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Evaluating the Efficiency of the Process Safety Management System through Analysis of Major Industrial Accidents in South Korea

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Abstract: The process safety management (PSM) system was introduced in South Korea in 1996, wherein a company voluntarily organizes and manages a chemical accident prevention system, which contributes to reducing chemical accidents. However, large- and small-scale chemical accidents occur frequently. This trend necessitates analysis and improvement of the PSM systems. This study aimed to analyze the correlation between major industrial accidents, their main causes, the status of accidents by company size and industry, and the PSM evaluation grade through an analysis of 130 accidents that occurred in the past 17 years (2005–2021). The results showed that small- and medium-sized enterprises (SMEs) with fewer than 100 employees accounted for 36% of all accidents, indicating a higher occurrence rate than large companies. Additionally, the proportion of companies with inadequate PSM levels, rated as M-grade (M+, and M−), were 67.0%, suggesting a high probability of major industrial accidents. The results of this study show that a company's voluntary safety management can be induced by an improved PSM system and management plan, which is expected to prevent major industrial accidents.

Keywords: process safety management (PSM); process safety report; safety operation plan; major industrial accidents

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1. Introduction

In the 1970s, due to the worldwide occurrence of large-scale accidents caused by chemical substances, the Severe Industrial Accident Prevention System was enacted. The European Union issued the Seveso II Directive (96/82/EC, 96.12.09) on 3 February 1997, which supplemented the Seveso I Directive (82/501/EEC) issued in 1982. In particular, the focus on environmental protection has been strengthened, including environmental hazardous substances. Later, in Seveso III, which was revised in 2012, the list of single substances was expanded to 48, including heavy oil and alternative fuels, and the list of hazardous substances was expanded to include biogas in natural gas. Items newly added to Seveso III included the revision of the hazard indication system by the GHS, strengthening information provision to citizens in the process of land-use planning and risk management of major industrial accidents, strengthening risk notification to residents who need to evacuate in the event of an accident, and accident-strengthened investigations. On the other hand, the government authorities receiving the safety report should examine the appropriateness of it, and organize a team to check whether the safety measures suggested by the workplace are being implemented [1,2].

The US PSM system was established as a federal law (29 CFR 1910.119) by the Safety and Health Administration under the Ministry of Labor in 1992 and was regulated as an obligation of each employer. The standard quantity is set for 136 types of chemicals, and is also applied to workplaces with facilities handling 10,000 pounds or more of combustible materials. For approximately 25,000 workplaces in 127 industries, PSM was applied by

expanding the level of chemical substances to the same level as the risk management plan (RMP) based on the US Environmental Protection Agency (EPA) air cleaning law. The US workplaces voluntarily prepare process safety reports, and consultation with and training of workers are very important. The Occupational Safety and Health Administration of the United States does not have a process to regularly check whether the process safety report has been implemented; however, the state government is implementing it through a compliance check of the EPA's RMP report [3–6].

To prevent major industrial accidents and minimize their consequences, the UK has applied and operated 41 single substances and 13 synthetic substances in facilities that handle more than the prescribed amount in accordance with the Severe Industrial Accident Prevention Act of 1984. Since then, as the Seveso II Directive has been revised, a PSM system has been implemented based on the Control of Major Accident Hazards (COMAH) Act, which amended the CIMAH in 1998. The employer must prove that hazardous facilities are safely operated in accordance with the COMAH Act or establish a safety report and emergency action plan within the factory, while the local responsible authority establishes an emergency action plan outside the factory and periodically inspects it. Accordingly, harmful and dangerous facilities must be reported, and safety reports must be submitted and renewed every five years [1,7].

Germany introduced the Seveso II Directive into the PSM System, which had been managed by the Federal Leakage Prevention Act. In accordance with the Federal Leakage Prevention Act and the Major Accident Prevention Regulation (Major Accidents Ordinance, 2005), harm and risk exceeding the prescribed amount are applied to workplaces that handle substances. According to this law, workplaces must submit process safety reports and the government reviews, confirms, and notifies the workplaces. Additionally, the process safety report is to be periodically updated in accordance with the provisions of the Act [8].

The PSM system, introduced in 1996 and implemented till date, has significantly contributed to the reduction and prevention of chemical accidents in Korea [9]. The Korean government held a workshop on major industrial accidents jointly with the International Labor Organization (ILO) in 1992. They conducted research to introduce the system from 1993 to 1995, nurtured experts through overseas training, and held a seminar on preventing major industrial accidents in 1993; in 1995, a PSM system was introduced to the Occupational Safety and Health Act, which was implemented in 1996 [10,11]. A major industrial accident is defined, in Article 33-5 of the Enforcement Decree of the Occupational Safety and Health Act, as accidents that may cause immediate damage to workers in the workplace or damage to areas near the workplace due to the leakage of hazardous substances, hazardous facilities, fire, and explosion [12–15]. PSM is a system introduced by the Occupational Safety and Health Act to prevent accidents (leakage, fire, and explosion) that occur in workplaces that handle large amounts of hazardous substances, such as petrochemical plants [10,16,17]. In other words, PSM is a technology-intensive equipment industry and as disaster prevention management by technicians in one field became difficult, it was introduced due to the need for risk assessment and systematic and comprehensive safety management systems. In addition, support from the management and voluntary participation of all members were required; it can be said that PSM was to provide accurate information to secure the trust of the local community and to comply with the regulations of international organizations [16,18,19]. Ultimately, this is to prevent major industrial accidents that may cause immediate damage to workers in the workplace or damage to areas near the workplace due to the leakage of harmful or hazardous substances, fire, or explosion [9,20–24].

The key to PSM system is to prepare and submit process safety reports [2–4,9]. A process safety report is prepared to prevent accidents that may cause damage to workers in the workplace and neighboring areas due to leakage, fire, or explosion of hazardous substances in workplaces with hazardous substances and hazardous facilities These workplace voluntarily refer to a system to prevent major industrial accidents by implementing and

practicing those measures. The process safety report refers to document related data, such as drawings of harmful and dangerous facilities within the workplace, as well as all related facilities. The risk of accident potential in the process or facility is evaluated to identify the risk factors. It is a compilation of detailed action plans for each of the 12 elements, such as safety operation plan, emergency measures plan, etc. [9,17,25].

PSM begins with the order in which the 12 factors are named [9,17,26,27]. First, a risk assessment is conducted based on process safety data to establish a safe operation plan for normal times and an emergency action plan in case of an emergency. In the case of repair work, such as equipment failure, the employer ensures that the work is carried out after taking precautionary measures to guarantee that there is no further risk according to the safety work permit procedure; the employer also ensures that sufficient information to workers is provided and necessary training, such as safety training, according to the contractor's safety management plan, is conducted. Next, the employer establishes an annual education and training plan, and implements necessary education for workers, such as regular and occasional education. When a facility is changed or operated after a new installation, a preoperative inspection is conducted according to the preoperative inspection guidelines to confirm the safety conditions and to correct any deficiencies. In addition, if changes occur in the related process, change management must be carried out without omission and according to the change factor management plan, and necessary measures, such as updating related process safety data and conducting worker training must be done. In addition, regular self-audits are conducted to check whether PSM elements are properly implemented. In the event of a chemical accident, an appropriate accident investigation team is formed to investigate the cause of the accident and immediately make improvements where needed [28,29].

Despite the implementation of PSM systems, chemical accidents still occur. Current PSM systems are based on technological developments, facility maintenance, and management. It has been pointed out that this does not sufficiently reflect the changing social conditions, such as the increase in maintenance work and subcontractors performing dangerous work. In 2006, Lee et al. [11] surveyed the satisfaction level of PSM target workplaces and measured PSM business performance based for the 10 years since the introduction of the PSM system in Korea using the PSM business performance measurement and effect analysis. The mid- and long-term directions for indicator development and PSM system operations were presented. Furthermore, Lee et al. [30], in a 2008 study on the rationalization of PSM system application standards, examined the background of domestic PSM system application standards and their operation in EU member states, such as the UK and the United States. In this study, we investigated and analyzed the data and evidence and the current state of PSM in Korea to find more scientific and objective evidence suitable for the situation in the country, and suggested a plan to rationalize the criteria for application of the PSM system. In a study on the expansion of substances subject to the PSM system, Lee et al. unified the selection criteria for the domestic PSM system into the handling and storage of hazardous substances [31]. Based on the results of previous studies and the systems of developed countries, the feasibility of expanding the type and amount of applicable substances was reviewed and presented herein.

2. Methods

This study analyzed the legal system of a PSM program operating in Korea for process safety management. Furthermore, there were distinct ways in which the correlation between the number of major industrial accidents that occurred in the past 17 years (2005–2021) and workplaces that were required to submit PSM evaluations was investigated. In particular, PSM levels were compared and analyzed through an analysis of PSM evaluation grades over the past three years. The correlation between the results of the 2021 PSM evaluation grades and the characteristics of industries and workplace sizes by region was analyzed in relation to major industrial accidents.

3. Law of Process Safety Management in South Korea

To prevent the several major accidents that occurred in Korea from the end of the 1980s to the beginning of the 1990s, new safety management systems, such as PSM, became necessary in chemical plants [9,10,27]. The PSM system was introduced to prevent major industrial accidents that can immediately harm workers in the workplace or cause damage to nearby areas because of leaks, fires, explosions, or other hazardous incidents involving dangerous substances [28]. The system involves workers who voluntarily identify and eliminate, or reduce potential hazards in both the process and major equipment in the workplace, minimizing the occurrence of accidents, and enhancing the safety of the process. Therefore, a business owner with hazardous or dangerous facilities, as prescribed by the Presidential Decree, shall prepare a process safety report and submit it to the Minister of Employment and Labor for review to prevent an accident, prescribed by the Presidential Decree as, likely to cause immediate damage to employees in the place of business or to the neighborhood of the place of business, due to leakage of a dangerous substance from the facilities, fire, or explosion [27]. The legal basis of the PSM system is established under Article 49-2 (Submission of Process Safety Reports) of the Industrial Safety and Health Act, and it applies to facilities belonging to the industries specified in Article 33-6 (Facilities Subject to Submission of Process Safety Reports) of the Enforcement Regulations of the Industrial Safety and Health Act. For other workplaces, the PSM system applies to all process facilities that handle the 51 harmful or dangerous substances in quantities greater than the regulated amount [32–34].

- Refineries
- Reprocessing of petroleum refining byproducts.
- Petrochemical organic chemicals or synthetic resins
- Fertilizer industry
- Pesticide/herbicide industry
- Explosive powder/fireworks products

The PSM system was expanded from 21 types of substances to 51 types in 2014, and was implemented in all workplaces in 2015, resulting in an increase in the submission of process safety reports from small and medium-sized businesses [15]. Process safety reports are classified into four contents: ① process safety data, ② process risk evaluation report, ③ safety operation plan, and ④ emergency measures plan. They are also composed of 12 detailed elements that work together organically, as shown in Figure 1 [27].

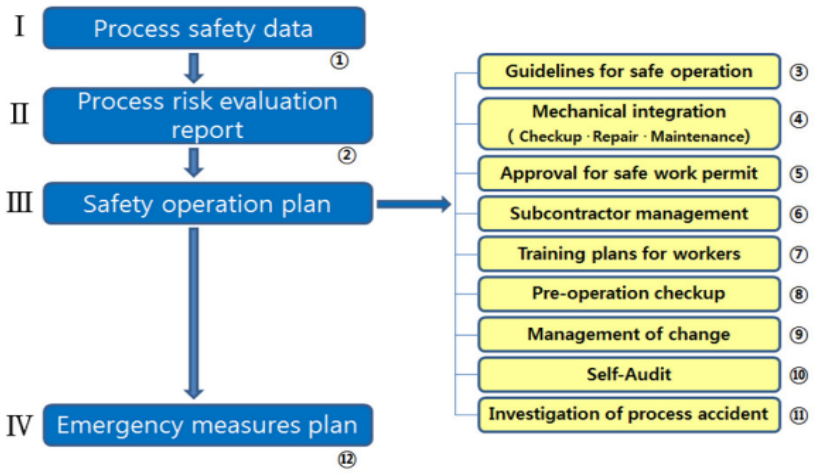

Figure 1. Contents of process safety reports [27].

If a business owner establishes or moves a harmful and dangerous facility or alters its major structural part, as determined by the Ministry of Employment and Labor (MOEL), the owner shall prepare a process safety report and submit it to the MOEL within 30 days

for a review, as prescribed by the Ordinance of the MOEL, and the MOEL will provide a written notice of the results of the review to the relevant business owner within 30 days, as shown in Figure 2. In cases where it is deemed necessary to maintain and promote the safety and health of employees, the MOEL may order amendments to the relevant process safety report. MOEL conducts a compliance evaluation of PSM within two years after the confirmation of the process safety report and classifies the results into four grades—P, S, M+, and M—based on the evaluation [35]. A re-evaluation will be conducted during the future evaluation period, as shown in Table 1.

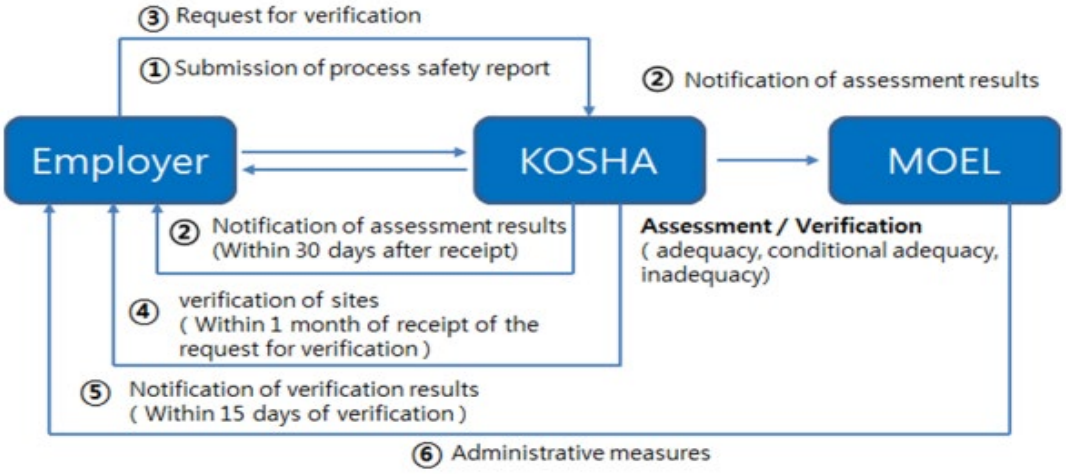

Figure 2. Procedure of process safety report assessment and verification [27,34].

Table 1. List of PSM grade.

Grade	Implementing Condition Assessment
P (Progressive) (Excellent)	Inspection once every four years after a rating evaluation
S (Stagnant) (Good)	Inspection once every two years
M+ (Mismanagement) (Normal)	Inspection and consulting once a year
M− (Mismanagement) (Bad)	Inspection twice a year, or inspection once a year

4. Analysis of the Operating Status of PSM

To analyze the current status of PSM operations, a survey was conducted on business establishments that have been subject to PSM submissions over the past 17 years, as shown in Figure 3 [9]. In 2005, there were 788 companies, but by 2021, approximately 2.7 times more (2145 companies) were subject to PSM submission. As mentioned earlier, business establishments' subject to PSM submission must undergo re-evaluation for one to four years, depending on their evaluation grade. Figure 4 shows the PSM grades for the past three years, excluding establishments that were not assigned PSM grades. Based on the PSM evaluation grades for the past three years, it can be analyzed that P-grade establishments accounted for 4.7% of the total, S-grade establishments for 37.2%, M+ grade establishments for 45.8%, and M-grade establishments for 12.4%. The level of PSM improved annually. In particular, in 2022, the M+ and M− grades decreased by 8.4% and 49.7%, respectively, indicating a relatively higher increase in P and S grades.

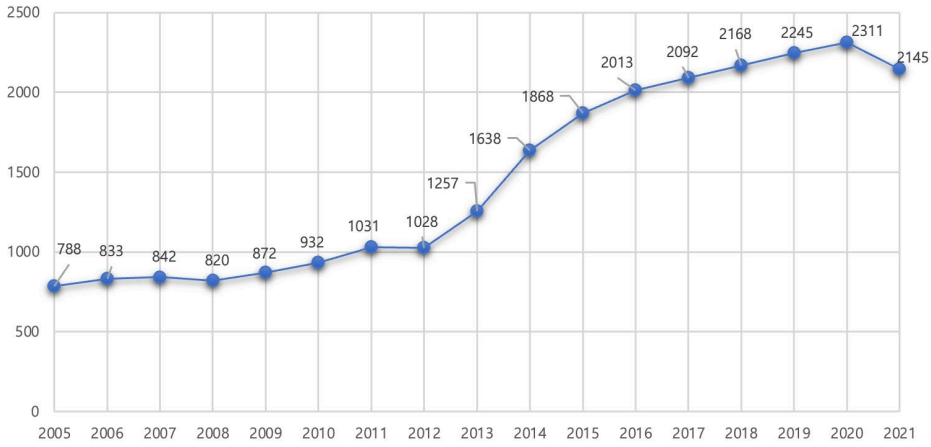

Figure 3. Number of business establishments subject to PSM over the past 17 years.

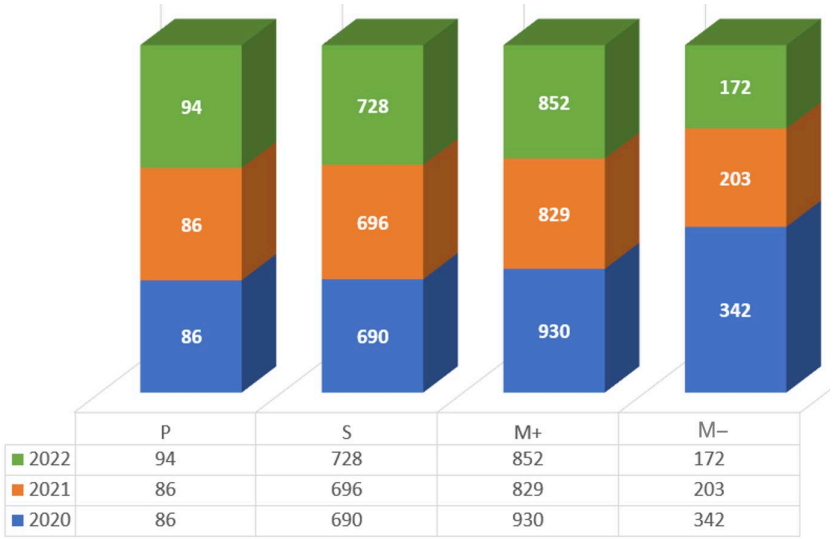

Figure 4. Status of PSM grades over the past 3 years.

Table 2 presents the PSM grades by industry for the PSM submission targets for 2021. Among the 2145 facilities, 331 that did not receive PSM grades were excluded, leaving 1814 facilities, of which 1614 were subject to PSM regulations for handling harmful or dangerous substances in regulated quantities, while the remaining 200 were subject to management control by industry for handling harmful or dangerous facilities. Petroleum refinery businesses had the highest proportion of P-grade at 56.5% by industry classification, followed by petrochemical businesses at 17.2%, and explosives at 7.1%. In terms of overall grades, P-grade accounted for 4.7%, S-grades for 38.4%, M+ for 45.7%, and M− for 11.2%.

Table 2. PSM grade status of businesses subject to PSM submission by industry in 2021.

No. of Employees	Petroleum Refinery	Petro Chemical	Fertilizer	Pesticide	Explosive	Harmful or Dangerous Substances	Total
P	13	27	0	0	1	45	86
S	9	62	3	2	6	614	696
M+	1	46	0	0	6	776	829
M−	0	22	0	1	1	179	203
Total	23	157	3	3	14	1614	1814

Conversely, Table 3 shows the PSM grade status by the size of the workplace, considering the number of regular employees in 2021. Analyzing the PSM grades by industry and company size, it can be seen that large companies have better PSM than small and medium-sized companies, as the proportion of P-grade ratings are relatively higher. In particular, businesses with fewer than 100 employees accounted for 61.4% of the total 1814 businesses, with 1113 establishments, and among them, only 34 businesses (3.1%) were rated P-grade. This percentage is significantly lower than the overall average of 4.7% for the P-grade. For the inadequate PSM grade of M (M+, M−), businesses with fewer than 100 employees accounted for 67.0%, which is 10.2% higher than the overall M-grade of 56.8%. Therefore, additional efforts are needed to enhance the PSM of small and medium-sized enterprises, such as activating a safety culture within the organization, strengthening the willingness of company owners, and providing education for workers.

Table 3. PSM grade status of subject to PSM submission by number of regular workers in 2021.

No. of Employees	P	S	M+	M−	Total
<100	34	333	576	170	1113
100–299	32	202	158	26	418
300–500	6	62	43	1	112
>500	14	99	52	6	171
Total	86	696	829	203	1814

5. Analysis of the Correlation between Major Industrial Accidents and PSM Grades

5.1. Analysis of Major Industrial Accidents by Company Size

The analysis of major industrial accidents that occurred in the last 17 years (2005–2021), based on the size of the workplace and considering the number of regular workers, is shown in Table 4. Among the 130 accidents, 18 (13.8%) occurred in workplaces with fewer than 50 employees, 29 (22.3%) occurred in workplaces with 50 to fewer than 100 employees, 32 (24.6%) occurred in workplaces with 100 to fewer than 300 employees, 24 (18.5%) occurred in workplaces with 300 to less than 1000 employees, and 27 (20.8%) occurred in workplaces with 1000 or more employees. Analyzing the correlation between PSM-grade businesses and major industrial accidents among the 130 major industrial accidents that occurred in the past 17 years (2005–2021), businesses with fewer than 100 regular workers had the highest rate of accidents with 47 incidents, accounting for 36.1% of the total. This is consistent with the fact that the M-grade, which indicates inadequate PSM, accounts for 67.0% of businesses with fewer than 100 regular workers, as mentioned in Table 4, indicating a correlation between the PSM level and the occurrence of major industrial accidents.

Table 4. Status of major industrial accidents by business size.

No. of Employees	No. of Accident	Percent (%)
Total	130	100%
<50	18	13.8%
50–100	29	22.3%
100–300	32	24.6%
300–1000	24	18.5%
>1000	27	20.8%

5.2. Analysis of Major Industrial Accidents by Region

The following analysis examines the occurrence of major industrial accidents by region, dividing the country into seven regions based on geographical characteristics, as shown in Tables 5 and 6. Each of the seven regions has individual industrial characteristics based on their geographical features. For example, regions ① and ⑦ are known for their semiconductor industry, while regions ①, ②, and ⑤ are known for their automobile industry. Regions ②, ④, and ⑥ are home to large-scale industrial complexes for petrochemical and

oil refining industries, which are representative industries of Korea. Additionally, region ① has a high concentration of small and medium-sized businesses in the machinery, dyeing, and plating industries. As shown in Figure 5, regions ②, ④, and ⑥ where representative petrochemical and oil refining industries are located, have relatively high occurrences of major industrial accidents, accounting for 63% of the total. In addition, in region ①, which has many small and medium-sized businesses, the second-highest number of major industrial accidents occurred, as shown in Tables 5 and 6.

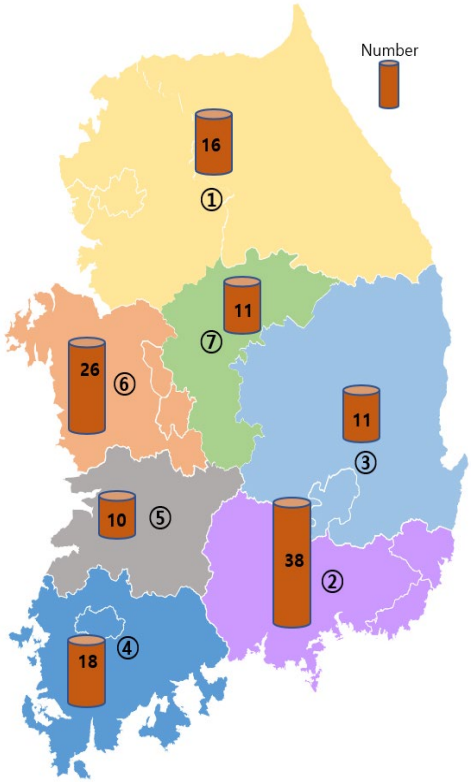

Figure 5. Analysis of major industrial accidents by region (2005–2021).

Table 5. Regional status by industrial characteristics.

Region	Characteristics
① Metropolitan Area	- semiconductor and display and automobile industries - small and medium-sized chemical industry
② South Gyeongsang Province	- oil and petrochemical industries - automobile industries
③ North Gyeongsang Province	- chemical industries - small and medium-sized chemical industry
④ South Jeolla Province	- oil and petrochemical industries - automobile industries
⑤ North Jeolla Province	- chemical industries - small and medium-sized chemical industry
⑥ South Chung cheong Province	- oil and petrochemical industries - display and automobile industries
⑦ North Chung cheong Province	- chemical and semiconductor Industries - small and medium-sized chemical industry

Table 6. Status of major industrial accidents by region since 2005.

Classify	Sum	① Metropolitan Area	② South Gyeongsang Province	③ North Gyeongsang Province	④ South Jeolla Province	⑤ North Jeolla Province	⑥ South Chungcheong Province	⑦ North Chungcheong Province
Year	130	16	38	11	18	10	26	11
2005	5	2	1	-	1	-	1	-
2006	3	1	1	-	-	-	1	-
2007	4	1	1	-	1	1	-	-
2008	6	-	1	1	2	1	1	-
2009	4	-	3	-	-	-	1	-
2010	5	-	2	2	1	-	-	-
2011	3	-	2	1	-	-	-	-
2012	5	-	-	3	-	1	-	1
2013	5	1	1	-	2	1	-	-
2014	11	1	2	2	2	1	2	1
2015	11	2	4	-	2	1	1	1
2016	11	1	4	-	2	-	3	1
2017	4	-	3	-	-	-	-	1
2018	12	2	2	-	2	-	5	1
2019	12	1	3	-	1	1	4	2
2020	15	1	6	-	-	1	6	1
2021	14	3	2	2	2	2	1	2

5.3. Analysis of Major Causes of Major Industrial Accidents

Looking at the occurrence of major industrial accidents since 2005, it can be seen that there were fewer than six incidents each year until 2013. However, from 2014, the number of incidents increased to 11, 12, or 15. This was due to the expansion of the scope of PSM-targeted workplaces since 2014 and the clarification of the definition of major industrial accidents, which resulted in a rapid increase in the number of targeted workplaces and accidents. The government defined a major industrial accident as "an accident that causes one or more injuries due to a fire, explosion, or leakage in PSM equipment", to improve the issue of the previous unclear definition of major industrial accidents and to strengthen the autonomous safety management of workplaces to prevent such accidents, as shown in Figure 6.

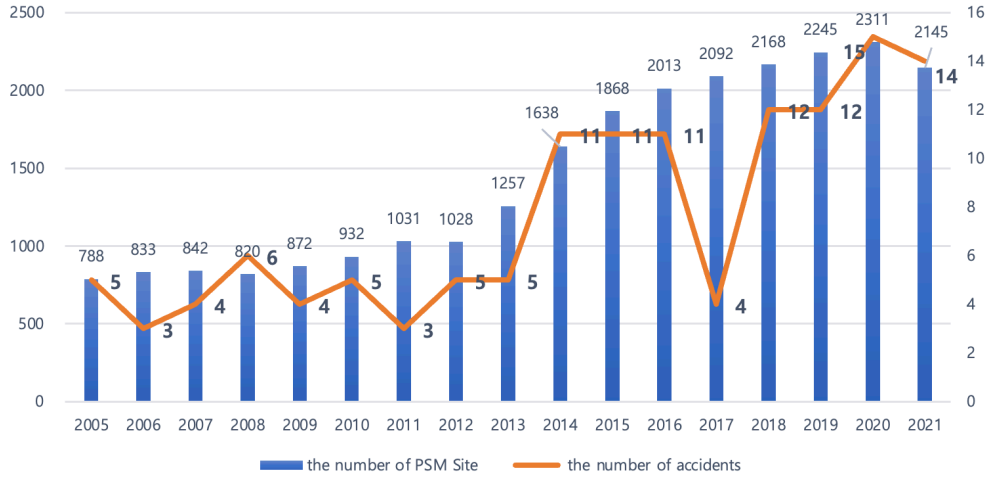

Figure 6. Number of PSM sites and accidents by year.

Next, to identify the causes of major industrial accidents, we analyzed the causes of accidents by year, starting from 1998, in PSM workplaces. Table 7 shows the results of the analysis of the causes of major industrial accidents that have occurred in PSM workplaces since 1998, categorized into ① risk assessment, ② safety operation procedure, ③ facility maintenance, ④ safety work permit, ⑤ management of chance, and ⑥ emergency control plans. When a chemical accident occurs, the inspector at the Ministry of Employment

and Labor investigates the cause of the accident. At this time, there were six categories of primary accident causes. When analyzing the correlation between the PSM system and accidents, it can be seen that accidents are steadily decreasing in the areas of risk assessment, facility maintenance, and management of chance, indicating that management in these areas is adequately carried out. On the other hand, safety operation procedure shows a steady increase in accidents, indicating the need for concentrated management of safety operation procedures, such as review and modification, as well as worker education. Additionally, although there was a slight decrease in accidents in 2021, there is a steady occurrence of accidents in safety work permits, indicating the need for consistent maintenance and management during the regular inspection and maintenance period of equipment.

Table 7. Proportion of causes of major industrial accidents by year.

Classification	1998		2000		2003		2007		2021	
	No.	%	No.	%	No.	%	No.	%	No.	%
① Risk assessment	55	32.7%	58	31.9%	13	17.3%	25	20.2%	15	11.5%
② Safety Operation Procedure	23	13.7%	26	14.3%	23	30.7%	31	25.0%	64	49.2%
③ Facility maintenance	8	4.8%	10	5.5%	8	10.7%	16	12.9%	14	10.8%
④ Safety work permit	66	39.3%	71	39.0%	29	38.7%	46	37.1%	33	25.4%
⑤ Management of chance	15	8.9%	16	8.8%	2	2.7%	4	3.2%	3	2.3%
⑥ Emergency control plan	1	0.6%	1	0.5%	0	0.0%	2	1.6%	1	0.8%

6. Results and Discussion

The implementation of the PSM system not only reduces losses occurring due to the reduction in major industrial accidents, but also contributes to the creation of national profits by conducting risk assessments with domestic technology when exporting plants. These effects have been attributed to the fact that "safety investment is costly" [9,36,37].

It served as an opportunity to change the perception of business owners that investment in safety is the loss and cost to "safety is business and profit". As the Severe Accident Punishment Act was enforced in 2022, interest in establishing and implementing a safety and health management system has grown significantly, and industries that need to implement the PSM system in particular are responding to the implementation of the Severe Accident Punishment Act without much difficulty. This is because if the PSM system is well followed, it establishes and implements the safety and health management system described in the Severe Accident Punishment Act [38].

By analyzing the main causes of major industrial accidents, it was found that accidents occurred because of non-compliance with safe driving and work permit procedures. In addition, as the number of deaths due to major industrial accidents was most often caused by accidents during maintenance and repair work, it can be said that accidents occur because the PSM system established in the workplace does not actually operate properly in the field.

To prevent major industrial accidents, such as leakages, fires, and explosions, during maintenance and repair work, the following two key elements of PSM, derived from the results of accident cause analysis, must be thoroughly implemented. First, safety work permit procedures, such as maintenance and repair, must be strictly followed. It must be issued and approved after on-site confirmation of safety measures for hazardous work. In addition, if on-site safety supervision is required during work, depending on the degree of risk, scale, and complexity of the work, the operation department will be present to meet all safety requirements. Actions on this matter must be confirmed. Second, it is necessary to prepare and comply with safe work (driving) procedures that reflect work risk assessments. The safety work procedure must be written in a safe way that conforms to the order of work from the beginning to the end of the actual work process to be performed by the worker, so that the harmful risk factors that exist at each stage of the work can be eliminated. Stakeholders, such as employees of the relevant department, as well as workers

from related departments and subcontractors, should be educated and familiarized with them. In particular, it is necessary to establish and implement the principle that workers work safely according to the safety work procedures that they are fully aware of and do not carry out work without safe procedures in place. Regardless of how well a PSM system for the prevention of major industrial accidents is documented and procedurally established, it is meaningless if not implemented in the field. Therefore, it should not be forgotten that the key task for workplaces subject to PSM is to secure the site operability of the established system and ensure its sustainability.

7. Conclusions

This study analyzes the current status and causes of major industrial accidents in Korea. Of the 130 major industrial accidents that occurred in the last 17 years (2005–2021), less than 100 companies accounted for the majority of incidents, only including 47 cases (36.1%). According to the results of the PSM grades by industry and company size in 2021, larger companies showed a relatively higher P-grade ratio, indicating that they are managing their safety and health practices better than small and medium-sized enterprises. In contrast, 67.0% of the small businesses with fewer than 100 employees were rated as M-grade (M+, and M−), indicating that their safety management practices were inadequate. Therefore, additional efforts are required to improve the safety management practices of small and medium-sized enterprises [39], such as activating a safety culture within the organization, strengthening the determination of business owners, and providing education to workers.

Meanwhile, by analyzing the causes of major industrial accidents that have occurred in PSM facilities since 1998, it was found that risk assessment, safety work permits, and management of chance areas have been steadily decreasing, whereas the safety operation procedure area has been steadily increasing. Therefore, there is a need to focus on managing safety operating procedures, such as reviewing and modifying safety procedures, and providing worker education. Furthermore, although there has been a slight decrease in accidents related to facility maintenance in 2021, accidents are occurring steadily. Therefore, it is necessary to manage daily inspections and ensure maintenance of equipment to prevent such accidents.

Despite the recent implementation of the PSM system, chemical accidents, including major industrial accidents that occur one after another, are not prevented early. To avoid the risk of chemical accidents in the long term, the current PSM system must change to suit the times. In particular, the safety report submission process should be maintained. It is necessary to eliminate the blind spot of chemical accidents by expanding to meet the real-time demands, focusing on substances with a high risk of harm, and establishing a newly introduced system through the revision of the Occupational Safety and Health Act. Subsequently, efforts to establish a national safety culture must be taken. In addition, as the current PSM system has been introduced and operated, it has been effective in preventing major industrial accidents caused by the leakage of hazardous substances, fires, and explosions. However, there is always a risk of major accidents owing to equipment defects or insufficient safety measures. Therefore, in the field, the PSM system must be continuously improved to fit the actual industrial site while complying with safety work permits, driving, and work procedures, which are the main elements of the PSM system. This process is expected to achieve the safety levels that are in place in the advanced countries. It is hoped that zero accidents will be realized in all industrial sites through the autoelectronic safety management.

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