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방재정책

# The Study for Hazardous Material Incidents in Korea

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## Abstract

Hazardous material (HazMat) is the material or substance that poses an unreasonable risk to human safety and health, and to property when transported in gases, solids, and liquids of all sizes. When HazMats are improperly released, they have potential to harm humans, property, or the environment to be considered hazardous, resulting in human-caused disasters. As the Korean economy has advanced, the use of HazMats has increased. And, the total number and the impacts of HazMat incidents have grown up. It increases the risk of HazMat incidents. When many goods of HazMats are transported from supply points to demand places, it is important to know what the types and characteristics of HazMat incidents are in terms of disaster management. The objectives of this research are: (1) to investigate types and characteristics of HazMats that generate HazMat incidents in Korea, and (2) to analyze time-series trends of HazMat incidents in terms of facilities and/or transportation. Statistical analysis methods including frequency analysis or analysis of category data are applied to examine the significance of difference in HazMat incidents.

***Keywords*** **:** Hazardous material, Hazardous material incidents, Human-caused disaster, Statistical analysis, Time-series trend

## 요 지

유해물질은 다양한 기체 · 액체 · 고체형태로 수송될 때 인간의 안전과 건강, 재산에 예측할 수 없는 위험을 야기시킬 수 있는 물질을 의미한다. 유해물질은 실수로 유출된다면 인명과 재산 그리고 환경측면에서 재난을 결과할 수 있다. 한국의 경제가 발전할수록 유해물질의 사용은 증가한다. 그리고 유해물질 사고의 총 건수와 영향 역시 증가하게 되어 유해물질 사고의 위험도도 증가하고 있다. 다양한 유형의 유해물질이 공급지에서 수요지로 이동할 때 유해물질 사고의 유형과 특성이 어떠한가를 아는 것은 재난관리 측면에서 매우 중요한 사항이다. 본 연구의 목적은 한국에서 유해물질 사고를 발생시키는 유해물질의 유형과 특성을 조사하고, 시설과 교통측면에서 유해물질 사고의 시계열적 추세를 분석하는 것이다. 본 연구는 빈도분석, 교차분석과 같은 통계분석기법을 유해물질 사고의 통계적 유의성을 분석하기 위해 적용하였다.

**핵심용어** : 유해물질, 유해물질 사고, 인적재난, 통계분석, 시계열 추세

## 1. Introduction

Shipments of hazardous materials are the critical function of industrially high-tech countries with very competitive chemical, biological, and radioactive industries in the 21$^{st}$ century. Hazardous material (HazMat) is a substance or material in any form or quantity that is capable of posing an unreasonable risk to safety, health, and property when transported in commerce (49 U.S. CFR part 105). HazMat includes hazardous substances, hazardous wastes, marine pollutants, elevated temperature materials, materials designated as hazardous (49 U.S. CFR 172.101), and materials that meet the defining criteria for hazard classes and divisions (49 U.S. CFR part 173 subchapter C). A wide assortment of HazMats including chemicals, radioactive materials, and infectious substances are moved throughout the high-tech countries by different modes of transportation (trucks, trains, ships, airlines, and pipelines), by a wide arrange of size from bulk quantities to small parcels, and by a various types of manufacturers (hazardous materials and packaging products), shippers, and carriers.

Safety of HazMat transportation is essential to high-tech countries that possess high values to human life and health. As HazMat shipments present some risks to public safety and security, human health, and the environment, ensuring the safe and secure transportation of HazMats requires the proper management of HazMat transportation risks that are shared by shippers, carriers, regulators, and emergency responders throughout the country, industry, the public, interested parties, and all levels of government (TRB, 2005). Consequently, the information of identifying potential HazMat hazards, computing the probability of HazMat incident occurrence, and understanding the consequences of such incidents is admirable to all levels of public and private sectors, sharing the responsibility of HazMat transportation safety.

Korea has achieved the remarkable economic development named “the Miracle of Han river” since the 1960s. Some part of this Korean economic success depends on chemical industries. As the Korean economy has advanced, many goods of hazard-

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ous materials have been transported from supply points to demand places. And, the risks and impacts of HazMat incidents have increased. At present, determining the acceptable, affordable, and comparable levels of HazMat risks with other risks inherent in Korean society becomes a very important task for a proper allocation of disaster management resources in view of "Safe Korea[1]."

The objectives of this research are: (1) to investigate types and characteristics of HazMats that generate HazMat incidents in Korea, and (2) to analyze time-series trends of HazMat incidents in terms of facilities and/or transportation. Statistical analysis methods including frequency analysis or analysis of category data are applied to examine the significance of difference in HazMat incidents.

## 2. Literature Review

Modeling risks of HazMat incidents is the core of building a safe and secure system of HazMat transportation. It requires products of long-term studies by various fields of experts in HazMat facility and transportation, risk analysis and management, emergency and disaster planning, and science and public health. Relevant HazMat incident research can be performed with collective efforts of the thousands of public and private entities responsible for ensuring the accuracy of shipment record and incident information of HazMat in transportation. The U.S. Department of Transportation launched the Hazardous Materials Transportation Program (HMTP) to identify and manage risks presented by HazMat transportation in 1974 (USDOT PHMSA, 2008). A wide range of HazMat incident studies have been performed with the basis of shipment record and incident information of HazMat.

USEPA (1976, 1980) provided a way of computing damages and threats caused by HazMat sites, and controlling HazMat spills. COES (1982, 1988) developed the State of California hazardous material incident emergency plan based on California HazMat incidents. Winder (1989) addressed the issue of an Australian System for Hazardous Material Incident Reporting (ASHMIR). Burgess, et. al. (2000) introduced a HazMats exposure information service. Cone and Davidson (1997) conducted to examine the preparedness of emergency departments to safely receive, decontaminate, and treat chemically contaminated patients. Shaw, et. al. (1986) and Kales, et. al. (2001) studied characteristics and injuries of HazMat incidents. Lindell and Perry (1996) pointed out the issue of earthquake-induced hazardous materials releases.

Modeling of environmental and transport risks for hazardous materials has been performed by Gabor and Griffith (1979), Pijawka, et. al. (1985), Gopalan, et. al. (1990), Willard (1991), Erkut and Verter (1995), Bruzzone (1996), Erkut and Verter (1998), Leonelli, et. al. (1999), Pet-Armacost, et. al. (1999), Zhang, et. al (2000), Verter and Kara (2001), Kara, et. al. (2003), and Martines-Alegria, et. al. (2003). Hendershot (1988) introduced basic chemical engineering principles to reducing intrinsic hazards of HazMat release incidents in chemical manufacturing facilities. Current and Ratick (1995) proposed a multi-objective model to assist decision makers in the location of facilities that HazMats, and in the routing of HazMats to these facilities.

Cox (1994) and Levitin and Siegelson (1996) insisted the importance of medical care to HazMat exposure patients by contaminating and managing with advance planning, specialized training and equipment, and response actions. Horton, et. al. (2003) studied secondary contamination of first responders from HazMats events from 1995 to 2001. Kirk, et. al. (1994) introduced a way of emergency department response to HazMats incidents. IEEE (2002) developed the IEEE standard for the exchange of vital data about HazMat and other cargo and contents of vehicles and buildings to support real-time interagency transportation-related incident management through common incident management message sets. Modeling the atmospheric dispersion of HazMat releases is implicated for homeland security (Ebrary, Inc., 2003; Sullivan, et. al., 2008).

Applying high-technologies to HazMat incidents is a relevant research subject in the field of HazMat transportation incidents. Pang (1990) performed studies using a unifying framework for the integration of information from various sensor-based and knowledge-based sub-systems of the high level programming and control of autonomous mobile robots in a HazMat spill emergency situation.

There has been a lack of research for HazMat incidents of Korea, comparing with international studies. Kim and Ahn (1999) and Ahn (2001) studied HazMat incidents in land, and introduced GIS based HazMat transportation management system. Ahn, et. al. (2004) developed the concepts and methods of applying HazMat to the National Emergency Response Information System (ERIS).

## 3. Research Data and its Problems

There are three data sets for analyzing HazMat incidents of Korea. The first data set is obtained from the Statistical Yearbook for Human-Caused Disasters (SYHCD) published by the National Emergency Management Agency (NEMA) of the Korean Government. The SYHCD data set is classified into nine types of human-caused disasters including environmental contamination incidents. The second data set is obtained from the Statistical Yearbook for Hazardous Materials (SYHM) published by NEMA. The last data set is obtained from the Emergency Information Service (EIS) DB system provided by the Chemical Emergency Information Center (CEIC) of Inje University established by the support of the Ministry of Environment, Korean Government.

The SYHCD data set is available from 1995 to 2006. However, analyses of HazMat incidents using the SYHCD data are very limited because the raw data is not available for analysis and the classification of human-caused disasters is obscure. The SYHM data set has much more information in terms of HazMat incident analysis, comparing with the SYHCD data set. However, the SYHM data set is only available for two years from 2006 to 2007. Thus, this research applies CEIC's EIS DB to trend analyses for HazMat incidents. The CEIC data set is composed of 1,120 observations from 1987 to 2006, and contains eleven variables including incident type, year, month, day, date, incident site, administrative region, local jurisdiction, incident factor, incident cause, and number of death. The major problem of using CEIC data set is the data accuracy.[2] Table 1 summarizes the comparison among the three data sets for HazMat incidents.

Figure 1 presents the incident frequency and death number of the three Korean data sets for HazMat incidents. This is the maximal data set available for this research. This research suggests the national HazMat incident reporting system as Winder (1989) introduced to the Australian government. Figure 2 shows the trend of reported and serious HazMat incidents with assistance of Incident Report Form 5800 of the U.S. government.

## 4. Analyses and Results

### 4.1 Hazardous Materials Causing HazMat Incidents

The post-industrial life-style of human being in the 21st century highly depends on chemical products such as plastic, tire, vinyl, acid, or synthetic fiber. European Union defines about one hundred thousand chemical materials, and has newly classified about three thousand chemicals since September 19th, 1981. The Ministry of Environment, Korean Government has designated about forty-one thousand chemicals. About four hundreds of new chemicals are annually introduced in Korea. The significant number of chemicals among all of chemicals is proofed or potential hazardous materials. The U.S. Department of Transportation defines 4,126 materials as HazMats. The U.S. Environmental Protection Agency considers 387 chemicals as extremely hazardous substances (EHSs). The Ministry of Environment, Korean Government defines more than 1,200 materials as hazardous materials including 558 toxicoids, 21 monitoring materials, 8 restricted materials, 59 banned materials, 56 potential HazMat incident materials, 100 VOCs, and 490 hazardous substances.

This research classifies causal materials or substances of the 1,120 CEIC HazMat incidents into five cause groups: petroleum-related goods, gas-related goods, chemical goods, waste goods, and miscellaneous goods. Figure 3 shows the incident numbers of five HazMat incident cause groups based on the CEIC incident data set. Two hundred and forty six cases of hazardous materials and substances are further identified from the 1,120 CEIC HazMat incidents, including combinations among hazardous materials and substances. Incident factors are defined to six groups and further twenty-five small categories. The distribution of six incident site groups is shown in Figure 4. Table 2 indicates the top twenty causal goods of 1,120 HazMat incidents.

The distribution of six HazMat incident site groups by five incident cause groups is shown in Figure 5. Petroleum-related

**Table 1.** Comparison of Three Data Sets for Hazardous Material Incidents of Korea

| Data Name | Provider | Available Year | Data Description |
|---|---|---|---|
| SYHCD | NEMA | 19952006 | Source data unavailable, limitation in variables |
| SYHM | NEMA | 20062007 | Source data unavailable, limited to two year data sets |
| EIS DB | CEIC | 19872007 | The accuracy of data is not guaranteed |

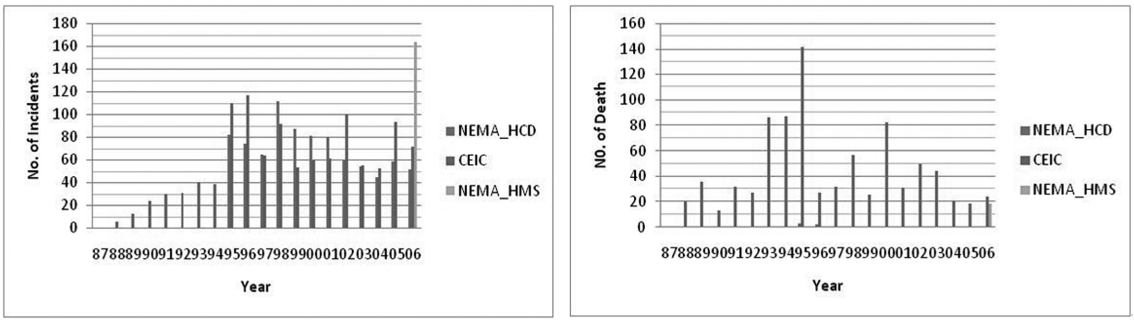


Fig. 1 Incident Frequency and Death Number of the Three Korean HazMat Data Sets

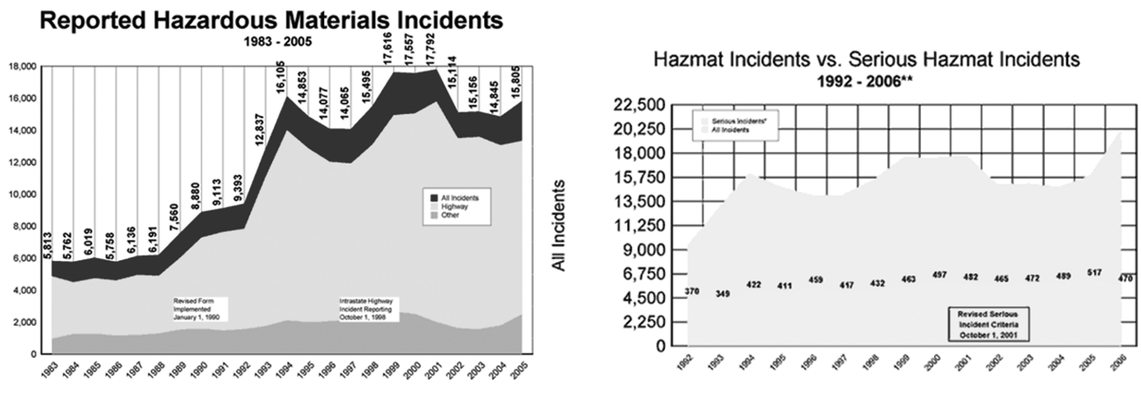


Fig. 2 Reported and Serious Hazardous Materials Incidents in U.S. (Source: http://hazmat.dot.gov/enforce/spills/spills.htm)

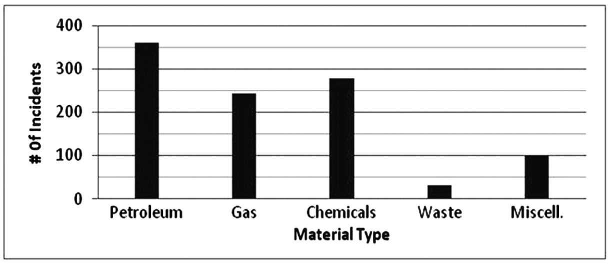


Fig. 3 Incident Numbers of Five HazMat Incident Cause Groups based on CEIC Data

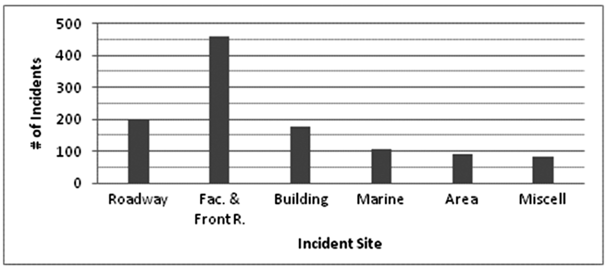


Fig. 4 Incident Numbers of Six Incident Site Groups

**Table 2.** Top Twenty Causal Goods of 1,120 HazMat Incidents

| Ranking | Goods *(Materials, Substances, Products)* | # of Incidents | Percentage |
|---|---|---|---|
| 1 | LPG(liquefied petroleum gas) | 96 | 8.57% |
| 2 | bunker fuel oil C | 83 | 7.41% |
| 3 | Crude oil | 80 | 7.14% |
| 4 | Light oil | 70 | 6.25% |
| 5 | City gas | 43 | 3.84% |
| 6 | Ammonia, Ammonia gas | 30 | 2.68% |
| 7 | General gas | 28 | 2.50% |
| 8 | Hydrochloric acid | 26 | 2.32% |
| 9 | Sulphuric acid, Sulphuric acid gas | 20 | 1.79% |
| 10 | Toxic gas | 18 | 1.61% |
| 10 | Sodium hydroxide | 18 | 1.61% |
| 12 | Jet engine fuel | 17 | 1.52% |
| 13 | Gasoline | 15 | 1.34% |
| 14 | Butane gas | 14 | 1.25% |
| 14 | Toluene | 14 | 1.25% |
| 17 | Kerosene | 12 | 1.07% |
| 17 | Oxygen | 12 | 1.07% |
| 17 | Explosives | 12 | 1.07% |
| 19 | Thinner | 10 | 0.89% |
| 19 | Hydrogen | 10 | 0.89% |

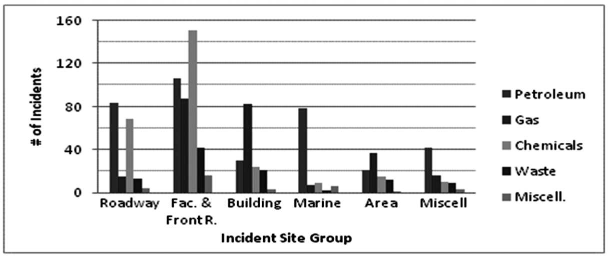


Fig. 5 Incident Numbers of HazMat Incident Site Groups by Incident Cause Groups

and chemical incidents dominate other types of incidents in roadways. Chemicals are the primary incident cause in facilities and front roads of facilities. Gas-related incidents dominate in buildings and areas, whereas petroleum-based incidents are major causes in marine and ports, and miscellaneous cases. The statistical test outcome of causality between HazMat Incident cause groups and incident site groups is provided in Table 3. The SAS software 9.1 is used for this analysis. This result indicates the significance of causality between HazMat incident cause groups and incident site groups.

### 4.2 Time-Series Trend of HazMat Incidents

If the national economy of Korea is in a growing trend, the total number of HazMat incidents would be in an increasing pattern unless the Korean government remarkably improves the HazMat incident management system. The long-term trend of the CEIC data set is shown in figure 1. This research evaluates the statistical significance of long-term pattern by applying correlation and regression analyses. Table 4 includes the statistical results of long-term trend evaluation. Figure 6 presents the scatter plot between year and the number of incidents with the regression model. They approve the significance of long-term trend of HazMat incidents.

This research further investigates the long-term trend by HazMat incident site groups. The statistical result of Table 5 indicates there is a strong causality between years and incident sites.

This research analyzes the date difference using HazMat incident site groups. Figure 8 presents the number of incidents by date, and by date with HazMat incident site groups. The statistical result of Table 6 indicates there is a strong causality between dates and incident sites.

## 5. Conclusion

Hazardous material incidents are the inherent problem of

**Table 3.** Statistics of Causality Between HazMat Incident Cause Groups and Incident Site Groups

| Variables | Statistic | DF | Value | Prob. | Note |
|---|---|---|---|---|---|
| Six Incident Site Groups vs. Five HazMat Incident Cause Groups | Chi-Square | 20 | 252.0406 | <. 0001 | Effective Sample Size = 1,015 Missing Data = 105 |
| | Likelihood Ratio Chi-Square | 20 | 249.2293 | <. 0001 | |
| | Mentel-Haenszel Chi-Square | 1 | 10.6223 | 0.0011 | |
| | Phi Coefficient | - | 0.4983 | - | |
| | Contingency Coefficient | - | 0.4460 | - | |
| | Cramer's V | - | 0.2492 | - | |

**Table 4.** Statistical Results of Long-Term Trend Evaluation

| Corr. Coef. | Variable | Par. Est. | Std. Err. | t value(Pr) | $R^2$(Adj $R^2$) | F value |
|---|---|---|---|---|---|---|
| 0.65648 (0.0017) | Intercept | 16.35263 | 12.25059 | 1.33(0.1986) | 0.4310 (0.3994) | 13.63 (0.0017) |
| | Year | 3.77594 | 1.02266 | 3.69(0.0017) | | |

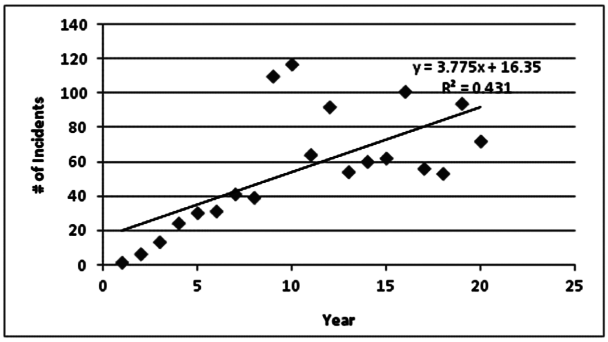


Fig. 6 Scatter Plot between Year and Incidents with the Regression Model

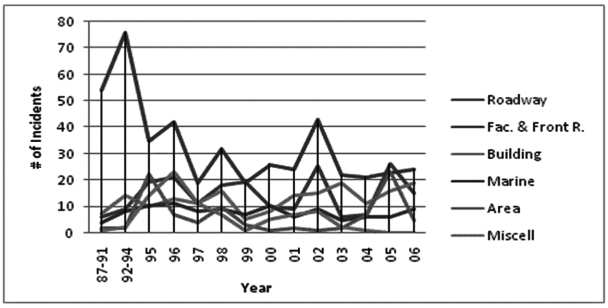


Fig. 7 Long-Term Trend by Incident Numbers of HazMat Incident Site Groups

industrially developed countries. Therefore, industrially high-tech countries consider the safe and secure transportation of HazMats as one of the primary goals in national policy. As the economy of Korea has advanced, the total number and the impacts of HazMat incidents have increased. Consequently, ensuring the HazMat incident management system becomes an emerging task to the Korean government.

This research describes the existing HazMat incident data sets of Korea and their problems. Top twenty causal goods that create HazMat incidents in Korea are provided based on the CEIC data set. The significance of HazMat incident-cause groups, long-term growth, and date difference among six incident site groups is statistically evaluated. These statistical results provide useful information in HazMat incident management of Korea.

Further studies are suggested in geographical distribution patterns of HazMat incidents, incident factors, incident causes, and number of death. Different statistical evaluation approach and GIS analysis are also recommended to be applied in this research. Additional analyses using the SYHCD and SYHM data sets are also encouraged to understand trends and patterns of HazMat incidents in Korea, and to improve the safety and security of Korean HazMat incident management system.

## Acknowledgments


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**Table 5.** Statistics of Causality Between Year Groups and Incident Site Groups

| Variables | Statistic | DF | Value | Prob. | Note |
|---|---|---|---|---|---|
| Fourteen Year Groups vs. Six HazMat Incident Site Groups | Chi-Square | 65 | 258.6112 | < .0001 | Sample Size = 1,120 |
| | Likelihood Ratio Chi-Square | 65 | 250.7541 | < .0001 | |
| | Mentel-Haenszel Chi-Square | 1 | 6.1660 | 0.0130 | |
| | Phi Coefficient | - | 0.4805 | - | |
| | Contingency Coefficient | - | 0.4331 | - | |
| | Cramer’s V | - | 0.2149 | - | |

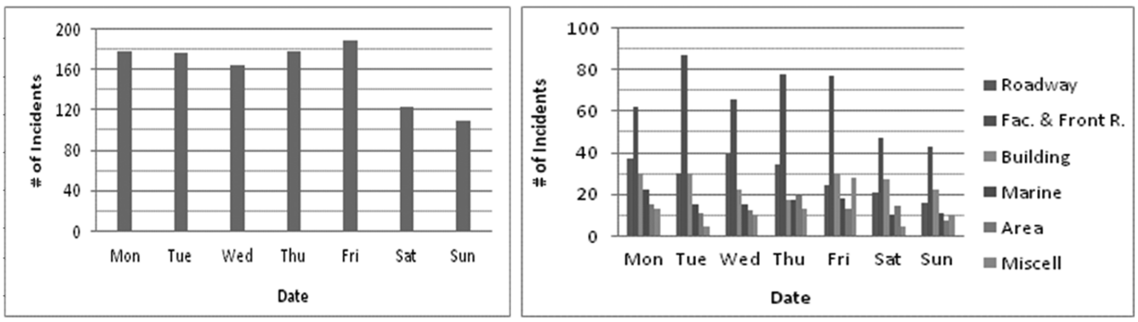


Fig. 8 Incident Numbers by Date, and by Date with HazMat Incident Site Groups

**Table 6.** Statistics of Causality Between Dates and Incident Site Groups

| Variables | Statistic | DF | Value | Prob. | Note |
|---|---|---|---|---|---|
| Seven Dates vs. Six HazMat Incident Site Groups | Chi-Square | 30 | 53.2802 | 0.0055 | Sample Size = 1,120 |
| | Likelihood Ratio Chi-Square | 30 | 53.1714 | 0.0057 | |
| | Mentel-Haenszel Chi-Square | 1 | 1.3476 | 0.2457 | |
| | Phi Coefficient | - | 0.2181 | - | |
| | Contingency Coefficient | - | 0.2131 | - | |
| | Cramer's V | - | 0.0975 | - | |

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Notes:

(1) Safe Korea" is the official slogan of the National Emergency Management Agency(NEMA) of the Korean government.

(2) The accuracy of CEIC's EIS database is not guaranteed because the data set is collected from newspaper articles. When we checked

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