Statistical Analysis of Dangerous Goods Accidents in Japan

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Abstract

Statistical analysis of accident cases concerning dangerous goods was carried out in order to clarify the causes of the accidents. The results of this investigation will be useful for preventing similar accidents in the future.

The number of dangerous goods accidents in Japan has been increasing, and the number of dangerous goods accidents reached a record high in the year 2000. Although various cause analyses have been conducted since the increasing trend in the number of accidents first became clear, as of yet, no analysis has clarified definitively the cause for this increase. One reason for these failures is thought to be that the quality of the accumulated data is neither uniform nor reliable.

In the present study, a previously constructed database of dangerous goods accident cases was rearranged to create a new database. The newly constructed database improved the accuracy of multivariate analysis and enabled statistical techniques, such as quantification theory, to be applied.

Keywords

Statistical Analysis, Dangerous Goods Accidents, Quantification Method of the Third Type, Simple Regression Analysis

1. INTRODUCTION

As shown in Fig. 1, the annual number of accidents involving dangerous goods in Japan showed a declining trend between 1980 and 1993, but began to increase after 1993 and the largest number of accidents was recorded in 2000. Although various studies have examined the causes for this increasing trend, the cause has not yet been clarified.

To date, over 10,000 accidents have been reported by local fire stations countrywide to the Fire and Disaster Management Agency (FDMA) of Japan, and these cases have been compiled as a report, “Accident cases concerning dangerous goods” (in Japanese). This report is available in digital form from Kikenbutu Hoan Gijutu Kyokai, Japan.

Figure 1 was generated based on the data gathered in the above-mentioned report. As defined by the FDMA, dangerous goods are liquid or solid chemical substances that easily catch fire or explode.

However, few statistical studies have been conducted on accidents, because the description of each accident is unique and individual reports may contain various ambiguities or uncertainties. Therefore, the effective application of a statistical method requires the rearrangement and categorization of accident cases.

By applying a statistical technique to the rearranged and categorized database, direct and indirect factors that have caused accidents can be analyzed from various viewpoints.

In the present study, factors affecting accidents concerning dangerous goods were analyzed by applying the quantification method of the third type and a single correlation coefficient to the above-mentioned accident database.

2. REARRANGEMENT AND CATEGORIZATION OF ACCIDENTS CONCERNING DANGEROUS GOODS INTO A DATATBASE

The FDMA publishes the “Accident cases concerning dangerous goods” report annually (FDMA 1970-1999). Using this report, a database of dangerous goods accidents form 1980 to 1999 (20 years) was compiled and used for the present study.

Each accident in the report was reported by an individual fire station. Although the FDMA has determined the format of accident reports, the contents of the reports are not uniform because description depends strongly on the individual inspector. As such, a number of reports contain unclear or insufficient descriptions. Therefore, rearrangement of the data was required before the database used in the present study could be constructed. In rearranging the data, special attention was given to accident type, facility type, accident cause, and ignition source. Categorization enables easy statistical analysis of the database by computer software. However, since the computer software does not accept null data empty columns were filled in with placeholder data. Therefore, the description of each accident was read thoroughly and the columns were filled in appropriately.

Each item in the new database is shown in Table 1. The facility type does not refer to a fixed facility, but rather the types of dangerous goods facilities defined by the FDMA. For example, in the facility type column, “tank truck” is listed as a kind of dangerous goods facility. A manufactory is a producer of some type of dangerous goods, and a handling factory is a producer of general goods from some type of dangerous goods. In the accident cause column, the differences between disoperation, unconfirmed operation, inadequate monitoring, and nonfeasance are not clear because for accidents arising due to human error, an inspector decides the accident cause subjectively, and the judgment of the inspector sometimes differs from that of a more objective third party, depending on the individual inspector.

3. STATISTICAL ANALYSIS USING THE QUANTIFICATION METHOD OF THE THIRD TYPE

The items listed in Table 1 were numerated by converting each category to a 0 or 1 for each accident case. If an accident fit a certain category, then that category was assigned a 1; otherwise, the category was assigned a 0. Thus, each accident has a corresponding array of 0’s and 1’s. The accident database was converted to a matrix composed of 0's and 1's, and was then analyzed using the quantification method of the third type (Yanai 1994).

3.1 Quantification method of the third type

The quantification method of the third type, which was developed in Japan, is not used to determine relationships between individual items in a database and some external standard. Rather, this method examines the similarity of categories in a database, similar to a principal component analysis of quantitative data.

In the present study, each item of the database, that is, the accident type, facility type, accident cause, and ignition source, were categorized in order to generate a matrix of the accident data, in which columns denote accident cases and rows indicate the categories of the items. The matrix was filled with 0's and 1's (Fig. 2a). The columns and rows were then exchanged to rearrange 1's diagonally, as shown in Fig. 2b.

Several solutions give good correlation between the columns and rows, that is, 1's appear to be arranged diagonally. Therefore, the two solutions that provided the best and the second best correlations were used.

3.2 Analysis results

a) Correlation between accident type, facility type, and accident cause

Figure 3 shows the correlation between the accident type, the facility type, and the accident cause. The distance between data plots shows the strength of the correlation between the data, i.e., data plots that are closer to each other are strongly correlated. The circles in the figure show data plots that are strongly correlated. The horizontal and the vertical axes are arbitrary. The meaning of each axis must be considered after plotting the figure. In this figure, fire accidents are situated on the right-hand side and leakage accidents are situated on the left-hand side.

The tank truck is distinct from other tank storage facilities and is strongly correlated with traffic accidents. Other tank storage facilities are plotted in the leakage area, indicating that accidents involving tank storage are usually leakage accidents rather than fire accidents. In addition, the correlation between accidents and material factors is relatively weak.

The manufactory and the handling factory are plotted in the fire accident area. In these facilities, leakage of dangerous goods, such as crude oil, easily catches fire. Gas stations are plotted in approximately the center of the horizontal axis, indicating that both fire and leakage accidents occur with the same frequency.

b) Correlation between facility type and accident cause for fire accidents

Figure 4 shows the correlation between the facility type and the accident cause for fire accidents. The movable tank storage, outdoor storage, pipeline and sales office facilities were excluded from this examination because these facilities experienced few fire accidents.

From the figure, the tank truck facility correlates with traffic accidents, and the gas station facility correlates with fire breakout and arson. The proximity of the underground tank storage and the outdoor tank storage, as well as that of the manufactory and the handling factory, indicate similar tendencies, respectively.

c) Correlation between facility type and accident cause for fire accidents at manufactories, handling factories, and gas stations

Concerning the facility type, the manufactory, handling factory, and gas station experienced several fire accidents among the dangerous goods facilities. Therefore, fire accidents were analyzed independently, and the result is shown in Fig. 5. On the horizontal axis, the plots of the manufactory and handling factory facilities are in close proximity to each other, but distant from the gas station facility.

The gas station is strong correlated with fire breakouts, arson, and traffic accidents, and so countermeasures for preventing the causes of such accidents are strongly recommended. On the other hand, accidents of the manufactory are caused by human errors, and those of the handling factory are caused by human errors and hardware errors, such as corrosion or deterioration.

d) Correlation between facility type and ignition source for fire accidents at manufactories, handling factories, and gas stations

As in Section c), the correlation between the facility type and the ignition source for fire accidents at manufactories, handling factories, and gas stations was analyzed.

The results of this analysis are shown in Fig. 6. Fire breakouts at gas stations are frequently caused by an open flame or an electric spark. An open flame is easily imagined as an ignition sources in the case of fire breakout or arson. Static electricity is also believed to be a major ignition source of fire breakouts at gas stations, but the present analysis shows a poor correlation between the gas station facility and static electricity as an accident cause. This may be due to the fact that countermeasures against static electricity are effectively employed in gas station facilities.

Auto-ignition and static electricity accident causes are plotted in close proximity to the manufactory, suggesting that countermeasures against static electricity are not sufficient in manufactories.

Several ignition sources are plotted in close proximity to the handling factory. Among these sources, welding arcs can be easily avoided by more careful welding, which should be an effective countermeasure for preventing fire accidents in handling factories.

e) Correlation between facility type and accident cause for leakage accidents

Next, the correlation between the facility type and the accident cause was analyzed. The indoor storage, movable tank storage, outdoor storage, and sales office facilities were omitted in this analysis because of the low number of leakage accidents for these facilities.

The results of this analysis are shown in Fig. 7. Similar to the results for fire accidents, the tank truck and traffic accidents are plotted next to each other and apart from other factors for leakage accidents. Namely, the leakage of a tank truck is strongly correlated with the traffic accident.

Causes that are strongly affected by human factors are plotted on the right-hand side of the figure, and Causes that are strongly affected by hardware factors are plotted on the left-hand side of the figure. The vertical axis is correlated with the facility type.

The causes of leakage accidents for the pipeline are similar to those of the tank storage facilities and are strongly correlated with hardware factors, such as application failure, breakage, and corrosion or deterioration.

The handling factory is plotted distant from other facilities. Leakage accidents in handling factories are frequently caused by human errors.

3.3 Summary of the analysis by the quantification method of the third type

Based on the newly rearranged accident database, the relations between items were analyzed using the quantification method of the third type. Although the findings were almost the same as those predicted empirically, a few unexpected findings, such the finding that static electricity is not strongly correlated with gas station fires, were obtained.

By the quantification method of the third type, various investigations become possible, based on the distance between plots, and the results of these investigations can be used to plan countermeasures to prevent accidents in future.

4. STATISTICAL ANALYSIS BY SIMPLE REGRESSION ANALYSIS

4.1 Simple regression analysis

The number of accidents that occur in one year may be expressed as a function of several factors, including financial, human, and hardware factors. There are several statistical data sources of such factors. Although the factors may not be independent, a simple regression analysis can be applied using the annual number of accidents independently. As such, a simple regression analysis was performed for the annual number of accidents and various factors in order to clarify the factor that has the largest influence on the number of accidents.

4.2 Statistical data source

In the present study, statistical data of the number of employees, plant investment amount, and the full unemployment rate of manufacturing industries were used.

As shown in Fig. 1, the trend of the number of accidents changed from decreasing to increasing in 1993. The period from 1980 to 2001 can be divided into two time periods based on this trend. The first period is the period in which the number of accidents decreased (from 1980 to 1992), and the second period is the period in which the number of accidents increased (from 1993 to 2001).

4.3 Regression coefficients between the number of accidents and each factor

A simple regression analysis was performed using the number of accidents and the causal factors. The regression coefficients between the number of accidents and each factor are listed in Table 2. We defined that some factor had a strong correlation if absolute value of the regression coefficient was larger than 0.8.

a) Full unemployment rate

There is no correlation between the number of accidents and full unemployment for the first period, whereas, for the second period, the correlation is strong.

However, the full unemployment rate is not considered to immediately influence the number of accidents. Layoff of workers may affect the number of accidents several years after the fact. Therefore, simple regression analyses were performed for the full unemployment rate data were shifted by one, two, or three years, respectively. The number of accidents was found to have the strongest correlation between the full unemployment rate shifted by two years. In short, the influence of the full unemployment rate on the number of accidents does not appear immediately, but is delayed by approximately two years.

b) Number of employees in manufacturing industries

During the first period, the number of employees is not strongly correlated with the number of fire accidents, but is strongly correlated with the number of leakage accidents. In addition, the number of employees is strongly correlated with the number of accidents during the second period. The number of employees also has a stronger influence on the number of accidents if the data are delayed by approximately two years, similar to the phenomenon of the full unemployment rate.

Namely, during the first period, the number of employees was increasing, and whereas during the second period, the number of employees was decreasing.

c) Plant investment in manufacturing industries

The amount of plant investment of manufacturing industries increased rapidly during the bubble period from the late 1980's to the early 1990's, and the number of accidents decreased during the same period. However, during the second period, there was no correlation between the amount of plant investment and the number of accidents. Thus, even though the amount of investment decreased, improvements in software, for example, helped to maintain safety.

4.4 Summary of simple regression analyses

By using statistical data from every fiscal year from 1980 to 2001, the simple regression analyses were performed for several factors that were considered to affect the number of accidents. Other factors, such as the gross domestic product (GDP), were also examined, but were either shown not to have strong correlations between the number of accidents or lacked statistical data.

A strong correlation was obtained between the number of accidents and the unemployment rate and the number of employees. Namely, the number of workers seems to be important in the prevention of accidents. However, practically speaking, the unemployment rate or the number of employees can not be altered solely for safety purposes. Improving the quality of safety education of the employees appears to be particularly important when the number of employees decreases.

The technical level for preventing an accident appears to have improved recently, as indicated by the fact that the correlation between the amount of plant investment and the number of accidents is not strong during the second period.

5. CONCLUSIONS

A cause analysis of dangerous goods facility accidents was performed by the quantification analysis of the third type. For the fire accidents, the manufactory and the handling factory were similar with respect to accident cause. Fire accidents at gas station facilities are strongly affected by external factors so that countermeasures against these factors are indispensable. The main cause of tank truck facility accidents is shown to be traffic accidents. However, for other tank storage facilities, which experienced few fires, the tendency of fire accidents could not be clarified.

For the leakage accidents, it was not possible to clarify correlation between items, except that between the tank truck facility and traffic accidents. However, the handling factory and the gas station tend to be unique compared to other facilities.

By the simple regression analysis between the number of accidents and various factors, the number of accidents was determined to have a strong correlation with the unemployment rate. Since the unemployment rate cannot be reduce easily, the quality of safety education of employees must be improved as the employment rate decreases.

References

1) Fire and Disaster Management Agency (FDMA) of the Japanese government, 1970-1999, Accident cases concerning dangerous goods, FDMA, Tokyo.
2) Haruo Yanai, 1994, Multivariate Data Analysis Method (in Japanese), Asakura Shoten, Publishers, Tokyo.

Accident Type	Facility Type	Accident Cause	Ignition Source
1. Fire	(A) Manufactory	a) Design Failure	i) Impact Spark
2. Leakage	(B) Indoor Storage	b) Application Failure	ii) Friction Heat
	(C) Outdoor Storage	c) Corrosion, Deterioration	iii) Hot Surface
	(D) Indoor Tank Storage	d) Breakage	iv) Welding Arc
	(E) Outdoor Tank Storage	e) Breakdown	v) Thermal Radiation
	(F) Underground Tank Storage	f) Maintenance Failure	vi) Electric Spark
	(G) Tank Truck	g) Disoperation	vii) Static Electricity
	(H) Gas Station	h) Unconfirmed Operation	viii) Open Flame
	(I) Movable Tank Storage	j) Inadequate Monitoring	ix) Auto-ignition
	(J) Handling Factory	k) Nonfeasance	x) Overheating
	(K) Sales Office	l) Arson	xi) Other Source
	(L) Pipeline	m) Traffic Accident	
		n) Fire Accident	
		o) Earthquake, Other Natural Disaster	
		p) Under Inspection, Other Cause	

Table 1 Items in the database of the present study for accidents related to dangerous goods

	Overall period (1980-2001)			Decrease stage (1980-1992)			Increase stage (1993-2001)		
	Fire	Leakage	Total	Fire	Leakage	Total	Fire	Leakage	Total
Full unemployment rate	0.64	0.50	0.61	0.04	-0.08	-0.07	0.84	0.95	0.94
〃 (shifted two years forward)	0.75	0.58	0.71	0.37	-0.32	-0.22	0.84	0.98	0.97
Number of employees	-0.54	-0.87	-0.84	0.39	-0.78	-0.69	-0.91	-0.96	-0.96
〃 (shifted two years forward)	-0.32	-0.82	-0.73	0.44	-0.87	-0.78	-0.92	-0.99	-0.98
Plant investment amount	0.19	-0.43	-0.28	0.43	-0.71	-0.61	-0.13	-0.05	-0.08
〃 (shifted two years forward)	-0.02	-0.54	-0.43	0.35	-0.81	-0.74	-0.68	-0.61	-0.65

Table 2 Simple regression coefficients between number of accidents and various factors

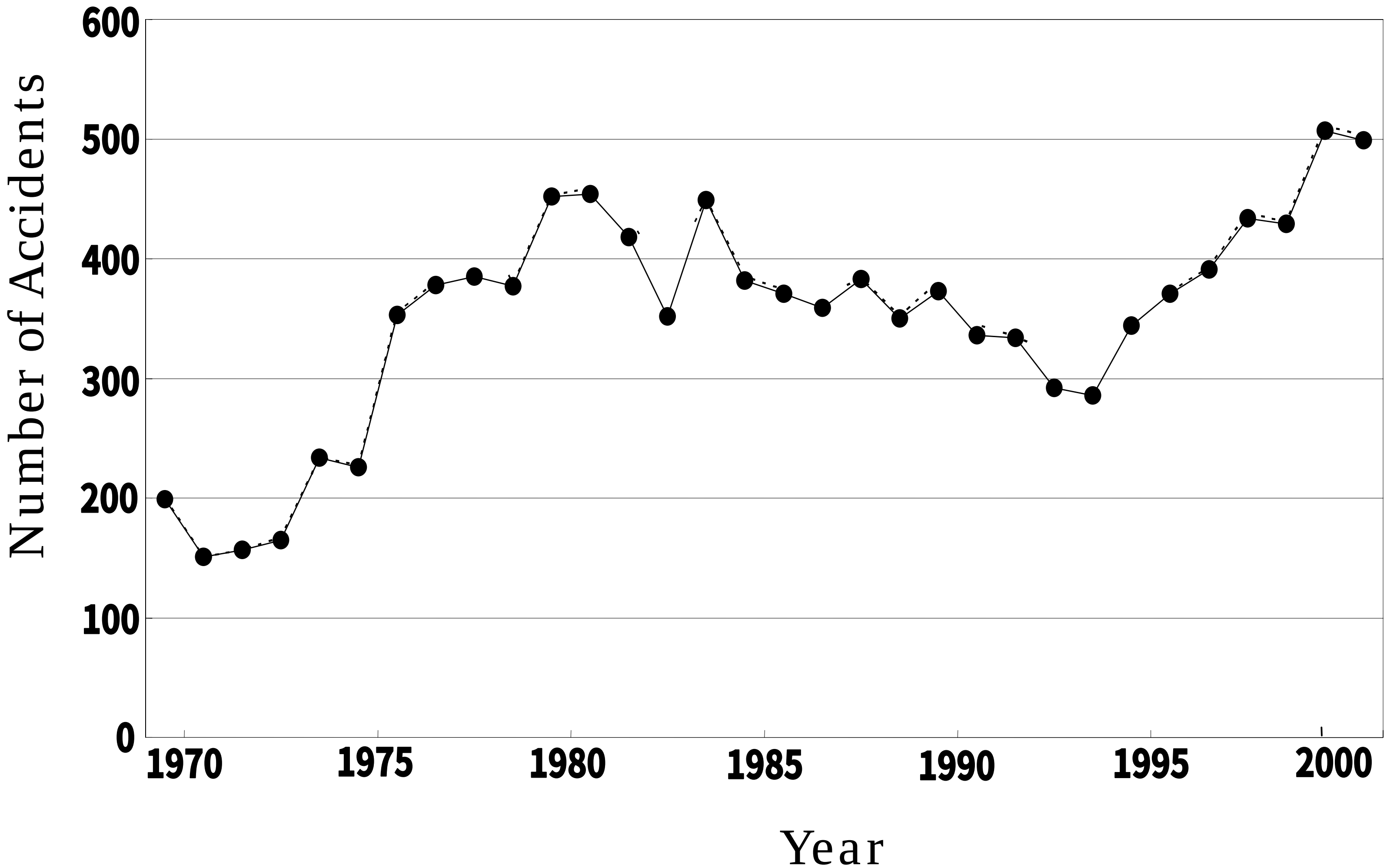

Figure 1. Annual number of dangerous goods accidents

	a	b	c	d
w	0	1	1	1
x	1	0	0	0
y	0	0	1	0
z	0	1	0	1

a)

	a	d	b	c
x	1	0	0	0
z	0	1	1	0
w	0	1	1	1
y	0	0	0	1

b)

Figure 2. Example of the quantification method of the third type

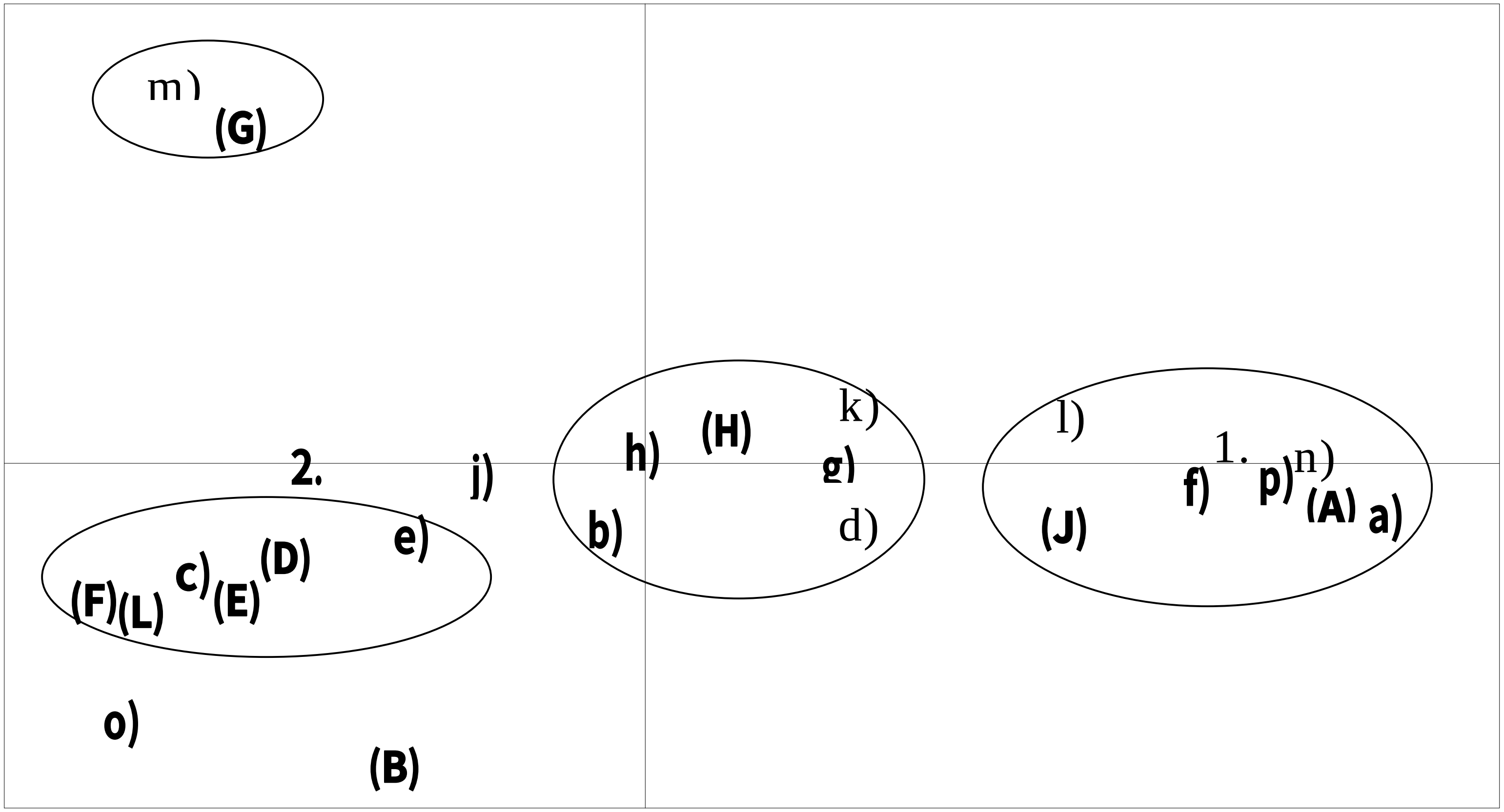

Figure 3. Correlation between accident type, facility type, and accident cause

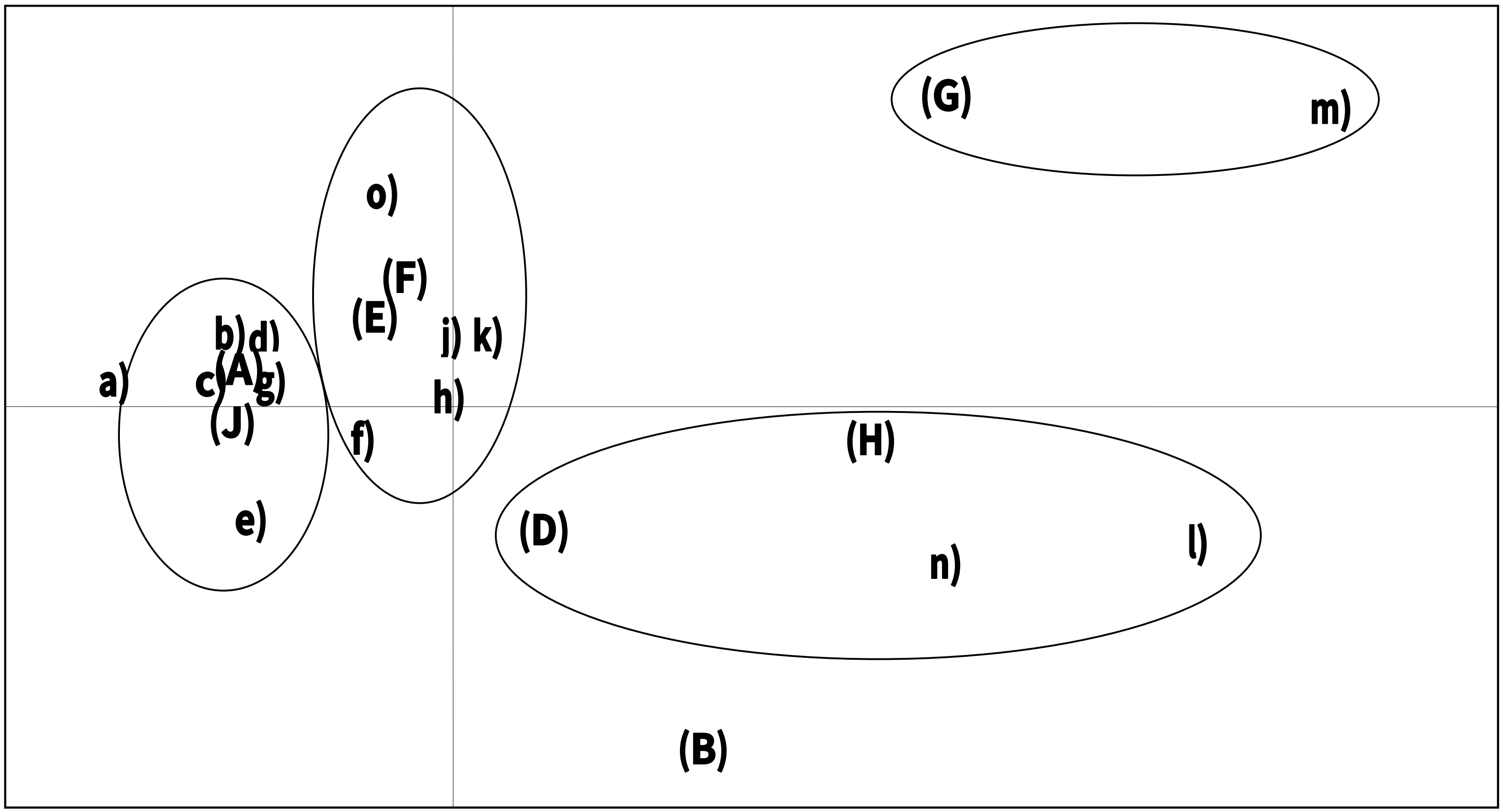

Figure 4. Correlation between facility type and accident cause for fire accidents

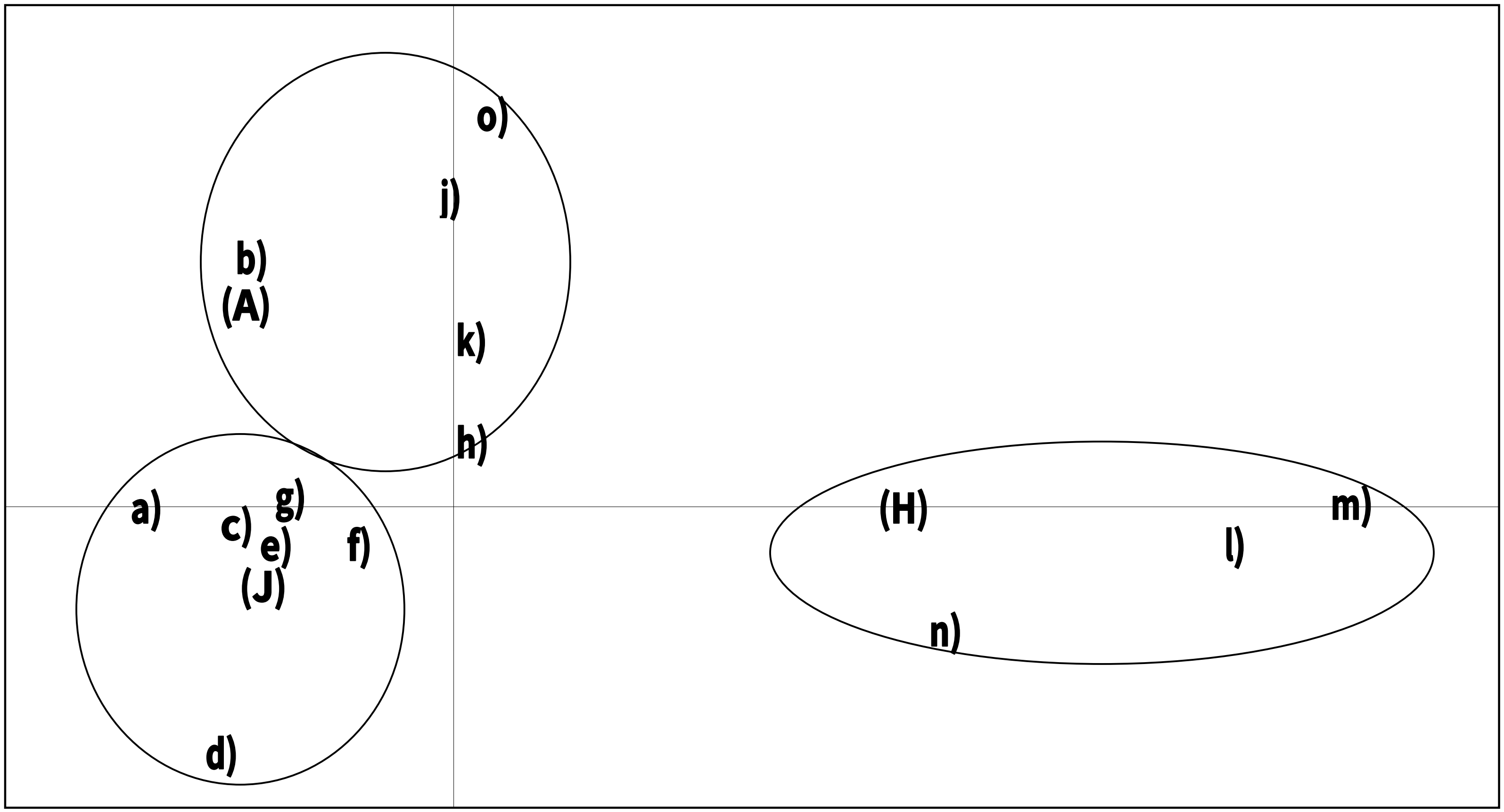

Figure 5. Correlation between facility type and accident cause for fire accidents at manufactories, handling factories, and gas stations

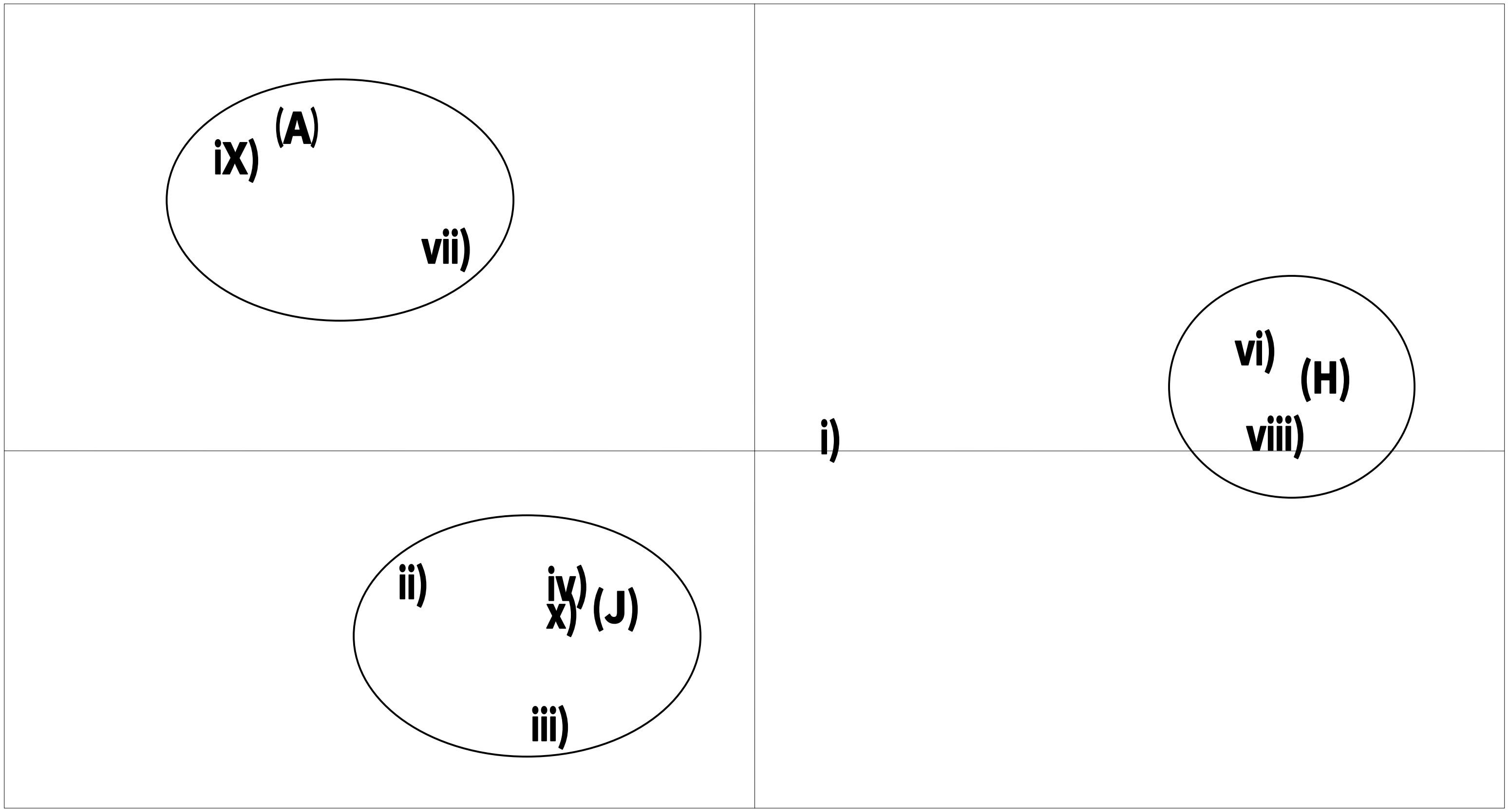

Figure 6. Correlation between facility type and ignition source for fire accidents at manufactories, handling factories, and gas stations

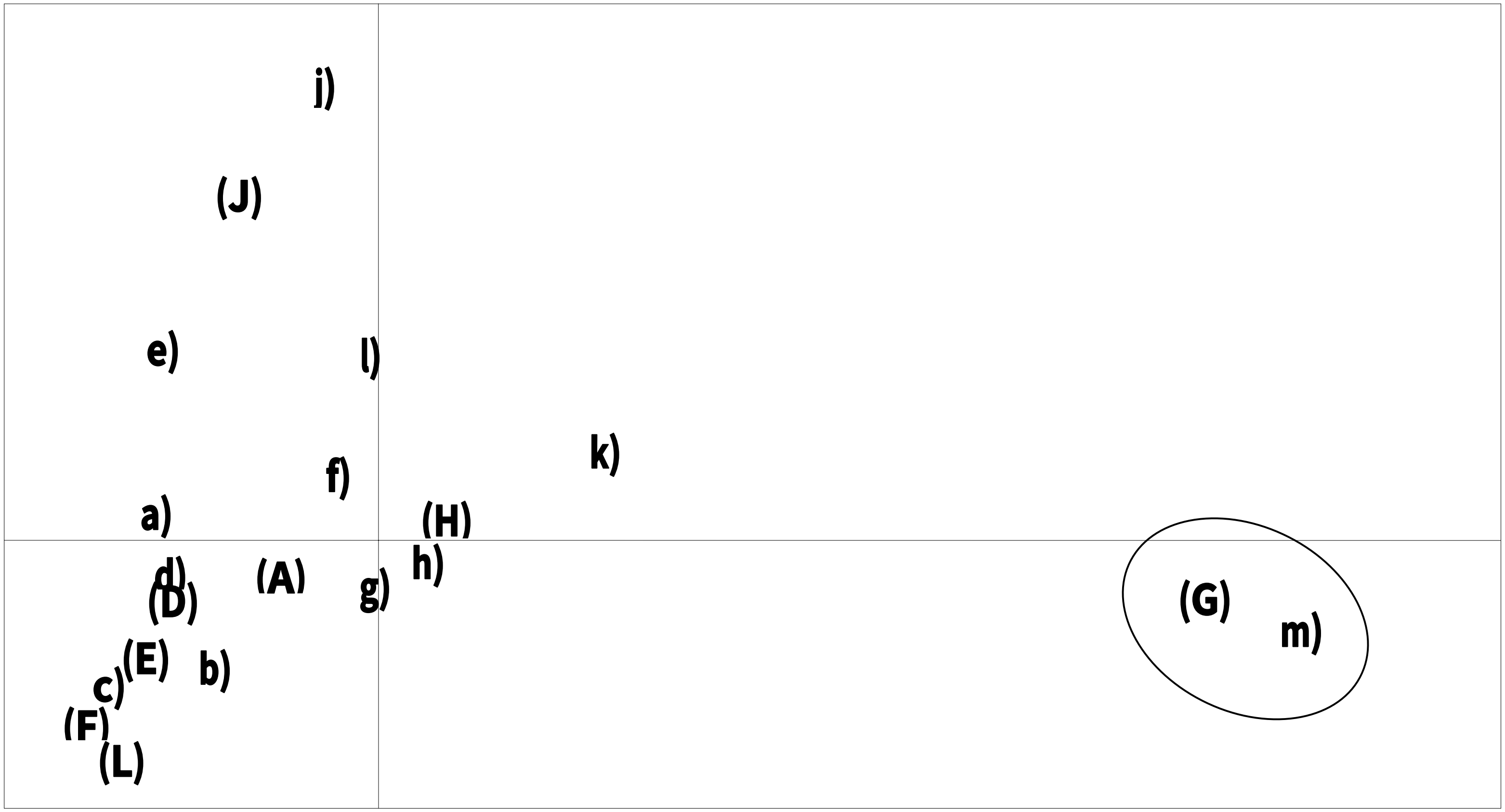

Figure 7. Correlation between facility type and accident cause for leakage accidents