cause of the powered machine accidents is believed to be the lack of automated safety devices[2] with the second being the lack of safety facilities. However, over 80% of these hazardous machines is now equipped with safety devices largely due to the continuous government support. However, the accident rate record has not shown the substantial improvement as expected. The increasing accident rate in the SMIs proves that there are more causes in the human factors (unsafe activity) as compared to mechanical factors (unsafe state). There is a great need for study from the viewpoint of the works at the work site. The third major cause can be the lack of administrative support, which is also an area of weakness for most of SMIs. Safety management in SMIs is covered by very few people, if at all, and there is a lack of detailed management strategy with respect to the practical and effective countermeasures. As a consequence, safety management in the small-scale industry generally tends to be defensive and involuntary.

To overcome this chain of vicious cycle, Department of Labor(DOL) in Korea has been promoting seriously to establish a autonomous safety management program aimed at accommodating the voice of customers in the safety management. Opinions gathered from the plant site, and opinions by the workers are gathered through questionnaire surveys. Safety programs based on the result of the survey are planning to be established.

As an alternative to the method of traditional safety counseling activities, a group decision making tool using the AHP (Analytic Hierarchy Process) is suggested and designed to effectively implement the self-guided identification of the risk factors and hazardous elements in the plant site. Actually, preventive actitivities proposed so far has been mainly focused on installation of safety devices and education of safe operation. However, it has not provided a safe environment for power press work since it has been decided and excuted by only government's side. Therefore, previous approaches has been lacking the consideration of actual information from on-site. This study tries to construct a framework of workplace risk factors and safety guidelines for power press machines based on practical opinions of workers and safety personnel. To distribute this system of safety management tool to numerous plant site managed by SMIs, a user-friendly computer software of the AHP are also designed and educated. This paper describes the structure and the result of the AHP-based safety enhancement program.

2. Method

The required documentation in the current safety management program mandated by government contains only the descriptive statistics and records. The nature and cause of the accident can be ambiguously described and often, as a result, are not considered in depth in the analysis. In supplement to the typical analysis of the accident records, this study focused on the risk factors expressed by the workers. It is presumed that hierarchically structuring these risk factors and their countermeasures will help the site managers to investigate the accident systematically, thus to improve the potential effectiveness of the countermeasures. These hierarchical structures will also help the safety managers at site to quantify the worker's opinion based on their perception of relative importance while simultaneously focusing on the causes-and-countermeasures of the accident risks for their own plant. The quantified opinion gathered through the AHP program can also help to resolve the differences in individual opinion. The uses and advantages of AHP as a group decision-making tool have been reported extensively in the literature[4].

In this study, the hierarchical structure of the risk factors in industrial accident was constructed from the industry survey, records review and interview with safety managers. Twenty-one industries in the vicinity of Seoul-Inchon industrial complex participated in the survey. The group of industries participated in this study mainly consisted of furniture and metal indutries. The size of the industries ranged from 50 to 300 workers. From these industries, sixty-two safety managers and safety-management consultants participated in the actual weighting of the risk factors.

2.1 Analytic Hierarchy Process (AHP)

AHP is developed by T.L. Saaty and has been published extensively in the decision science area[4]. There have been numerous case studies, critiques and improvements related to the use of AHP. Although the detailed procedure of AHP can be found elsewhere[6][7], the key concept important to the formulation of this study is briefly explained. AHP expresses the decision problem as a hierarchy or a network structure. AHP is a form of multi-attribute decision making which represents the decision variables as a list of prioritized entities. The primary advantage of AHP is that it uses the intuitive perspective or experience of the decision-maker systematically to arrive at the decision quickly and effectively when the situation is uncertain.

The logic behind the prioritized hierarchy can be explained by the following mathematical procedure. Let the criterion at certain level of the hierarchy be c_1, $c_2 \cdot c_n$, and let relative importance between c_i and c_j be a_{ij}. Then the pairwise comparison matrix A can be expressed as:

$$A = (a_{ij}) \qquad i, j = 1, \cdots, n$$

$$\text{If} \quad a_{ij} = \beta, \quad a_{ji} = \frac{1}{\beta} \quad \text{where } \beta \neq 0$$

$$\text{If} \quad c_i \,\&\, c_j \text{ are equally important,} \quad a_{ij} = a_{ji} = 1$$

Then A becomes

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & & & \vdots \\ \frac{1}{a_{1n}} & \cdots & \cdots & 1 \end{bmatrix}$$

The relative important scale or the weighting scale, β, can be a set of any real number. The 9-point scale proposed by Saaty[6] is the most widely used evaluation scale. It is shown in Table 1.

Table 1. 9 point scale by Saaty

Importance	Definition
1	Equal Importance
3	Weak Importance
5	Strong Importance
7	Very Strong Importance
9	Absolute Importance
2, 4, 6, 8	Intermediate Importance between two numbers
Reciprocal	Value of a_{ij} with respect to a_{ji}

The result of AHP is the estimated relative weight of the criterion c_1, c_2, ⋯ , c_n or w_1, w_2, ⋯, w_n. Two methods(eigenvalue method and logarithmic least squares method) are used to estimate the w_i's[5]. In the eigenvalue method,

$A_w = \lambda_w$ ··················(1)

Where λ is the eigenvalue of the matrix A.

$W = (w_1, \cdots, w_n)^T$: Vector of relative weights of $c_1, \cdots, c_n$

To solve (1),

$|A-\lambda I| = 0$ ··················(2) ,

when A is the matrix with order n, there are n-number of $\lambda_1, \cdots, \lambda_n$

If for all $a_{ii} = 1$, then $\sum_{i=0}^{n} \lambda_i = n$ ··················(3)

Let the MAX { $\lambda_1, \cdots, \lambda_n$ } be λ_{max}, if λ_{max} = n, all other λI = 0, then the matrix becomes $Aw = nw$ ················(4)

Saaty[6] defined the concept of consistency using the equation (4). Using the property that the perfect matrix satisfies: $\lambda_{max} = n$, $Aw = \lambda_{max} w$ ···············(5)

Saaty[4] proved that as λ_{max} approached n, the consistency of the decision increased. The consistency ratio was CR=CI/RI. CI was the consistency index where:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad \cdots\cdots\cdots\cdots\cdots (6)$$

RI is the random index where it can be thought as the average CI of the complete random matrix. The value of RI changes as n changes. Table 2 shows a typical value of RI for the different n.

Table 2. Value of random index

N	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

When the consistency was perfect (λ_{max} = n), then CI = 0, CR = 0. However, in general, CI>0, CR>0. Saaty[5] proposed that the decision was consistent when CR was less than or equal to 0.1. The final prioritized output of the relative importance could be calculated:

$$x_i = \sum_j c_j \; a_j^{\,i} \qquad i = 1, 2, \cdots \qquad j = 1, 2, \cdots$$

c_j : *weight of the j-th criteria*

a_j^i : *weight of the i-th alternative with respect to the j -th criteria*

Group decision-making using AHP can be approached in two ways. The first method is to construct a combine matrix using the geometric mean of the different matrix value. The second method is to calculate the weight of each matrix and then gets the average of the result. In the case study conducted by Kim[1], the performance of the two methods seems indifferent.

2.2 Data Collection and AHP Structure

Using the survey of 21 industries, the structure of the risk factors and countermeasures are designed. The top level of the hierarchy is defined as safety guideline for mechanical injuries. The second and the third level consists of the 'risk factors' and 'specified risk factors' respectively. The lowest level, called the alternatives level in AHP, are defined as the counter measures. Since all the countermeasures are not related to all the risk factors, the structure of the hierarchy is imperfect[5].

Since the matrix between the risk factor and countermeasures are imperfect, a revised weight is needed at the countermeasure stage. The revised weight is devised to reduce the dominating effect of the countermeasures when the number of countermeasure is different. The revised weight can be defined:

$$P_i^{'} = P_i / P_{max} \qquad i = 1 \cdots k$$

$P_i^{'}$ = *revised weight of the i – th alternative(countermeasure)*

P_i = *original weight of the i – th alternative(countermeasure)*

$P_{max} = Max\{P_i \cdots P_n\}$

Using this revision, the most important alternative (countermeasure) is assigned the weight of 1 and all the other measures are assigned the value between 0 and 1. Figure 1 shows the structure of the hierarchy and the Tables 3,4,5,6 show the complete list of risk factors and countermeasures developed.

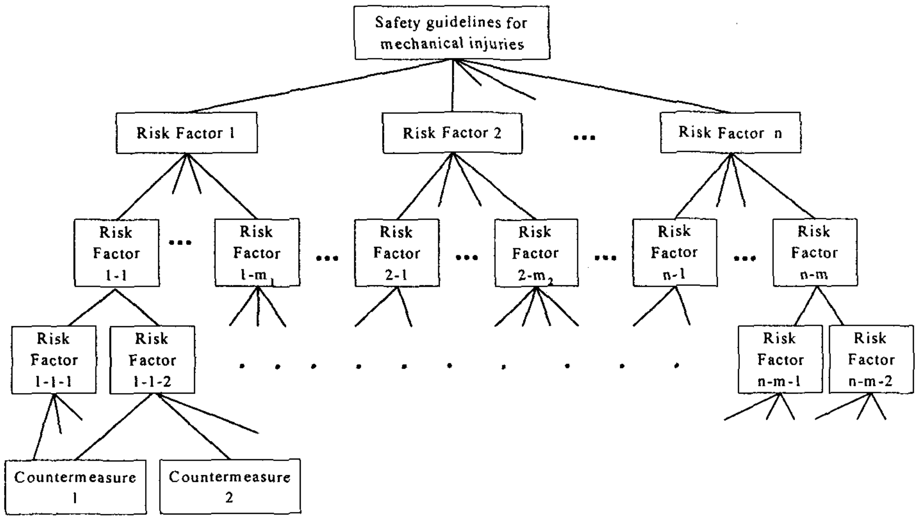

Figure 1. AHP structure of safety guidelines for mechanical injuries

Table 3. Human-related risk factors and their countermeasures

2nd Level Risk Factor	3rd Level Risk Factor	Possible Countermeasures
Psychological factor	Preoccupation during the task	Employment training and counseling
		Work hazard awareness program
	Unconscious misjudgment	Work hazard awareness program
	Intentional task omission	Task standardization
		Emphasis on the safety over productivity
		Work hazard awareness program
	Monotonous task and boredom	Periodic change of task schedule
		Task posture change
		Work hazard awareness program
Physiological factor	Fatigue	Suitable resting break
		Education of right task posture
	Worker' s health level	Regular health inspection
		Allocating flexible workload according to the health state
Organizational factor	Physical defect	Usage of supporting tools
	Labor relations	Encouragement of social activity
	Absence of suitable communication	Labor-management meeting and inter-employee meeting

Table 4. Machine-related risk factors and their countermeasures

2nd Level Risk Factor	3rd Level Risk Factor	Possible Countermeasures
Defect of machine and equipment	Improper structure of machine and equipment	Improve the structure of machine and equipment
		Introduce recall system
		Install safety device
		Use officially approved machine and equipment
		Recommend manufacturer to add safety device to machine at the design stage
	Improper control panel	Improve the design of control panel
		Introduce recall system
		Use officially approved machine and equipment
	Machine trouble	Improve inspection of machine and equipment
		Introduce recall system
		Use officially approved machine and equipment
		Subsidized fund for the replacement of old machine
	Not using proper manual tools	Provide proper manual tools and tool selection guidance
	Lack of safety devices	Add proper safety device to machine
		Financial support for the replacement of old machine
		Recommend manufacturer to add safety device to machine at the design stage
Lack of machine and equipment automation	Absence of automatic material handling system	Financial support for the automation
		Automation of material handling system
		Educate cautious material handling
	Lack of mechanical task automation	Automation of mechanical task
		Financial support for the automation
Lack of protective equipment	Defect of protective equipment and clothing	Improve inspection of protective equipment and clothing
		Use officially approved protective equipment and clothing
	Absence of protective equipment and clothing	Provide protective equipment and clothing
	Not wearing protective equipment because of inconvenience	More strict regulation on protective equipment
		Improve work skill with protective equipment through the training
Facilities layout problem	Improper storage area	Adjust facilities layout to obtain suitable storage area
	Insufficient working and moving space	Adjust facilities layout to obtain sufficient working and moving space
Inspection and maintenance problem	Improper maintenance of manual tools	Improve inspection of manual tools
	Lack of protective equipment inspection	Improve inspection of protective equipment
	Lack of machine and equipment inspection	Improve inspection of machine and equipment
	Lack of safety device inspection	Improve inspection of safety device

Table 5. Task-related risk factors and their countermeasures

2nd Level Risk Factor	3rd Level Risk Factor	Possible Countermeasures
Inappropriate posture	Carelessness caused by monotonous task	Allocate task to avoid task boredom
		Designate the worker-in-charge of the task
		Schedule change to avoid boredom
	Not following the power-off rule	Regulate workers to execute certain task after powering off
		Develop a device for power safety
		Make the power-off easy
	Frequent access to the hazardous operation area	Install proper machine guarding
		Prescribe correct task procedure and method
		Automation of material feeding and extraction
		Regulate worker to use manual tool for removing chips and scraps
	Usage of excessive force	Use proper machine or manual tool
Excessive workload	Increased workload due to unbalanced line	Execute line balancing
		Automation of bottleneck operation
	Increased workload due to excessive order	Use temporary employees
		Automation of machine and equipment
		Utilize proper work shift system
Improper work environment	Noise	Use protective equipment
		Isolate machine and equipment
		Install barriers
	Improper illumination	Install suitable lighting
		Install improved wall painting
	Improper ventilation	Install ventilator to proper location
		Regulate worker to wear protective equipment
	Improper temperature	Install localized temperature control switch
	Hazard of fire and electric shock	Assign safety manager to hazardous machine
		Regular inspection of hazardous machine
		Prepare electrical safety device
	Improper housekeeping	Promote 5S campaign
		Assign regular time for workplace cleaning

Table 6. Management-related risk factors and their countermeasures

2nd Level Risk Factor	3rd Level Risk Factor	Possible Countermeasures
Absence of safety management	Absence of safety management organization and regulation	Construct safety management system and constitute safety management regulation
	Lack of safety education	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment
		Execute regular safety education for owner and manager
		Educate workers by safety professional
Defect of personnel management	Allocation of employee without considering their aptitude	Allocate jobs to employee' s aptitude
		Allocate new employee after compulsory legal education
	Absence of health management system	Execute regular health inspection for employee
	Lack of supervision for following employee	Execute regular safety education for owner, manager and director
		Regular meeting between supervisors and workers

As shown in the tables, there are 4 risk factors(human-related, machine-related, task-related, management-related) in the 1st level, 13 risk factors in the 2nd level, 42 risk factors in the 3rd level, and 86 specific alternatives(countermeasures) at the 4th level. The countermeasures are designed by the survey of 62 safety managers and safety consultants. The total number of countermeasures is 86 although same countermeasures can be related to many risk factors.

3. Results

As shown in Tables 3, 4, 5, 6, the third level risk factor and the countermeasures could be related through hierarchical structures and their relative weightings. Using the hierarchical structures developed, a computerized questionnaire format was programmed by Visaul Basic 4.0 with Access as the database tool. In the questionnaire, the respondents were asked to compare the relative importance of each pair of risk factors in the second, third, and fourth levels respectively. They were also asked to compare the relative importance of the countermeasures for each risk factors. All of the procedures and calculations were processed using the AHP software developed for this survey. Figure 2 showed a sample screen of the software that represented pairwise comparisons among the second level risk factors. A total of 62 safety consultants and plant managers weighted each matrix of the Figure 1 using the distributed software. Each data from a respondent was stored and revised to get the group result.

The finalized result of the relative weights on the risk factors and the countermeasures evaluated by the safety managers and consultants are shown in Table 7.

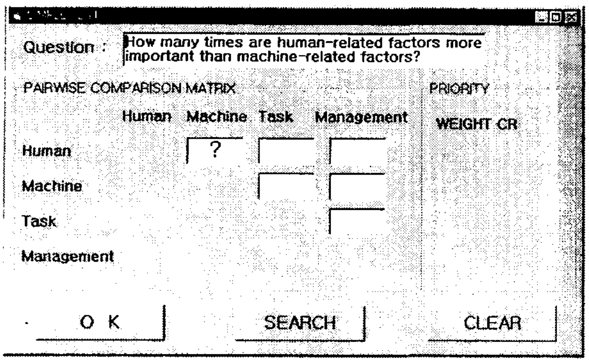

Figure 2. SIMPLE TEST : Pairwise Comparison

Table 7. Weight of alternatives(countermeasures) with respect to the 3rd level risk factors

3rd Level Risk Factor	Possible Counter Measure	Weight
1. Preoccupation during the task	Employment training and counseling	0.639
	Work hazard awareness program	1.000
2. Unconscious misjudgment	Work hazard awareness program	1.000
3. Intentional task omission	Task standardization	0.711
	Emphasis on the safety over productivity	0.921
	Work hazard awareness program	1.000
4. Monotonous task and boredom	Periodic change of task schedule	0.667
	Task posture change	1.000
	Work hazard awareness program	0.417
5. Fatigue	Suitable resting break	1.000
	Education of right task posture	0.852
6. Worker' s health level	Regular health inspection	1.000
	Allocating flexible workload according to the health state	0.923
7. Physical defect	Usage of supporting tools	1.000
8. Labor relations	Encouragement of social activity	1.000
9. Absence of suitable communication	Labor-management meeting and inter-employee meeting	1.000
10. Improper structure of machine and equipment	Improve the structure of machine and equipment	0.600
	Introduce recall system	0.300
	Install safety device	0.767
	Use officially approved machine and equipment	0.667
	Recommend manufacturer to add safety device to machine at the design stage	1.000
11. Improper control panel	Improve the design of control panel	0.976
	Introduce recall system	0.463
	Use officially approved machine and equipment	1.000
12. Machine trouble	Improve inspection of machine and equipment	1.000
	Introduce recall system	1.447
	Use officially approved machine and equipment	0.500
	Subsidized fund for the replacement of old machine	0.684
13. Not using proper manual tools	Provide proper manual tools and tool selection guidance	1.000
14. Lack of safety devices	Add proper safety device to machine	0.528
	Financial support for the replacement of old machine	0.340
	Recommend manufacturer to add safety device to machine at the design stage	1.000

15. Absence of automatic material handling system	Financial support for the automation	1.000
	Automation of material handling system	0.605
	Educate cautious material handling	0.721
16. Lack of mechanical task automation	Automation of mechanical task	1.000
	Financial support for the automation	0.683
17. Defect of protective equipment and clothing	Improve inspection of protective equipment and clothing	0.923
	Use officially approved protective equipment and clothing	1.000
18. Absence of protective equipment and clothing	Provide protective equipment and clothing	1.000
19. Not wearing protective equipment because of inconvenience	More strict regulation on protective equipment	1.000
	Improve work skill with protective equipment through the training	0.852
20. Improper storage area	Adjust facilities layout to obtain suitable storage area	1.000
21. Insufficient working and moving space	Adjust facilities layout to obtain sufficient working and moving space	1.000
22. Improper maintenance of manual tools	Improve inspection of manual tools	1.000
23. Lack of protective equipment inspection	Improve inspection of protective equipment	1.000
24. Lack of machine and equipment inspection	Improve inspection of machine and equipment	1.000
25. Lack of safety device inspection	Improve inspection of safety device	1.000
26. Carelessness caused by monotonous task	Allocate task to avoid task boredom	1.000
	Designate the worker in-charge for the task	0.769
	Schedule change to avoid boredom	0.769
27. Not following the power-off rule	Regulate workers to execute certain task after powering off	1.000
	Develop a device for power safety	0.574
	Make the power off easy	0.574
28. Frequent access to the hazardous operation area	Install proper machine guarding	0.614
	Prescribe correct task procedure and method	0.386
	Automation of material feeding and extraction	1.000
	Regulate worker to use manual tool for removing chips and scraps	0.273
29. Usage of excessive force	Use proper machine or manual tool	1.000
30. Increased workload due to unbalanced line	Execute line balancing	1.000
	Automation of bottleneck operation	0.556
31. Increased workload due to excessive order	Use temporary employees	0.213
	Automation of machine and equipment	1.000
	Utilize proper work shift system	0.426

32. Noise	Use protective equipment	0.245
	Isolate machine and equipment	1.000
	Install barriers	0.330
33. Noise	Install suitable lighting	1.000
	Install improved wall painting	0.563
34. Improper ventilation	Install ventilator to proper location	1.000
	Regulate worker to wear protective equipment	0.205
35. Improper temperature	Install localized temperature control switch	1.000
36. Hazard of fire and electric shock	Assign safety manager to hazardous machine	0.327
	Regular inspection of hazardous machine	0.615
	Prepare electrical safety device	1.000
37. Improper housekeeping	Promote 5S campaign	1.000
	Assign regular time for workplace cleaning	0.712
38. Absence of safety management organization and regulation	Construct safety management system and constitute safety management regulation	1.000
39. Lack of safety education	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	1.000
	Execute regular safety education for owner and manager	0.730
	Educate workers by safety professional	0.973
40. Allocation of employee without considering their aptitude	Allocate jobs to employee's aptitude	1.000
	Allocate new employee after compulsory legal education	0.613
41. Absence of health management system	Execute regular health inspection for employee	1.000
42. Lack of supervision for following employee	Execute regular safety education for owner, manager and director	0.961
	Regular meeting between supervisors and workers	1.000

Using the revised weights and the computerized AHP software, 21 industries were selected and re-visited. Since all the procedures of the AHP were computerized and distributed as a software, self-recorded result of the weighting matrix was collected and combined automatically.

As examples, Tables 8, 9, and 10 show the result for four companies in the sample. Each company has run their own AHP program and reported the combined result of the decision. Table 8 shows the highest-level risk factor weightings and table 9 shows the lowest level factor weightings for each company. Table 10 shows the top 5 countermeasures for each company.

Table 8. Top priorities in the 2nd level risk factors

Company	Order	2nd Level Risk Factor	Weight
A	1	Human	0.61
	2	Machine	0.23
	3	Task	0.11
	4	Management	0.05
D	1	Management	0.67
	2	Task	0.19
	3	Human	0.11
	4	Machine	0.03
G	1	Task	0.45
	2	Management	0.35
	3	Human	0.10
	4	Machine	0.10
K	1	Machine	0.41
	2	Task	0.41
	3	Management	0.11
	4	Human	0.06

Table 9. Top priorities in the 3rd level risk factors

Company	Order	3rd Level Risk Factor	Weight
A	1	Preoccupation during the task	0.201
	2	Unconscious misjudgment	0.134
	3	Fatigue	0.100
	4	Carelessness caused by monotonous task	0.081
	5	Absence of safety management organization and regulation	0.068
D	1	Lack of safety education	0.489
	2	Absence of safety management organization and regulation	0.098
	3	Lack of supervision for following employee	0.057
	4	Improper housekeeping	0.048
	5	Labor relations	0.039
G	1	Increased workload due to unbalanced line	0.197
	2	Absence of safety management organization and regulation	0.087
	3	Lack of safety education	0.087
	4	Allocation of employee without considering their aptitude	0.087
	5	Increased workload due to excessive order	0.066
K	1	Increased workload due to unbalanced line	0.250
	2	Lack of machine and equipment inspection	0.133
	3	Lack of safety education	0.079
	4	Improper structure of machine and equipment	0.059
	5	Increased workload due to excessive order	0.050

Table 10. Top 5 countermeasures for four representative companies

Company	Order	Countermeasure	Weight
A	1	Work hazard awareness program	0.425
	2	Employment training and counseling	0.129
	3	Suitable resting break	0.100
	4	Education of right task posture	0.085
	5	Allocate task to avoid task boredom	0.081
D	1	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	0.489
	2	Educate workers by safety professional	0.476
	3	Execute regular safety education for owner and manager	0.412
	4	Construct safety management system and constitute safety management regulation	0.098
	5	Labor-management meeting and inter employee meeting	0.063
G	1	Execute line balancing	0.197
	2	Automation of bottleneck operation	0.109
	3	Execute regular safety education for owner and manager	0.105
	4	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	0.087
	5	Construct safety management system and constitute safety management regulation	0.087
K	1	Execute line balancing	0.250
	2	Improve inspection of machine and equipment	0.162
	3	Automation of bottleneck operation	0.139
	4	Automation of mechanical task	0.093
	5	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	0.079

Although omitted due to space limitation, a total of 14 companies (66.7%) picked Human-Related risk factors as the most important factors. Based on the prioritized weights of the risk factors, the companies could be clustered on their risk factor characteristics and customized safety programs focusing on the characteristics of each company could be suggested and planned. In this study, as an example, the 21 companies participated in the survey were clustered by their risk factor characteristics such as Human-Related, Machine-Related, Task-Related, Management-Related. Top 10 risk Factors and weights for each cluster of companies are listed in Tables 11, 12, 13, and 14 respectively. Top 10 countermeasures for each cluster of companies are listed in Tables 15, 16, 17, and 18.

Table 11. Top 10 risk factors and their weights (Human-related)

Order	Risk Factor	Weight
1	Preoccupation during the task	0.152
2	Labor relations	0.149
3	Absence of suitable communication	0.076
4	Monotonous task and boredom	0.070
5	Unconscious misjudgment	0.059
6	Intentional task omission	0.052
7	Lack of safety education	0.050
8	Absence of safety management organization and regulation	0.043
9	Fatigue	0.039
10	Increased workload due to unbalanced line	0.025

Table 12. Top 10 risk factors and their weights (Machine-related)

Order	Risk Factor	Weight
1	Lack of mechanical task automation	0.147
2	Lack of safety device inspection	0.094
3	Lack of machine and equipment inspection	0.087
4	Increased workload due to unbalanced line	0.084
5	Lack of safety education	0.044
6	Frequent access to the hazardous operation area	0.043
7	Machine trouble	0.040
8	Labor relations	0.039
9	Improper structure of machine and equipment	0.034
9	Preoccupation during the task	0.034

Table 13. Top 10 risk factors and their weights (Task-related)

Order	Risk Factor	Weight
1	Increased workload due to unbalanced line	0.160
2	Lack of safety education	0.087
3	Labor relations	0.068
4	Frequent access to the hazardous operation area	0.048
4	Usage of excessive force	0.048
6	Increased workload due to excessive order	0.046
7	Improper structure of machine and equipment	0.040
8	Absence of safety management organization and regulation	0.038
9	Lack of mechanical task automation	0.036
10	Lack of machine and equipment inspection	0.035

Table 14. Top 10 risk factors and their weights (Management-related)

Order	Risk Factor	Weight
1	Lack of safety education	0.432
2	Absence of safety management organization and regulation	0065
3	Labor relations	0.051
4	Allocation of employee without considering their aptitude	0.047
5	Hazard of fire and electric shock	0.045
6	Improper housekeeping	0.037
7	Lack of supervision for following employee	0.035
8	Improper ventilation	0.033
9	Intentional task omission	0.030
10	Increased workload due to unbalanced line	0.024

Table 15. Top 10 countermeasures and their weights (Human-related)

Order	Counter Measures	Weight
1	Work hazard awareness program	0.333
2	Encouragement of social activity	0.149
3	Employment training and counseling	0.097
4	Labor-management meeting and inter-employee meeting	0.090
5	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	0.050
6	Execute regular safety education for owner and manager	0.049
7	Educate workers by safety professional	0.048
7	Emphasis on the safety over productivity	0.048
9	Periodic change of task schedule	0.047
10	Construct safety management system and constitute safety management regulation	0.043

Table 16. Top 10 countermeasures and their weights (Machine-related)

Order	Counter Measures	Weight
1	Automation of mechanical task	0.169
2	Improve inspection of machine and equipment	0.127
3	Give a subsidy for machine automation	0.100
4	Improve inspection of safety device	0.094
5	Execute line balancing	0.084
6	Work hazard awareness program	0.058
7	Execute regular safety education for owner and manager	0.052
8	Recommend manufacturer to add safety device to machine at the design stage	0.051
8	Use officially approved machine and equipment	0.051
10	Automation of bottleneck operation	0.047

Table 17. Top 10 countermeasures and their weights (Task-related)

Order	Counter Measures	Weight
1	Execute line balancing	0.160
2	Automation of bottleneck operation	0.089
3	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	0.087
4	Educate workers by safety professional	0.084
5	Automation of mechanical task	0.082
5	Execute regular safety education for owner and manager	0.082
7	Encouragement of social activity	0.068
8	Improve inspection of machine and equipment	0.058
9	Use officially approved machine and equipment	0.054
9	Recommend manufacturer to add safety device to machine at the design stage	0.054

Table 18. Top 10 countermeasures and their weights (Management-related)

Order	Counter Measures	Weight
1	Execute safety education after employing new worker, changing work contents, introducing new safety device and installing new machine and equipment	0.432
2	Educate workers by safety professional	0.420
3	Execute regular safety education for owner and manager	0.394
4	Work hazard awareness program	0.066
5	Construct safety management system and constitute safety management regulation	0.065
6	Encouragement of social activity	0.051
7	Allocate jobs to employee' s aptitude	0.047
8	Prepare safety device for prevention of fire and electric shock	0.045
9	Regular meeting between supervisors and workers	0.042
10	Promote 5S campaign	0.037

4. Conclusion

Management and guidance of safety management concerns in SMIs have mainly relied on the consultants experience in the past. Opinions of the managers at the plant site and also of the workers were often ignored and not counted as important. The approach adopted by this study showed that the voice of the employees at the plant site could be integrated systematically into the safety management program using the group decision-making tool such as AHP. Based on the result of AHP analysis, customized risk factor identification and design of countermeasures were made possible. For the companies clustered as human-related priority, safety education programs, small-group activity, counseling program, and job rotation design were recommended. For the companies emphasizing management-related factors, installation of the programs such as self-motivated, self-ruled safety program, TPM(Total Productivity Management), and QM(Quality Management) were suggested. For the companies with "task-related priority", time and motion study, machine/equipment layout, periodic survey of the work and workplace were suggested. And finally for the machine-related priority group, safety devices facilitation and ultimate automation of safety device were recommended. Detailed action plans to take could be planned in all cases by the result of the AHP as shown in Tables 8 through 12.

Use of AHP in the self-guided safety planning shows promising results and the companies participated in the survey are preparing their own customized safety plan. The safety review by the government is also planning to use AHP process extensively. Group decision making tool to self-record and evaluate the safety program initiated by the plant site managers and worker seems to be an effective tool with the positive review of the first attempt to establish a self-guided safety management program in the SMIs.

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