Objectives: Authors investigated the pattern of the rate of occupational injuries and illnesses (ROII) at the level of enterprises in order to build a network for exchange of experience and knowledge, which would contribute to workers’ safety and health through safety climate of workplace.

Methods: Occupational accidents were analyzed at the manufacturing work site unit. A two step clustering process for the past patterns regarding the ROII from 2001 to 2009 was investigated. The ROII patterns were categorized based on regression analysis and the patterns were further divided according to the subtle changes with Mahalanobis distance and Ward’s linkage.

Results: The first clustering of ROII through regression analysis showed 5 different functions: 29 work sites of the linear function, 50 sites of the quadratic function, 95 sites of the logarithm function, 62 sites of the exponential function, and 54 sites of the sine function. Fourteen clusters were created in the second clustering. There were 3 clusters in each function categorized in the first clustering except for sine function. Each cluster consisted of the work sites with similar ROII patterns, which had unique characteristics.

Conclusion: The five different patterns of ROII suggest that tailored management activities should be applied to every work site. Based on these differences, the authors selected exemplary work sites and built a network to help the work sites to share information on safety climate and accident prevention measures. The causes of different patterns of ROII, building network and evaluation of this management model should be evaluated as future researches.

Key Words: Safety culture, Occupational injuries and illnesses, Network, Clustering

Introduction

Since 1975, Korea has kept track of the rate of occupational injuries and illnesses (ROII) as an indicator for workers’ safety and health. The ROII steadily fell from 4.39% in 1975 to 0.77% in 2001 and to 0.70% in 2009. As of 2009, out of 13,884,927 workers nationwide, 97,821 have become victims to workplace accidents and diseases, leading to 2,181 deaths. In particular, 34% of the injuries and illnesses (32,997 workers) belonged to the manufacturing industries.

The Korean economy has currently been moving from manufacturing to the services industry as part of the de-industrialization process. This trend requires reforming the policies for the sake of workers’ safety and health. However, due to the rise in the services sector, manufacturing workers’ safety and health possibly fails to receive due attention. Moreover, the workers are always under pressure to improve productivity and quality. This mental burden causes the workers to ignore safety rules and regulations, thus exposing them to high workplace risk [1].

Traditional measures to prevent occupational injuries and illnesses separately analyzed people, technology, and the work context by means of focusing on sociological, technological,
or organizational approach [2]. However, these traditional measures have clear limitations in responding to the continuously changing work conditions [3]. Against this backdrop, various alternatives such as Health and Safety Management Best Practices [4,5], Safety Improvement Projects [6-8], and Risk Management System [9] have been presented. In addition, a number of researchers are delivering studies on safety culture and safety climate, though their clear definitions are yet to be determined [10,11]. Safety culture refers to workers’ belief in safety, while safety climate means a sum of mindsets among workers about safety. If the safety climate is shared, the ROII can be lowered. A previous study found that as two manufacturing sites exchanged safety knowledge, their safety climates improved, with subsequent fall in the ROII [12]. Most of the theories on accident occurrence focus primarily on environmental factors and work conditions [13]. However, a number of empirical researches point a finger at flawed machinery or unfavorable behaviors by workers as the main reasons behind accidents, placing priority on indirect factors like physical work environments and unsafe work behaviors. Sound safety culture plays a key role in removing both direct and indirect factors causing occupational accidents. The presumed effect of safety climate on workplace injuries has often been examined in studies that related an assessment of safety climate to injuries that occurred prior to that assessment time. But there are important theoretical differences between the safety climate → injury and injury → safety climate conceptualization [14].

There are several factors, which positively contribute to safety culture including values, concepts, attitudes, and safe behaviors shared by workers, policies to reduce work risk and their execution. Worksites can upgrade their organizations and safety culture through policies, incentives for the workers, continuous training, fluid information about the risks, preventive planning, emergency planning, internal control, and benchmarking techniques. Workers’ perspectives on safety culture are interdependent, and not isolated [15]. Safety climate suggests a temporary assessment on safety culture by finding shared concepts among the workers within the organization [16]. Therefore, depending on the current environments or other main factors, safety climate can easily be changed [17]. In the meantime, safety culture barely changes since it is voluntarily built by the organization. Since safety behaviors within the organization are determined by unified mechanisms for human relations, communication, role playing, imitation, and indications [18], communications and exchanges among organizations are necessary to build safety culture.

This study focused on a network among worksites for safety climate improvement and prevention of injuries and illnesses. To build this network, it is necessary to sort the worksites with similar ROII patterns into each group. However, there has been lack of the standards to categorize the ROII patterns. Therefore, it would require excessive amounts of time and cost to build a model for ROII similarity. In this context, this study clustered worksites, which presented similarity in ROII patterns in the past. The authors wished to determine whether the database obtained by analyzing each cluster and its characteristics would contribute to safety culture and prevention of injuries and illnesses at work place.

**Materials and Methods**

**Data collection**

The Korea Occupational Safety and Health Agency runs the databases on worksites nationwide and occupational injuries...
Among those having bought the insurance, the manufacturing sector accounted for 16% (257,686) in 2009. Currently, the rate of injuries and illnesses at work has been stagnant at the 0.7% level. Therefore, it is assumed that large-sized workplaces should play a key role in further lowering the rate. Against this backdrop, this study targeted manufacturing sites with 300 or more employees with the ROI as an object variable. The data preprocessing showed that 295 worksites continuously operated from 2001 to 2009, maintaining the same workplace management numbers (Table 1).
Data analysis model

Pattern fitting for the ROI and clustering step 1

The 295 manufacturing sites surveyed took different patterns in the ROIIs from 2001 to 2009. Through the clustering step 1, the worksites were divided according to ROI patterns. In order to identify minimum commonalities, the overall trend had to be understood. To this end, various regression analyses were delivered. The ROI (y) consisted of the model estimation (c) and the error term (ε), which could not be explained by the models. To sort out the model with minimum ε, the patterns were demonstrated by a linear function, a quadratic function, a logarithm function, and a sine function, as presented in Fig. 1 [19]. The author chose the one with maximum F statistics regarding the function, depending on the coefficients - α, β, and γ as variations for the five functions.

In the linear function, the worksites were categorized by α and β. The α signaled the ROI rate in the past. When β was positive, the ROI was on the rise. In this context, the negative β indicated the falling ROI. In the quadratic function, the positive γ meant the rising ROI after the fall, while the negative referred to the drop after the rise. In the logarithm function, the worksites with the positive β witnessed the increasing ROI, but the rising rate was slowing down. Meanwhile, those with the negative β showed the falling ROI, but the decreasing rate was also slowing down. In the exponential function, the ROI in the worksites with the positive β recently went up more rapidly after the steady rise. Moreover, the rate in the worksites with the negative β recently fell more sharply after the gradual decrease.

Hence, the ROIIs in each regression analysis were different, depending on the coefficients - α, β, and γ. Therefore, this study conducted a cluster analysis to estimate more consistent ROI patterns by setting α, β, and γ as variations for the five functions.

In this case, it was important to remember that β, which signaled the ups and downs of ROI, had very different meanings whether it was positive or negative, although the β absolute values near zero were categorized into a single cluster. To address this issue, β was converted into the values from the equation (1) through the sigmoid function, which maximizes gaps among the values around a certain point while reducing the gaps among the values above the point by converting the values into an S shape.

\[ x' = \frac{a}{1 + e^{-\frac{\beta}{\gamma}}} + d \]  

(1)

In the equation above, a and b refer to the area of the sigmoid function and the shape, respectively with location-related coefficients, c and d. When a was set at 2, b at 0, c at 0.01, and d at -1, the previously mentioned issue of the cluster analyses was resolved [20].

Clustering step 2

Clustering step 2 aimed to understand the density of the clusters consisting of N worksites in the P dimension built by parameter coefficients, which had been estimated by the pattern fitting analysis. Based on the cluster types and the similarity measurements, there exists several methods. When the distance between the objects is long, similarity increases. This measurement is usually conducted by Euclidean distance, Minkowski distance, Mahalanobis distance, Canberra distance, and Czekanowski distance [21]. However, Euclidean distance and Minkowski distance do not have scale invariance. To solve this

| Year | Worksites | Workers | Injuries and illnesses | ROI (%) | ROI deviation (%) |
|------|-----------|---------|------------------------|---------|------------------|
| 2001 | 295       | 435,247 | 2,781                  | 0.64    | 28               |
| 2002 | 295       | 448,474 | 3,538                  | 0.79    | 37               |
| 2003 | 295       | 428,930 | 4,906                  | 1.14    | 68               |
| 2004 | 295       | 444,409 | 5,338                  | 1.20    | 66               |
| 2005 | 295       | 455,322 | 3,866                  | 0.85    | 44               |
| 2006 | 295       | 436,312 | 3,055                  | 0.70    | 36               |
| 2007 | 295       | 442,902 | 2,764                  | 0.62    | 32               |
| 2008 | 295       | 409,975 | 2,888                  | 0.70    | 62               |
| 2009 | 295       | 440,986 | 2,154                  | 0.49    | 29               |

ROI: rate of occupational injuries and illnesses.
issue, standardization can be applied by dividing variations by standard deviations and removing measurement units. Application of Mahalanobis distance [equation (2)] can also provide a solution by considering causalities among variations.

\[ D_{MH} = \|x_r - x_k\| = (x_r - x_k)^T S^{-1} (x_r - x_k) \]  \hspace{1cm} (2)

Based on the distance matrix-D estimated by Mahalanobis distance, the worksites were clustered by merging and dividing. There are several methods for clustering, such as single linkage, complete linkage, average linkage, median linkage, centroid linkage, and ward's linkage. The single linkage is convenient to pick isolated clusters, requiring relatively short time for calculations. The complete linkage focuses on cluster density. Ward’s linkage minimizes information losses caused by clustering objects. Since the number of objects (worksites) was relatively low, this study chose wards' linkage.

![Fig. 2. Results of the first step clustering through regression fitting.](https://www.e-shaw.org)
Results

ROI analysis on manufacturing sites with 300 or more workers

The analysis on manufacturing sites with 300 or more workers revealed that the ROI had climbed by 2003. Since then, the rate has steadily dropped, posting 0.49% in 2009. Meanwhile, the entire manufacturing industry recorded a whopping 1.04% in 2009. Therefore, it is assumed that small-sized manufacturing sites are responsible for the majority of injuries and illnesses.

When the number of workers at each individual worksite was designated as weighted values, the ROI deviations were very high, posting 68% in 2003 and 62% in 2008. This means

Fig. 3. Results of ROI pattern classification through the 2nd step clustering.
that businesses have significantly high gaps in terms of capability of preventing occupational injuries and illnesses (Table 2).

**ROII pattern clustering**

As a result of the first step clustering through the regression analysis, 29 worksites were assigned to the linear function, with 50 to the quadratic function, 95 to the logarithm function, 62 to the exponential function, and 54 to the sine function. Those at which injuries or illnesses had rarely occurred from 2001 to 2009 were classified separately. Fig. 2 shows the regression coefficients converted by the sigmoidal function.

Fig. 2 presents the results from the cluster analyses on the worksites classified by the ROII patterns in the first step clustering in accordance with the five functions. In doing so, the ROII patterns at each cluster were drawn to understand their characteristics. In the linear function, among three clusters, Cluster 1 had a rising ROII, with Cluster 2 having a dropping rate. Cluster 3 demonstrated an extremely low ROII, which was still falling. In the quadratic function, Cluster 1 showed the rising pattern after the fall, while the ROII in Cluster 2 dropped after the climb. Cluster 3 also demonstrated the decrease after the increase, and the fluctuation was significant. In the logarithm function, Cluster 1 recorded a very low ROII, which was still dropping. In Cluster 2, the rate was high, but dipping. The ROII in Cluster 3 was low, but rising. In the exponential function, Clusters 1 and 2 had declining ROII, while Cluster 3 presented a rising trend. The sine function had wide-range fluctuations on an annual basis, thus making it difficult to identify the consistent trend.

In the step 2 cluster analysis, 14 clusters with similar ROII patterns were created. Fig. 3 presents the relations between the falling rate of injuries and illnesses and the ROII. The worksites, at which injuries or illnesses had not or rarely occurred, were considered as leaders in accident prevention. Since these leading businesses have secured various prevention measures and sound workplace culture, those in the other clusters should benchmark them. In addition, it is necessary to build a network for workplaces to exchange information on prevention of inju-

![Diagram](https://www.e-shaw.org)

**Fig. 4. Safety culture network for accident prevention.**
ries and illnesses. Companies are profit groups, participating in the race of harsh competition. However, in terms of promoting workers’ safety and health, businesses should pursue co-existence and partnership, refraining from competition.

Cluster 3 in the linear function showed a relatively low ROI, which was still declining. Therefore, the worksites in this cluster should share information on prevention of illnesses and injuries with those in Cluster 2 in the linear function and those in Cluster 1 of the exponential function which had a dropping, but still high ROI.

Clusters 2 and 3 in the quadratic function demonstrated a falling ROI trend after the past climb. It is assumed that they had identified the risk factors and prepared sound prevention measures. In this context, it is recommended that these workplaces provide information to those in Cluster 1 in the quadratic function, of which ROI recently rose after the past fall, and those in the sine function, which showed wide fluctuations without clear ROI trends. By understanding these ROI patterns in each cluster and their characteristics, the network for prevention of occupational illnesses and injuries can be forged (Fig. 4).

**Discussion**

This study surveyed manufacturing sites with an aim to build a network for exchange of safety knowledge, which would contribute to workers’ safety and health and safety climate. The authors formed clusters according to the worksites’ sizes and business types to facilitate the exchange of safety knowledge. However, the worksites showed different ROI patterns even within the same clusters. Therefore, in addition to the businesses types and sizes, other factors should be considered including companies safety policies, leadership of senior manager, the attitudes of safety managers, education programs for workers, and solutions for workplace risk factors in order to accurately determine the safety statuses in each worksite. However, it is far from time- and cost-effective if all these factors are investigated into. Therefore, on the assumption that the ROI is a comprehensive indicator resulting from all the previously mentioned safety-related factors, the authors divided the worksites into the clusters with similar ROI patterns.

The worksites were separated according to the five functions, and then categorized into ROI patterns, thus creating 14 clusters. It was found that each cluster had unique characteristics regarding ROI patterns. Based on these differences, the authors selected exemplary worksites and built a network to help the worksites to share information on safety climate and accident prevention measures. The network for safety knowledge will lead to collective intelligence - which makes better value judgments by a group of laymen than those by one or two experts - for safety climate among workers [22]. Workplace conditions and safety climate can be dramatically improved with the help of workers’ intelligence. To this end, a proper network should be in place for efficient exchange of information on health and safety, since this network promotes cooperative relations among similar worksites and helps to benchmark exemplary workplaces. Especially, safety managers and senior managers can play the key important role in sharing experience among worksite and delivering the exchanged information to workers. Typically, businesses are profit-driven. However, workers’ safety and health should not be viewed from the perspectives of profits, but from those of the public good. Only when safety and good health among workers are secured, can labor force be supplied to the economy on a stable basis.

Authors suggest the necessity of future validation researches on clustering based on ROI using relative criteria or external criteria. Some action demonstration program applied to sampled worksites in future will confirm validation clustering, efficiency and effectiveness of networking among worksites for workers’ safety and health by developing safety climate.

**Conflict of Interest**

No potential conflict of interest relevant to this article was reported.

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