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Identifying Characteristics of Incidents at Hazardous Material Facilities

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Abstract

Safety and quality assessment systems are very important in manufacture, storage, transportation, and handling of hazardous materials(hazmat) to prevent hazmat disasters. At present, hazardous materials exist everywhere in our daily lives with various forms of plastics, household products of cleaning and washing detergents, fertilizers or petroleum-related products. However, hazardous materials are dangerous substances when they are released to human or environment. Hazardous materials become very widely used substances in the age of oil-based industrial economy. The Korean Ministry of Environment (KMOE) describes about one hundred thousand types of chemicals are produced and used worldwide. Over four hundred new chemicals are introduced in every year. A crucial question for the Korean hazardous material management may have been raised: Will you be safe from hazardous material incidents? The gas leak disaster at Union Carbide's Bhopal, India in 1984 that made over 6,400 people killed and 30,000 to 40,000 people seriously injured is the representative case for the safety of hazmat. Korea becomes vulnerable to hazmat disaster due to the development of high-tech industry. Thus, the risk assessment system is required to Korea for transferring abandoned hazmat management systems to self-correcting safety systems. This research analyzed characteristics of various hazmat incidents applying statistical analysis methods including frequency analysis or analysis of category data to hazmat incidents for ten years. All of three analyses of category data indicate the significance of causality between hazmat incident site groups and seasons, regional groups, and incident casualty groups.

Key words : Hazardous Material, Facility Incident, Statistical Analysis, Analysis of Category Data

요 지

안전 및 품질 평가시스템은 유해물질 재난을 예방하기 위해 유해물질의 생산・저장・수송・취급에 매우 중요하다. 현재 유해물질은 플라스틱, 가정의 세척제, 비료 또는 석유관련제품으로 우리의 일상생활 어디에서든지 존재하고 있다. 그러나 유해물질은 인간이나 환경에 누출되었을 때 매우 위험한 물질이다. 유해물질은 석유기반 경제시대에 매우 폭넓게 사용되고 있다. 우리나라의 환경부는 전세계적으로 유해물질의 유형이 약 십만개가 넘을 것으로 추산하고 있다. 또한 매년 4백개 이상의 새로운 물질이 개발되고 있다. 따라서 유해물질 관리측면에서 우리는 유해물질 사고로부터 안전한가에 대해 의문이 제기될 수 있다. 1984년에 발생해 6,400명이 넘는 사망자와 3만명 이상의 부상자를 낸 인도 보팔사고는 이러한 우리의 유해물질 안전에 대한 불안을 증폭시키는 대표적인 사례이다. 우리나라는 최근 산업의 고도화로 각종 유해물질 사고가 빈번하게 발생하고 있다. 따라서 낙후된 유해물질 관리시스템을 자기관리가 가능한 안전시스템으로 전환하기 위한 위험평가시스템의 구축이 우리사회에 요구되고 있다. 본 연구는 유해물질 위험평가시스템 구축을 위한 기반을 제공하기 위해 지난 10년동안 유해물질 관련시설에서 발생한 사고사례들을 연구의 대상으로 하여 유해물질 시설사고의 특성을 빈도분석, 교차분석 등의 통계기법을 적용하여 분석하였다. 분석결과 사고시설 유형과 연도, 계절, 발생지역, 사망자 발생간 관계가 있는 것으로 나타났다.

핵심용어 : 유해물질, 시설사고, 통계분석, 교차분석

1. Introduction

Safety and quality assessment systems are very important in manufacture, storage, transportation, and handling of hazardous materials(hazmat) to prevent hazmat disasters. At present, hazardous materials exist everywhere in our daily lives with various forms of plastics, household products of cleaning and washing detergents, fertilizers or petroleum-related products. However, hazardous materials are dangerous substances when they are released to human or environment. Thus, the safety of hazardous material transportation and storage is essential in advanced countries with high-tech chemical industries.

Hazardous materials become very widely used substances in the age of oil-based industrial economy. The Korean Ministry of Environment (KMOE) describes about one hundred

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thousand types of chemicals are produced and used worldwide. Over four hundred new chemicals are introduced in every year. The U.S. Department of Transportation (U.S. DOT) identifies 4,126 types of materials as hazmats in 2008. The Korean government identifies more than 1,200 chemicals as hazmats based on the 「Dangerous Chemicals Management Presidential Ordinance § 13」.

A crucial question for the Korean hazardous material management may have been raised: Will you be safe from hazardous material incidents? How risky do your daily activities from hazardous material release or contact? There have been cases in which thousands of people died from single, catastrophic events such as the gas leak at Union Carbide's Bhopal, India in 1984 because of the explosion of insecticide plant. Safety systems failed and warning was not given until well after the leak, when gas built up in a storage tank. The methyl-iso-cyanate made over 6,400 people killed and 30,000 to 40,000 people seriously injured. The total number of casualty increased from injuries to lungs and nervous systems(Waugh, 2000).

The use of hazardous materials makes our society a high-risk system. Perrow(1999) proposes the high-risk systems into three categories: 1) hopeless and abandoned systems because the inevitable risks outweigh any reasonable benefits, 2) less risky systems with considerable effort or where the expected benefits are so substantial, and 3) self-correcting systems to some degree and could be further improved with quite modest efforts. The risk assessment method and process is essential in transferring a society from the hopeless and abandoned systems to self-correcting systems. The risk assessment process begins with the understanding of existing risky incidents such as hazardous materials.

The objective of this research is to identify characteristics of various hazmat incidents occurred in facilities. Statistical analysis methods including frequency analysis and analysis of category data are applied to examine several hypotheses in hazmat facility incidents.

2. Research Data and Analysis Method

The Korean government provides three sources of hazardous material incidents made enable for hazmat incident studies. Kim and Moore, II(2008a) provides detailed information for the three data sets of hazardous material incidents. This research summarizes the key information of the three hazmat data sets. The first data set is the statistical yearbook data for human-caused disasters published by the National Emergency Management Agency(NEMA). The data set includes environmental contamination incidents collected from 1995 to 2006. The problems are that this data have a significant limitation and the source data sets are not available for analyses.

The second data set for hazardous material incidents is the statistical yearbook data for hazardous materials published by NEMA. This second data set has much more information compared with the first data set. However, this data sets is only available from 2006 to 2007.

The last data set is the Emergency Information Service (EIS) database provided by the Chemical Emergency Information Center (CEIC) of Inje University. The Inje CEIC was established by the support of the Ministry of Environment, Korean Government. The CEIC data set is consisted of 1,120 cases of hazardous material incidents from 1987 to 2006. The data set contains eleven variables including incident type, year, month, day, date, incident site, administrative region, local jurisdiction, incident factor, incident cause, and number of death. This research adopts the CEIC data set as the research data for hazardous material incident analyses.

Facility-related hazmat incidents among the 1,120 CEIC cases are identified as 648 cases. The remaining cases were occurred at transport, marine sites or areas. Statistical analysis methods are applied as the major research approach. Frequency analysis and analysis of category data are used to examine several hypotheses for hazmat incidents in facilities.

3. Description of Hazardous Material Facility Incidents

The hazmat incident sites of six-hundred forty eight facility cases are composed of gas stations (26 cases, 4.01%), factories & open storage yards (414 cases, 63.89%), construction sites (26 cases, 4.01%), commercial buildings (58 cases, 8.95%), houses (44 cases, 6.79%), public facilities (69 cases, 10.65%), LPG stores (5 cases, 0.77%), and basement & pipelines (6 cases, 0.93%). Figure 1 shows the distribution of the eight incident site groups. Factories and open storage yards are the first hazmat incident sites. Commercial buildings, houses and public buildings are also noticeable hazmat incident sites.

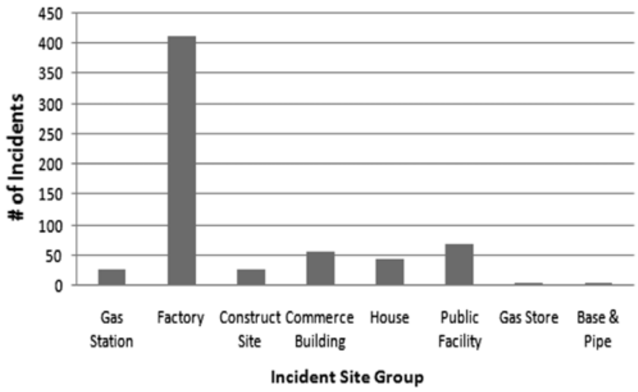

Fig. 1. Distribution of Hazardous Material Incident Site Groups.

The occurrence of hazardous material incidents is varied year by year, month by month, and date by date. This research presents the difference between the total number of hazmat incidents and that of facility hazmat incidents. The yearly distribution between the total and the facility numbers of hazmat incidents is shown in figure 2. The gap between the total number and the facility number of hazmat incidents were big during the periods of 1994 to 1997, and 2004 to 2006.

Figure 3 presents the monthly distributions between the total and the facility numbers of hazardous material incidents. The numbers of hazmat incidents between February and March, and between June and November exceed those of total hazmat incidents. The total numbers of hazmat incidents are significantly higher in January, April, May and December.

Figure 4 presents the date distributions between the numbers of total and those of facility hazardous material incidents. The numbers of hazmat incidents in Tuesday, Friday, Saturday, and Sunday(mostly weekends) exceed those of total hazmat incidents. The total numbers of hazmat incidents are higher in Monday, Wednesday, and Thursday.

The distributions of hazmat incident factors between the total and the facility are presented in table 1. "Leakage" is the most significant incident factor in total, but the second in facility hazmat incidents. "Explosion" is the second incident factor in total, where as "Leakage" is the second incident factor in facility. "Release," "Fire," and "Other" are the remaining of top five hazmat incident factors in total and facility.

The regional distributions of the total and the facility numbers of hazardous material incidents are presented in table 2. Kyonggi province is the highest administrative region in both total and facility hazmat incidents. The Seoul metropolitan city is the second administrative region in total and facility. "Ulsan" and "Jeonnam" exceed ten percent of share in facility incidents.

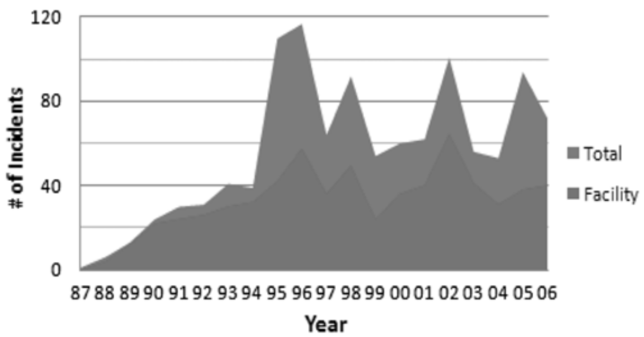

Fig. 2. Yearly Distributions of Hazardous Material Incidents in total and Facility

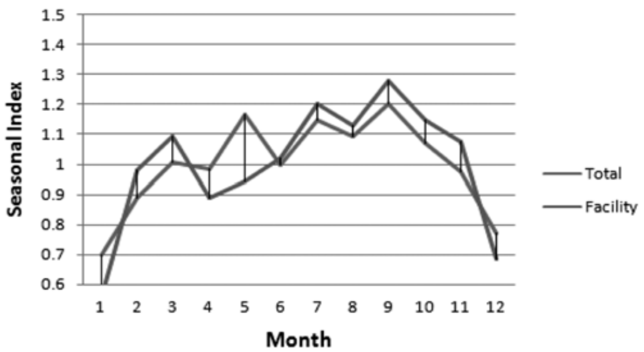

Fig. 3. Monthly Distribution of Hazardous Material Incidents in total and Facility

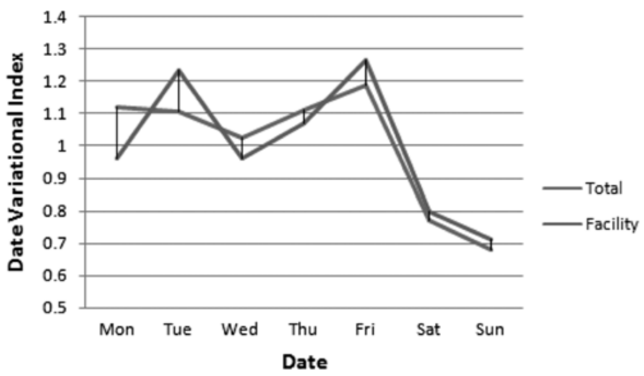

Fig. 4. Date Distributions of Hazardous Material Incidents in total and Facility.

Table 1. Distributions of Hazardous Material Incident Factors in Total and Facility

Incident Type	Total(%)	Facility(%)
Leakage	337(30.1%)	168(25.9%)
Release	82(7.3%)	29(4.5%)
Pipe Burst	12(1.1%)	8(1.2%)
Suffocation	4(0.3%)	3(0.5%)
Poisoning	4(0.3%)	3(0.5%)
Noise	1(0.1%)	1(0.2%)
Contact	1(0.1%)	0(0.0%)
Rollover	5(0.5%)	0(0.0%)
Collision	1(0.1%)	0(0.0%)
Fire	100(8.9%)	79(12.2%)
Explosion	300(26.8%)	244(37.7%)
Release & Fire	4(0.3%)	1(0.2%)
Leakage & Fire	4(0.3%)	2(0.3%)
Explos. & Fire	11(1.0%)	7(1.1%)
Rel. & Explo.	2(0.2%)	0(0.0%)
Leak. & Explo.	4(0.3%)	3(0.5%)
L. & E. & Fire	1(0.1%)	1(0.2%)
Roll. & Rel.	13(1.2%)	0(0.0%)
Roll. & Fire	1(0.1%)	0(0.0%)
Roll. & Explo.	1(0.1%)	0(0.0%)
R. & F. & E.	1(0.1%)	0(0.0%)
Coll. & Fire	1(0.1%)	0(0.0%)
Other	183(16.4%)	85(13.1%)
None	47(4.2%)	14(2.2%)

Table 2. Regional Distributions of Hazardous Material Incidents in Total and Facility

Region	Total(%)	Facility(%)
Seoul	120(10.7%)	80(12.4%)
Pusan	59(5.3%)	30(4.6%)
Daegu	41(3.4%)	27(4.2%)
Incheon	42(3.8%)	28(4.3%)
Kwangju	23(2.0%)	14(2.2%)
Daejeon	36(3.2%)	18(2.8%)
Ulsan	116(10.4%)	71(11.0%)
Kyonggi	125(11.4%)	92(14.2%)
Kwangwon	48(4.3%)	17(2.6%)
Chungbuk	48(4.3%)	22(3.4%)
Chungnam	80(7.1%)	30(4.6%)
Jeonbuk	42(3.7%)	25(3.9%)
Jeonnam	115(10.3%)	64(10.0%)
Kyongbuk	77(6.9%)	32(4.9%)
Kyongnam	80(7.1%)	40(6.2%)
Jeju	9(0.8%)	4(0.6%)
Missing	59(5.3%)	54(8.3%)

Table 3. Distributions of Five Hazardous Material Incident Cause Groups in Total and Facility

Incident Cause	Total(%)	Facility(%)
Petroleum	361(35.6%)	136(21.0%)
Gas	244(24.0%)	176(27.2%)
Chemicals	278(27.4%)	173(26.7%)
Waste	99(9.8%)	67(10.3%)
Miscellaneous	33(3.2%)	96(14.8%)

Table 4. Number of Death in Total and Facility Hazardous Material Incidents

No. of Death	Total(%)	Facility(%)
0	843(75.3%)	433(66.8%)
1	142(12.7%)	106(16.4%)
2	63(5.6%)	48(7.4%)
3	25(2.2%)	19(2.9%)
4+	47(4.2%)	42(6.4%)

The distributions of the total and the facility numbers of five hazardous material incident cause groups are presented in table 3. “Gas” is the most significant hazmat incident cause group in terms of facility hazmat incidents, whereas “Petroleum” is the most in total hazmat incidents. “Chemicals” are the second in terms of both total and facility. “Petroleum” is the third in facility. The share(14.8%) of “Miscellaneous” is noticeable in facility, compared with total incidents.

The distributions of hazardous material incident death in total and facility are presented in table 4. “Zero death” is the most frequent group in terms of total hazmat incidents and facility hazmat incidents. However, the share of “Zero death” in facility is lower than that in total. The shares of one or more casualties are higher in facility than total.

4. Statistical Analyses

Evaluation of hazardous material incidents requires a relevant risk assessment method. Gabor and Griffith(1979) introduced the community vulnerability assessment method to acute hazardous material incidents. Shaw, et al.(1986), Kales, et al.(2001) and Kara, et al.(2003) provided the ways of understanding characteristics of hazmat incidents and computing risks of hazmat incidents. This research adopts statistical analyses methods that Kim and Moore, II(2008b) applied to roadway incident cases of hazardous materials. The null hypotheses are evaluated by the analysis of category data. The following three hypotheses are evaluated.

1) Hypothesis 1 : the number of hazardous material incidents occurred in incident sites are same indifferent from seasons.

Eight hazmat incident site groups in figure 1 categorized into six groups: gas stations and LPG stores (group 1), factories & open storage yards (group 2), construction sites (group 3), commercial buildings (group 4), houses (group 5) and pipelines, basements & public facilities (group 6). The chi-squared statistic which is denoted χ^2 is defined as follows:

$$\chi^2 \text{ statistic} = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where

O_i is the observed frequency in category i, E_i is the expected or hypothesized frequency in category i, and K is the total number of categories.

The degree of freedom is (r−1)×(c−1) = (6−1)×(4−1)=15. The critical value of χ^2 at the α=0.05 significance level is 24.996. The statistics of causality between six hazmat incident site groups and four seasons are provided in table 5. The value of χ^2 = 32.3659 is well above the critical value of χ^2 = 24.996 at the α=0.05. This result indicates the significance of causality between two variables. In other words, the number of hazardous material incidents occurred in hazmat incident sites are different by seasons. This is observed in table 6. Hazmat incident site group 1 and 5 are more observed in fall and winter seasons, where as hazmat incident site group 2, 3 and 6 have high frequencies in spring and summer seasons.

This research also evaluated the causality between six

Table 5. Statistics of Causality Between Six HazMat Incident Site Groups and Four Seasons

Variables	Statistic	DF	Value	Prob.	Note
Six Incident Site Groups vs. Four Seasons	Chi-Square	15	32.3659	0.0057	Sample Size = 648
	Likelihood Ratio Chi-Square	15	34.7105	0.0027	
	Mentel-Haenszel Chi-Square	1	0.0235	0.8782	
	Phi Coefficient	-	0.2235	-	
	Contingency Coefficient	-	0.2181	-	
	Cramer's V	-	0.1290	-	

Table 6. The Seasonal Distribution by Groups

Group	Spring	Summer	Fall	Winter	Tot.
G 1	4	2	17	8	31
G 2	99	126	114	75	414
G 3	18	20	16	4	58
G 4	16	7	10	11	14
G 5	15	17	26	17	75
G 6	6	9	6	5	26
Tot.	158	181	189	120	648

hazmat incident site groups and four year groups: 1988-1997, 1998-2000, 2001-2003, and 2004-2006. The result indicates the significance of causality(χ^2 = 72.59, Pr <.0001) between two variables.

2) Hypothesis 2 : the number of hazardous material incidents occurred in incident sites are same indifferent from administrative regions.

Sixteen administrative regions of South Korea are further categorized into three regional administrative groups in table 7.

The same chi-squared statistic is applied in order to evaluate the deviations of the observed frequencies from the expected frequencies. The degree of freedom is $(6-1)\times(3-1)=10$. The critical value of χ^2 at the α=0.05 significance level is 18.307. The statistics of causality between six hazmat incident site groups and three regional groups are provided in table 8. The value of χ^2 = 49.0255 is well above the critical value of χ^2 = 18.307 at the α=0.05 significance level.

This result indicates the significance of causality between two variables. In other words, the number of hazardous material incidents occurred in hazmat incident sites are different by regional administrative groups. It is observed in table 9. All of six groups are highly observed in RAG 3.

Hazmat incident site group 6 is more observed in RAG 1 than RAG 2, where as hazmat incident site group 2, 3 and 5 have higher frequencies in RAG 2 than RAG 1.

3) Hypothesis 3 : the number of hazardous material incidents occurred in incident sites are same indifferent from incident deaths.

Human casualty cases are divided into two groups: death cases and no-death cases. The same chi-squared statistic is applied in order to evaluate the deviations of the observed frequencies from the expected frequencies. The degree of

Table 7. Three Regional Administrative Groups

No.	Administrative regions
1	Seoul
2	Six metropolitan cities
3	Nine provinces and other

Table 9. The RAG Distribution by Groups

Group	RAG 1	RAG 2	RAG 3	Tot.
G 1	8	8	15	31
G 2	24	127	263	414
G 3	15	16	27	58
G 4	12	12	20	75
G 5	14	19	42	75
G 6	7	6	13	26
Tot.	80	188	380	648

Table 8. Statistics of Causality Between Six HazMat Incident Site Groups and Three Regional Administrative Groups

Variables	Statistic	DF	Value	Prob.	Note
Six Incident Site Groups vs. Three Regional Administrative Groups	Chi-Square	10	49.0255	<0.0001	Sample Size = 648
	Likelihood Ratio Chi-Square	10	46.1474	<0.0001	
	Mentel-Haenszel Chi-Square	1	12.0270	0.0005	
	Phi Coefficient	-	0.2751	-	
	Contingency Coefficient	-	0.2652	-	
	Cramer's V	-	0.1945	-	

Table 10. Statistics of Causality Between Six HazMat Incident Site Groups and Two Death Groups

Variables	Statistic	DF	Value	Prob.	Note
Six Incident Site Groups vs. Two Death Groups	Chi-Square	5	18.5132	0.0024	Sample Size = 648
	Likelihood Ratio Chi-Square	5	20.2764	0.0011	
	Mentel-Haenszel Chi-Square	1	3.8938	0.0485	
	Phi Coefficient	-	0.1690	-	
	Contingency Coefficient	-	0.1667	-	
	Cramer's V	-	0.1690	-	

Table 11. The Casualty Distribution by Groups

Group	No Casualty	1+ Casualty	Tot.
G 1	26	5	31
G 2	262	152	414
G 3	40	18	58
G 4	25	19	75
G 5	63	12	75
G 6	17	9	26
Tot.	433	215	648

freedom is $(6-1)\times(2-1)=5$. The critical value of χ^2 at the α=0.05 significance level is 11.070. The statistics of causality between six hazmat incident site groups and two incident death groups (no casualty, one or more casualties) are provided in table 10.

This result indicates the significance of causality between two variables. In other words, the number of hazardous material incidents occurred in hazmat incident sites are different by incident deaths. It is observed in table 11. The proportional difference between no casualty and 1+ casualty is reduced in hazmat incident site group 3.

5. Conclusion

Safety of hazardous material management systems is very important in manufacture, storage, and handling of hazardous material goods. The Korean hazardous material management should begin with the risk evaluation of hazardous material incidents.

This research identified characteristics of various hazmat incidents occurred in facilities.

Basic information for hazardous material incidents in facilities is provided. The three analyses of category data indicate that the causalities of the three cases are statistically significant at the α=0.05 level of significance. Hazmat incident site group 1 and 5 are more observed in fall and winter seasons, where as hazmat incident site group 2, 3 and 6 have high frequencies in spring and summer seasons.

According to hypothesis test 2, Hazmat incident site group 6 is more observed in RAG 1 than RAG 2, where as hazmat incident site group 2, 3 and 5 have higher frequencies in RAG 2 than RAG 1. The hypothesis test 3 shows that the proportional difference between no casualty and 1+ casualty is reduced in hazmat incident site group 3. These statistical results provide useful information for the hazmat incident management of Korean facilities.

Further studies are suggested in geographical distribution patterns of hazmat incidents, incident factors, and incident causes. Different statistical methods and GIS analysis are also recommended to be applied in this research data set.

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