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Developing Concentration Index of Industrial and Occupational Accidents: The Case of European Countries

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ABSTRACT

Background: From only frequency rate of industrial accidents, it is difficult to define the industry composition of accident statistics in a nation. This study aims to propose and develop a new index for measuring the degree of concentration of industrial accidents using the concept of the *Herfindahl-Hirschman Index* in the case of European countries.

Methods: Using the concept of the *Herfindahl-Hirschman Index*, the concentration index of accidents in the country is developed, and the conditions of European countries are compared using indexes of frequency rate and concentration ratio.

Results: The frequency rate and concentration ratio of fatal and nonfatal accidents in European countries are compared. According to the economic condition and geographical position, different patterns of accidents concentration are presented in terms of frequency rate and concentration ratio.

Conclusion: We develop the concentration index of industrial and occupational accidents that identifies the industrial ratio of accident occurrence, and the differentiated strategy can be formulated such as approaches to reducing frequency and prioritizing target industries.

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1. Introduction

Measuring the occupational injuries for analyzing safety and health at work has been recognized as a precondition for managing occupational accidents [1]. The World Health Organization has focused on increasing the importance of occupational health and safety to ensure that workers can safely adapt to their work [2]. Above all, countries should annually survey the descriptive statistics of accidents for monitoring the health and safety level at work in the industry [3]. The descriptive statistics include time lost, frequency of injury, and the number of deaths caused by accidents and disasters [4]. The International Labour Organization (ILO) provides the key indicators of safety and health at work through statistics such as time lost, fatal and nonfatal injuries, and labor inspection through a web site, collected from major countries [5]. Most countries also individually survey the statistics for occupational safety and health management.

These data have usually been used to measure the degree of seriousness of industrial accidents by measuring the frequency of occupational injuries and their severity, which is measured using

time lost due to the accidents [3,6]. Because construction sites, chemical plants, and service areas are prone to accidents, there is an increasing concern for occupational safety and health management in the construction, chemical, and service industries [7]. Many global and national institutes publish disaster statistics for frequency of accidents and time lost as a measure for mitigating and preventing occupational accidents and disasters [8,9]. After monitoring the patterns and trends of health and safety statistics in industries, responsible agencies and institutes such as ILO, Occupational Safety and Health Administration (OSHA), and Health and Safety Executive have taken the decision to manage industrial conditions to reduce hazards and accidents.

However, almost all countries have focused only on the number of accidents in industry. Although frequencies of occupational injuries are similar with the countries, the component ratio of the occupational injuries of countries at the individual industry level can be different. For example, assume that each of the three industries in Country A has 20 accidents while the three industries in Country B have 5, 5, and 50 accidents, respectively. In this case, the total frequency for Country A and B is 60 accidents, but Country B

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has an industry that is more dangerous compared to Country A. The overall index indicates that the nations are managing the safety issues well, but the risk of specific industries, which exhibit chronically unsafe behavior and conditions, has deteriorated. According to similar concept of Pareto and root-cause analysis for safety management, it is more important to identify and prioritize the hazardous industries or firms to be controlled [10–12]. Thus, examining the concentration of accidents with respect to a specific industry could have a more significant meaning for accident management, rather than doing the overall frequency and severity of accidents of industries. When accidents are concentrated in a particular industry, that industry should be managed with increased focus.

Thus, this study aims to propose and develop a new index for measuring the degree of concentration of industrial accidents. For this, we apply the *Herfindahl-Hirschman Index* (HHI), one of the indexes for measuring concentration and industrial share in the market, industry, or national level [13]. The HHI is defined as the sum of squares of the component ratio according to the level of a target [13]. Among the concentration index such as Gini index and Entropy index, the HHI is useful in that it is easy to calculate the index and understand the result [14]. In the European and other developed countries, HHI is considered an economic measure and an indicator for monitoring competition and concentration [15]. Owing to this concept, this index has been usually applied to measure the degree of concentration into other fields such as transportation, computer algorithm, and telecommunications [16,17].

In this study, the concentration index for industrial accidents at the national level is defined as HHI of accidents (called as the HHI_A) which presents the two concentration ratios of fatal accidents (deaths or mortalities) and nonfatal accidents (injuries) for the countries with respect to each industry. It is calculated as the sum of squares of occupational injuries in each industry within a country. The HHI_A notes how many fatal or nonfatal accidents are concentrated in specific industries within a country. From HHI_A , we find the country that includes specific industries with a large share of fatal or nonfatal accidents. Furthermore, based on HHI_A for fatal and nonfatal accidents, a case study on several European countries has been presented. Because the industrial characteristics of European countries differ in terms of region, economy, and culture, the concentration of industrial accidents can be different. The results of HHI_A among countries are compared using the positioning map in terms of frequency rate and concentration ratio. The differences among the indexes developed in this study provide policy makers and industrial managers with the outlook to focus considerably on risky industries that have a higher concentration ratio of industrial accidents.

2. Materials and methods

2.1. Conventional statistics for occupational accidents

Several statistical measures have been developed for measuring the degree of severity of accidents and disasters. Among them, three indexes have usually been used for the above purposes. First, “injury rate” is defined as the number of workers injured in an accident per workers as a fraction of 100 or 1000. Also, “fatal injury rate” represents the number of workers died in an accident per workers. Second is the “frequency of rate of injury,” defined as the rate of the number of injuries in 200,000 work hours by OSHA 1996 standard, which has also been adopted by ILO [3]. Third is the “severity of the rate of injury,” defined by the OSHA 1996 standard as the rate of the number of losses a day caused by accident in 200,000 work hours. However, in addition to these standards, some

countries have modified these indexes to adapt to their own national conditions. For example, frequency rate of injury is calculated as the rate of number of accidents in 1,000,000 work hours in a method for injury frequency rate of Health and Safety Executive of United Kingdom and Korea Occupational Safety and Health Agency of South Korea.

In this study, we simply define frequency rate (FR) of accidents in a nation as the number of accidents divided by total number of employees in a nation. Because the frequency rate of accidents is dependent on the size of the economy or the number of employees, FR can be used as the representative index for measuring the absolute number of industrial accidents per employee. Based on FR, this study proposes two indexes in the form of the equations (1) and (2): *frequency ratio of fatal accidents (FR-F)* and *frequency ratio of nonfatal accidents (FR-NF)*. *Fatal accidents* mean accidents that cause the death (or mortality), while *nonfatal accidents* mean accidents that lead to the injury, not the death.

$$FR - F = \frac{\text{Number of fatal accidents(deaths) in a nation}}{\text{Total number of employees in a nation}} \quad (1)$$

$$FR - NF = \frac{\text{Number of non-fatal accidents(injuries) in a nation}}{\text{Total number of employees in a nation}} \quad (2)$$

2.2. Development of concentration index of injuries

2.2.1. Index for concentration ratio in economics

Conventionally, two indexes are deemed to be of importance in measuring the economic concentration ratio: the *concentration ratio of N-Firm (CR#N)* and *HHI*. These two indexes are published in some countries and international economic institutes for monitoring market conditions [14,18].

First, *CR#N* is defined as the sum of the market shares of top *N* firms with the highest market shares. For example, assume that the automobile market consists of 10 firms. Of the 10 firms, if the top three firms enjoy market shares of 18%, 12%, and 10%, respectively, then, the *CR#3* (or presented as *CR3*) of the automobile market is measured as 40%. It is a very simple index for diagnosing competition conditions of current market.

However, *CR#N* has a limitation in measuring all of the components in the system. Thus, a different index was developed for calculating the concentration ratio using the ratios of all the components. In economics, the *HHI* is widely used for economic concentration of a specific industry. The *HHI* is defined as the sum of squares of the economic size of an individual market divided by total economic size of all markets, as shown in Equation (3). If the market shares are even, i.e., $1/N$, the *HHI* is found to be the same as the market shares of $1/N$. The range of *HHI* can indicate the market conditions in different situations as shown in Table 1. Thus, *HHI* can be used as a measure of the degree of economic concentration of industries or markets.

$$HHI = \sum_{i=1}^n \left(\frac{\text{Economic size of market } i \text{ in an industry}}{\text{Total economic size of market in an industry}} \right)^2 \quad (3)$$

2.2.2. Development of concentration index

The concentration ratio of industry accidents is developed in this study by borrowing this concept of *HHI*. With respect to fatal and nonfatal accidents, two indexes for HHI_A have been developed in the forms of Eqs. (4) And (5). According to the original equation

of HHI, the concentration of industrial accident can be measured as the sum of the squared ratios of the number of accidents (death or injury) in an industry to the total number of accidents in all industries. In the equation, the n denotes the number of industries included in a nation. Here, unlike the measure where frequency is considered because this index is obtained by measuring the proportion of accidents in individual industries to total industrial accidents in the country, the number of employees in each country is not considered for this index. The HHI_A-F and the HHI_A-NF are defined as the HHI of fatal accidents and the HHI of nonfatal accidents, respectively.

3. Results

3.1. Data collection

The data for the illustration were collected from the ILO website, which provides the key indicators of the labor market. The ILOs web page (www.ilo.org/ilostat/) provides data for various parameters such as population, employment, working time, earnings, and labor cost, labor productivity, and safety and health at work. We gathered the statistics for accident data of fatal and nonfatal injuries and the number employees for 6 years from

$$HHI_A-F = \sum_{i=1}^n \left(\frac{\text{Number of fatal accidents(deaths) in an industry } i \text{ of a nation}}{\text{Total number of fatal accidents(deaths) in a nation}} \right)^2 \quad (4)$$

$$HHI_A-NF = \sum_{i=1}^n \left(\frac{\text{Number of non - fatal accidents(injuries) in an industry } i \text{ of a nation}}{\text{Total number of non - fatal accidents(injuries) in a nation}} \right)^2 \quad (5)$$

2.2.3. Evaluation of concentration condition

The HHI provides a numerical base for categorizing the economic conditions of markets into four types: perfect competition, monopolistic competition, oligopoly, and monopoly. Although several criteria have been suggested to classify markets according to their conditions, these four categories are widely used for identifying market competition [18]. Accordingly, HHI_A-F and HHI_A-NF can be used for diagnosing industrial concentration of accidents like original HHI in economy. However, in both theory and practice, our study is limited in deciding the range of decoupling because this study is the first empirical study on suggesting a new measure of identifying the concentration ratio of accidents in industry or country. Thus, the criteria of dividing the level of concentration are simply proposed with the average value as shown in Table 1.

2010 to 2015 (downloaded from the menu of *safety and health at work* through the ILOs web page) as shown in Table 2. The 21 target European countries with the standard industry composition of International Standard Industrial Classification (ISIC) were selected based on data availability. Statistics for some years were missing for some countries. Accident statistics are available for only 21 countries for all 27 industries as per ISIC-rev.4 from 2010 to 2015. Also, for reflecting the different industry composition among countries, the number of employees is also collected. However, it should be noted that among the 21 countries, only Finland has no data for fatal and nonfatal accidents in ILO table of 2015, and thus, the results for Finland show the average value from 2010 to 2014.

3.2. Concentration of industrial and occupational accidents

3.2.1. Overall statistics

Based on the proposed accident indexes, the FR and the concentration of fatal and nonfatal accidents are calculated as shown in Table 3. Each value indicates the average FR and HHI_A from 2010 to 2015. The European nations rank differently according to the different indexes. First, for fatal accidents, Portugal has the highest FR-F (0.0000375, i.e., 3.75 per 100,000), followed by Romania and Austria, but the HHI_A-F indicates that the accidents of Austria are mostly dependent on a few dangerous industries (25.4%), followed by Cyprus and Greece. A gap between the two indexes represents the different implications by each of indexes. It is revealed that the nation which has the largest gap in the ranks according to FR-F and HHI_A-F is Greece (a difference of 16 ranks) followed by Italy and France. To be specific, Greece shows a higher ranking for HHI_A than FR-F, but Italy and France represent a lower rank for HHI_A than for FR-F. This indicates that Greece has managed the total number of

Table 1
Degree of accident concentration with respect to HHI

Previous approach for market [18]		Current approach for accident	
Range	Market concentration	Range	Accident concentration
0.00 < HHI < 0.10	Perfect competition	Below the average value of HHI_A	Low concentration
0.10 < HHI < 0.18	Monopolistic competition		
0.18 < HHI < 0.40	Oligopoly	Above the average value of HHI_A	High concentration
0.40 < HHI	Monopoly		

HHI_A , HHI of accidents; HHI, *Herfindahl-Hirschman Index*.

Table 2
Data collection

Data	Contents	Year	Accident index used
Fatal injury	The number of accidents generating the <i>deaths</i> of employees	2010–2015	FR-F, HHI_A-F
Nonfatal injury	The number of accidents generating the <i>injuries</i> of employees	2010–2015	FR-NF, HHI_A-NF
Employee	The number of employees in the industries of country	2010–2015	FR-F, FR-NF

HHI_A , HHI of accidents; HHI, *Herfindahl-Hirschman Index*; FR-F, frequency ratio of fatal accidents; FR-NF, frequency ratio of nonfatal accidents.

Table 3
Frequency rate and concentration ratio (average value from 2010 to 2015)

Nation	Fatal accident				Nonfatal accident			
	FR-F*1000	Rank	HHI _A -F	Rank	FR-NF*1000	Rank	HHI _A -NF	Rank
Austria	0.0338	3	25.4%	1	0.0160	9	12.7%	12
Belgium	0.0140	15	17.4%	5	0.0137	11	13.5%	8
Croatia	0.0221	6	18.9%	4	0.0076	15	13.5%	9
Cyprus	0.0163	12	25.0%	2	0.0034	19	14.6%	7
Czech Republic	0.0256	5	13.9%	17	0.0093	13	23.7%	1
Denmark	0.0145	14	12.6%	21	0.0200	5	11.2%	17
Finland	0.0132	16	16.1%	8	0.0194	6	10.0%	21
France	0.0210	7	12.7%	20	0.0229	2	11.8%	16
Germany	0.0124	17	14.5%	13	0.0213	4	13.2%	10
Greece	0.0072	19	22.7%	3	0.0024	20	15.7%	6
Hungary	0.0095	9	16.1%	9	0.0049	17	17.6%	4
Italy	0.0265	4	12.8%	19	0.0152	10	12.0%	14
The Netherlands	0.0056	21	14.1%	16	0.0165	8	10.9%	18
Norway	0.0184	10	16.1%	7	0.0097	12	12.7%	13
Portugal	0.0375	1	17.0%	6	0.0271	1	15.8%	5
Romania	0.0343	2	14.1%	15	0.0004	21	18.4%	3
Slovakia	0.0205	8	15.9%	10	0.0038	18	20.6%	2
Spain	0.0175	11	15.7%	11	0.0228	3	10.5%	20
Sweden	0.0095	18	14.4%	14	0.0075	16	12.0%	15
Switzerland	0.0156	13	13.7%	18	0.0190	7	12.8%	11
United Kingdom	0.0071	20	15.7%	12	0.0079	14	10.6%	19

HHI_A, HHI of accidents; HHI, *Herfindahl-Hirschman Index*; FR-F, frequency ratio of fatal accidents; FR-NF, frequency ratio of nonfatal accidents.

*Bold letters mean top five European countries.

fatal accidents, but some dangerous industries are more dangerous than the others are and lead to a greater number of fatal accidents. However, Italy and France have a higher FR-F with a low HHI_A-F. Thus, in these countries, occurrences of fatal accidents are distributed more or less evenly among most of the industries.

On the other hand, for nonfatal accidents, there are distinct differences among several countries. Compared with the rankings for fatal accidents, some developed countries such as France, Spain, Germany, and Denmark are positioned higher in terms of FR-NF. However, HHI_A-NF shows that the Eastern European countries, namely Czech, Slovakia, and Romania rank among the first three countries. The nations that have a higher FR-NF show a comparatively low value for HHI_A-NF such as France (rank of 16), Spain (rank of 20), Germany (rank of 10), and Denmark (rank of 17). Thus, some developed countries have managed that the accidents of industries are not driven into the serious accidents.

Numeric statistics are only not sufficient to explain the significant differences between fatal and nonfatal accidents. Thus, in the next section, we use the positioning map, that is, we position the countries in terms of FR and HHI_A indexes to monitor the distribution of European countries.

3.2.2. Frequency and concentration of "fatal accidents"

In Fig. 1, we find that the differences between FR-F and HHI_A-F values are highlighted with respect to 21 European countries. Here, we use a large scale of FR-F multiplied by 1,000 because values for the original FR-F are too small to present the results.

Based on the average value of FR-F and HHI_A-F as pointed out before in Table 1, the three countries, Austria, Croatia, and Portugal, are categorized in the group that has a comparatively higher value of both FR-F and HHI_A-F. The countries included in this group demonstrate a strong bias for industrial accidents. In other words, a few industries have generated most of the industrial accidents in the nation. These countries should try to reduce the general accidents generated from all industries. Moreover, specific policies

should be formulated for reducing the number of accidents in specific industries where several accidents occur.

Second, the three countries, Belgium, Cyprus, and Greece, show comparatively low FR-F. This result indicates that these countries have a low count of industrial accidents, but the accidents have occurred in several industries. Countries in this category should foremost manage the top industries where most of the accidents occur for efficiently increasing the degree of safety.

Third, the countries Czech, France, Hungary, Italy, Romania, and Slovakia have presented a high FR-F and low HHI_A-F. Thus, though industrial accidents have occurred, they are not limited to specific industries. Thus, they should formulate an overall industrial policy to control the risk factors in all industries in general.

Finally, the last group of countries shows a low frequency as well as concentration of fatal accidents. Several countries of Northern Europe such as Norway, Finland, and Sweden, which focus on health and welfare, have ranked low on both the criteria, and some developed countries, such as UK, Germany, and the Netherlands, have maintained a low degree of frequency and concentration. This implies that these countries have tried to reduce the accidents in general and for specific industries as well.

3.2.3. Frequency and concentration of "nonfatal accidents"

The second part analyses the frequency rate and HHI for nonfatal accidents that are defined as FR-NF and HHI_A-NF, respectively. Just like FR-F, FR-NF is multiplied by 1,000 to present the original small value of FR-NF on a larger interpretable scale. Fig. 2 presents a positioning map in terms of FR-NF and HHI_A-NF of European countries with average value presented by dotted lines.

Portugal is the only country that has both a high FR-NF and HHI_A-NF. This country occupies a similar position in the case of fatal accidents. This result indicates that Portugal has recorded a higher frequency and concentration of both fatal and nonfatal accidents. Thus, Portugal should consider innovative ways to reduce accidents of all the industries, specifically hazardous industries. In particular,

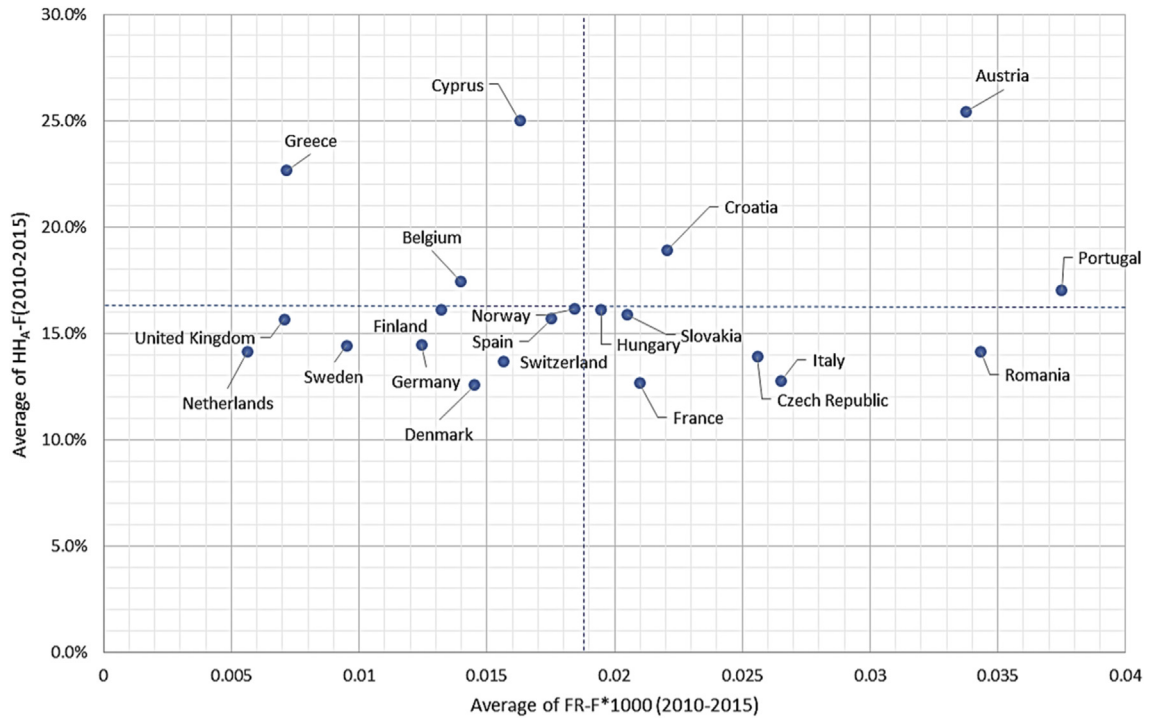


Fig. 1. FR and HHI_A for fatal accidents (Note: The dotted line means the average value). HHI_A, HHI of accidents; HHI, Herfindahl-Hirschman Index; FR-F, frequency ratio of fatal accidents.

compared with average values of European countries, addressing the frequency of accidents is a more pressing need than addressing the concentration of them.

Countries with a higher concentration of accidents are Cyprus, Czech, Greece, Hungary, Romania, and Slovakia. Although the frequency of nonfatal accidents is lower, these countries should focus on a few industries that are responsible for the higher share of industrial accidents. Thus, a strategy to reduce the concentration of accidents is required to maintain sustainable safety.

Third, most of the European countries show a higher frequency and lower concentration of nonfatal accidents. These countries attempt to foster a safety culture although nonfatal accidents are unavoidable in the process of increasing the productivity of the economy. The safety culture is a movement that manages minor and casual hazards in the industrial sites through collaboration and participation of all employees and employers. Thus, campaign and the safety movement can be considered sustainable solutions for reducing the number of inevitable nonfatal accidents.

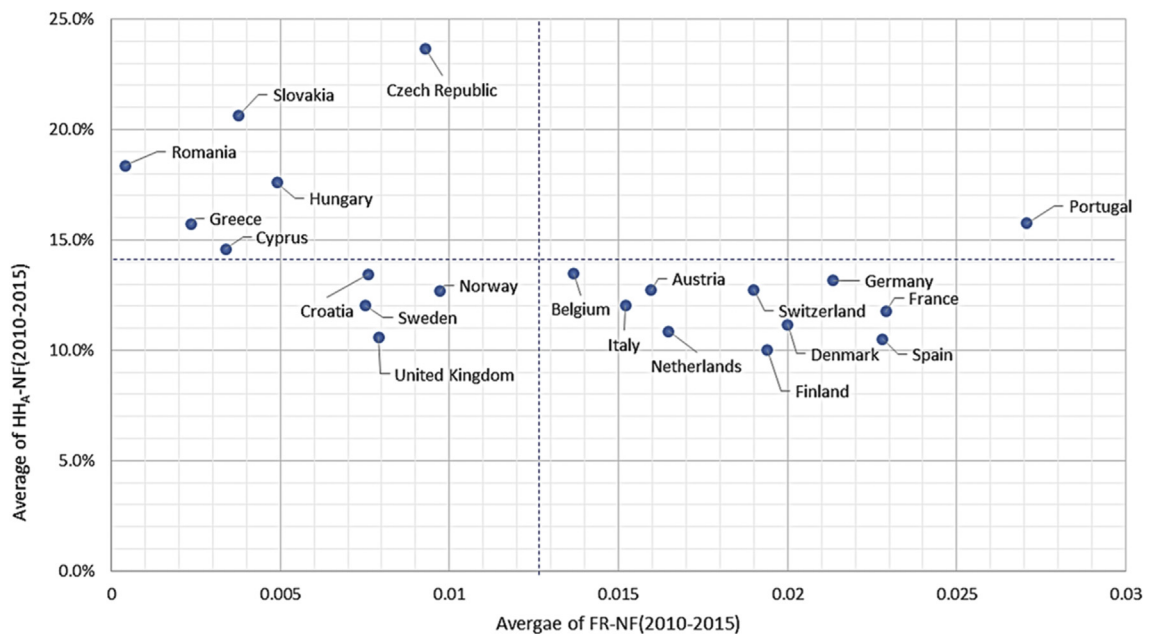


Fig. 2. FR and HHI_A for nonfatal accidents (Note: The dotted line means the average value). HHI_A, HHI of accidents; HHI, Herfindahl-Hirschman Index; FR-NF, frequency ratio of nonfatal accidents.

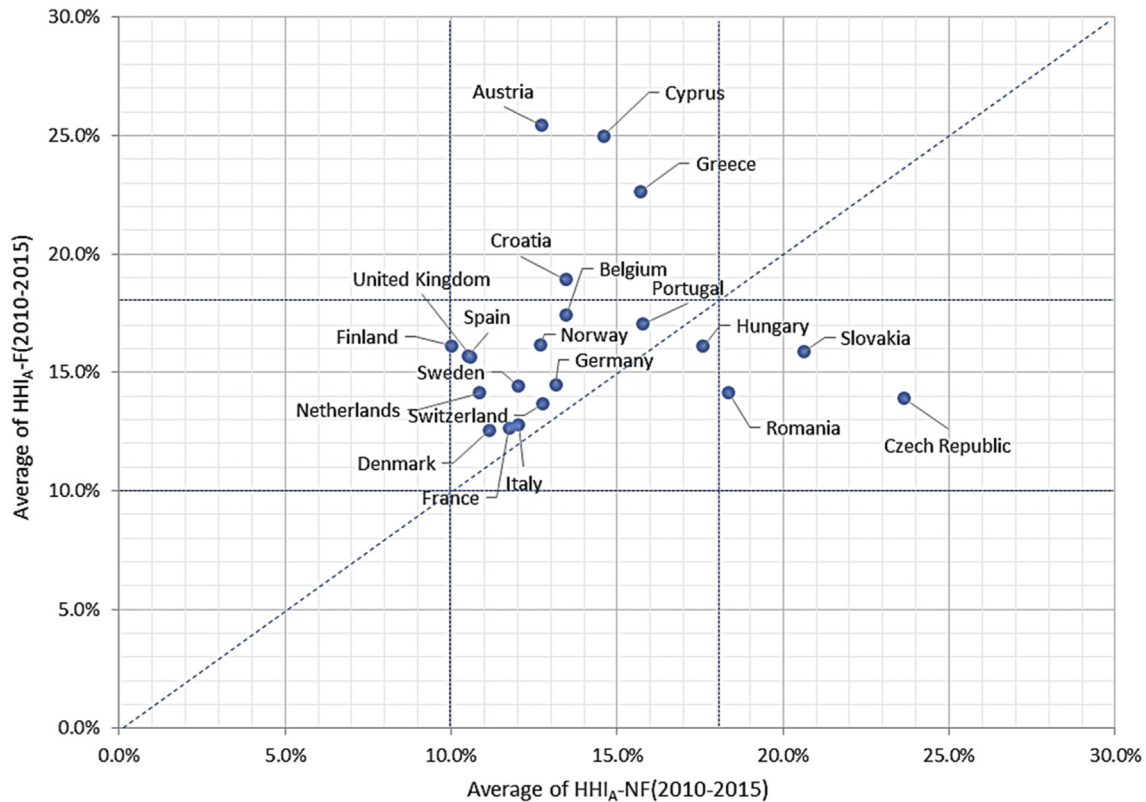


Fig. 3. Correlation of HHI_A between fatal and nonfatal accidents. HHI_A , HHI of accidents; HHI, Herfindahl-Hirschman Index.

3.3. Comparison of HHI_A values for fatal and nonfatal accidents

For identifying the differences between concentration of fatal and nonfatal accidents, we compare HHI_{A-F} and HHI_{A-NF} as shown in Fig. 3. The diagonal line stands for identical concentrations of fatal and nonfatal accidents and the dotted lines mean the level of concentration as described in Table 1. Because most of the nations are located above or under this diagonal line, this reveals that there is a difference of concentration between fatal and nonfatal accidents. Most of the countries are grouped above the diagonal line, which means they have higher levels of HHI_{A-F} than HHI_{A-NF} . Several countries in this group are revealed to have high concentration of fatal accidents with moderate concentration of nonfatal accidents: Austria, Croatia, Cyprus, and Greece. The countries falling below these countries have a moderate concentration of both fatal and nonfatal accidents. This indicates that except four countries, namely, Czech, Hungary, Romania, and Slovakia in Eastern Europe, most of the countries among the 21 European countries have included some focus industry that generate more fatal accidents than nonfatal accidents. Thus, most countries should formulate an emergency plan to focus on the industries that generate a greater number of fatal accidents.

4. Discussion

4.1. Comparative analysis between fatal and nonfatal accidents

Through the results of this study, we identify the different patterns of fatal and nonfatal accidents in the European nations. Four groups are made with every possible combination of FR and HHI_A , and the nations' conditions are monitored by matching fatal accidents with nonfatal accidents as shown in Fig. 4.

Most of the countries occupy the same positions for frequency and concentration ratio with respect to both fatal and nonfatal accidents such as Portugal, France, Italy, Cyprus, Greece, Norway, Sweden, and United Kingdom. These countries could make an integrated policy for dealing with both types of accidents, simultaneously.

Issues of managerial concern are extracted in the countries which have incompatible conditions with respect to patterns between fatal and nonfatal accidents. First, while some of the developed countries show patterns of a higher frequency rate of nonfatal accidents, the frequency rate and concentration ratio of fatal accidents have been well managed: particularly Denmark, Finland, Germany, the Netherlands, Spain, and Switzerland. These developed countries have grown through early industrialization, and this industrialization leads to mature economic and social growth. Minor accidents are inevitable during the development of various industries because the countries should sustain the economy level and economic growth. Although the nonfatal accidents do not directly result in the death or disability of workers, however, such indirect effect on the health and safety of workers could cause substantial accidents because of the accumulation of unsafe actions and conditions. Thus, the safety culture movement could resolve this situation by removing minor problems in the industrial sites.

Second, it is also interesting that the frequency rate of accidents in several countries of Eastern Europe such as Czech, Hungary, Romania, and Slovakia is lower, but the concentration ratio of both fatal and nonfatal accidents is higher. These results indicate that these countries are barely able to manage the accidents that lead to deaths in specific industries. Minor accidents are also concentrated in few industries. As the Eastern European countries have relatively immature industries and society compared with developed countries because of the late industrialization, managing risks in all

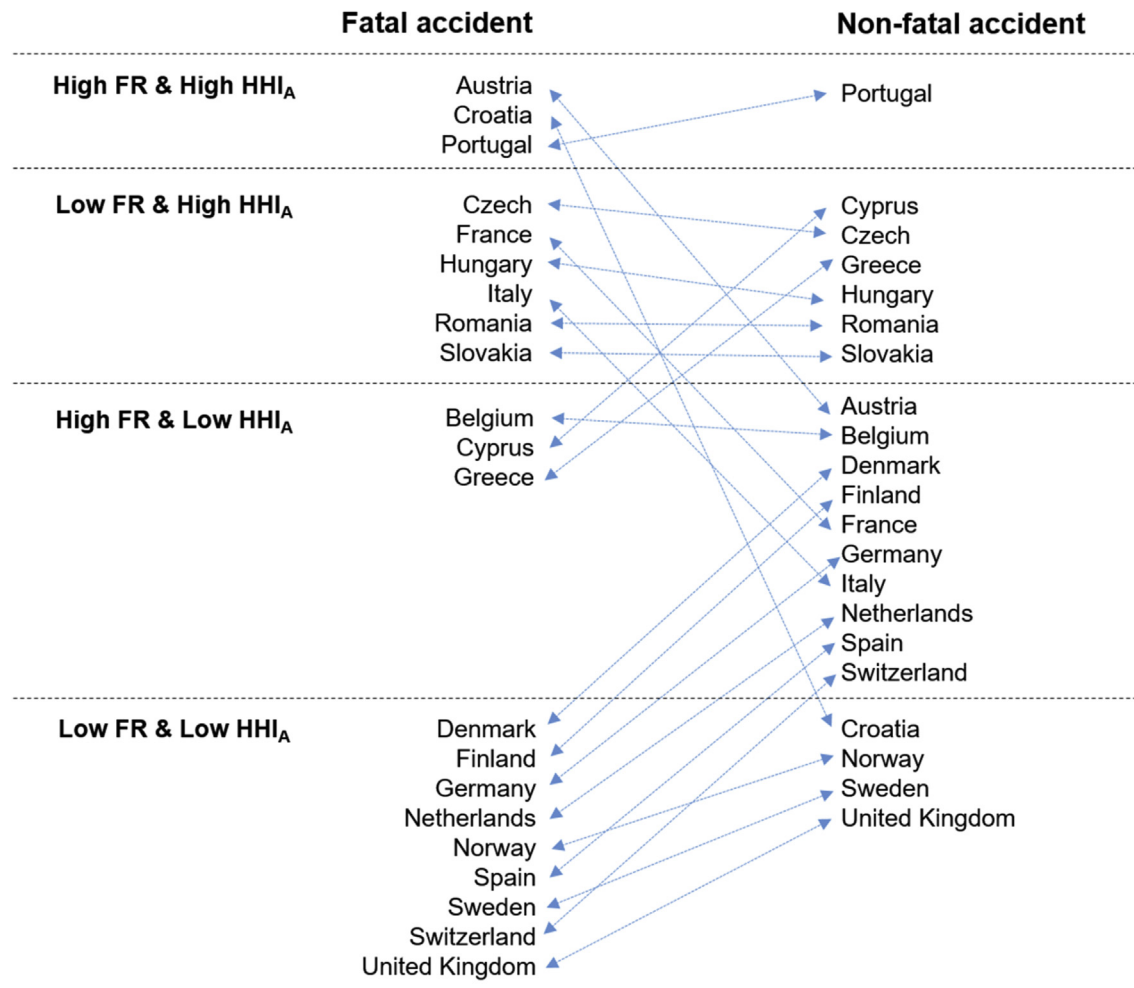


Fig. 4. Comparison between fatal and nonfatal accidents for European countries. HHI_A, HHI of accidents; HHI, Herfindahl-Hirschman Index; FR, frequency ratio.

industries may be problem and burdensome. Thus, a strategy could be implemented in any one direction: either direct reduction of fatal accidents or management of concentrated industries could be addressed first or first. Between the two, we prefer the strategy where the industries that face nonfatal accidents are inspected first because the fatal accidents could be driven by high concentrations of nonfatal accidents. An attempt by policy makers and safety managers to reduce the concentration ratio will affect the frequency level of fatal accidents. Consequently, these countries require a strategy that targets the specific risk-prone industries.

4.2. Practical applications for safety strategy formulation

We can formulate different safety strategies according to the level of fatal and nonfatal accidents as described in Table 4. The fatal accidents, which are caused by several critical problems such as leakage of hazardous materials, use of heavy equipment, and human errors, should be managed by the government. In this case, the facility, workers, and environment of the industrial sites should be strictly supervised based on the tight regulations. The managerial, technological, systemic, and legal solutions to these problems should be prepared to form the fundamentals of safety management. On the other hand, nonfatal accidents are generated by the minor and casual problems in and around the industrial sites. It is highly possible that these accidents are inevitable, and the risk of

those accidents are acceptable. In this case, voluntary regulations need to collaborate for maintaining records of injuries with the stakeholders, such as owners, employers, employees, and safety managers.

Interestingly, we also consider the different strategies in terms of discrepancy between the frequency and the concentration ratio. If the frequency is high and the concentration ratio is low, then safety of overall industries should be managed. It is important to prepare and publish the integrated manual for reducing general accidents to all industries. In contrast, the policy makers of the country should endeavor to find major industries with a higher concentration of accidents. By prioritizing the accident-concentrated industries, the strict regulations and rules of those industries are specifically introduced. In this respect, using both frequency and concentration ratio, various approaches to safety management can be developed to arrive at different solutions.

4.3. Limitations and future directions

Although this study proposes a useful concentration index for fatal and nonfatal injuries in country level, further future study is required to corroborate our result. Primarily, the economic level and structure of countries should be considered while analyzing the results. The concentration ratio should be different

Table 4
Managerial and practical implications for safety strategy formulation

Fatal	Nonfatal			
	High FR & High HHI _A	Low FR & High HHI _A	High FR & Low HHI _A	Low FR & Low HHI _A
High FR & High HHI _A	<p>Country: Portugal <u>Holistic management</u></p> <ul style="list-style-type: none"> • Roadmap for reducing both perilous and casual accidents • Collaboration between both government and corporation • Open innovation for managerial, technological, organizational, and legal solutions 			<p>Country: Croatia <u>Government-driven management of critical industries based on strict regulation and inspection system</u></p> <ul style="list-style-type: none"> • Government-driven audit policy • Focus on perilous factors • Tight regulation of accident-concentrated industry • Increase of supervisors in sites of accident-concentrated industry
Low FR & High HHI _A		<p>Country: Czech, Hungary, Romania, Slovakia <u>Management of accident-concentrated industries</u></p> <ul style="list-style-type: none"> • Tight regulation of accident-concentrated industry <i>(combined strategy is required)</i> 	<p><i>(combined strategy is required)</i></p>	
High FR & Low HHI _A			<p>Country: Belgium <u>Management of overall industries</u></p> <ul style="list-style-type: none"> • Integrated manual for reducing general accidents in all industries 	
Low FR & Low HHI _A	<p>Country: None <u>Corporation-driven management of critical industries based on voluntary regulation and safety culture</u></p> <ul style="list-style-type: none"> • Corporation-driven policy • Focus on casual factors • Voluntary regulation 			<p>Country: Norway, Sweden, UK <u>Sustainable management</u></p> <ul style="list-style-type: none"> • Construction of systemic management • Monitoring and control systems • Documentation of benchmarking manual

according to the respective national policies and economic strategies of the countries. In this study, Eastern and the Northern Europe show interesting results; these two regions have different economic regimes and industrial organization. Thus, the background of the countries should be analyzed. Second, for advanced analysis, the accident data at further decentralized industry specific levels should be considered because the industry composition differs among the countries. This study considers only two levels: nation and industry because of the lack of data availability; the ILO data are only used, not considering the nature of each country's policy. However, if the hierarchical subindustry data are collected, the concentration ratio can be sequentially and systematically measured from the top to the bottom level. In this case, the concentration ratio can prove to be of great use in interpreting the origin of accident occurrence from subindustries. For this, we started the domestic analysis, collecting subindustries' accident data of South Korea. Finally, we should develop concentration ratios using other concepts of concentration measures. Besides the economic measure, scientific, and statistical measures are helpful in suggesting various indexes to identify the status of industrial and occupational accidents.

5. Conclusion

This study aims at developing new statistical tools to identify the concentration of industrial accidents. So far, there has not been any suggestion on finding the composition ratio of the accidents. Not doing so makes it difficult to find industries in a nation that are particularly hazardous; we can only find the frequency of accidents in a nation. Various types of the concentration index are widely applied in economics to identify dispersion and inequality. Borrowing the concept of economic concentration, we develop the accident concentration index to measure the accident bias among industries. We chose the HHI in this study above other indexes because of its simplicity and applicability. Using data on fatal and nonfatal accidents published by ILO, we present a case study of European countries and justify the usefulness of the concentration ratio as a measure along with the frequency. From the results, we classify the European countries in terms of frequency and concentration ratio and suggest different safety strategies such as strict supervision and building a safety culture. As for the frequency level and HHI_A, this study reveals that most of the developed countries show both low frequencies and concentrations of accidents, but some Eastern European countries have a higher concentration of

nonfatal accidents. Frequency rates and concentration ratios will vary according to the economic structure and the degree of industrialization.

Conflicts of interest

The authors declare that there is no potential conflict of interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.shaw.2020.05.003>.

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