Research on Grey Relation Analysis of Chemical Plant Accidents

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Abstract: This paper proposes grey relation analysis approach using grey system theory to analyze. influence factors for calamity accidents in chemical plants. Examples from explosion, fire calamity and eruption, are used in the development of relation analysis model of calamity accident factors based on grey relation analysis. Future behavior index and accident influence factors are used for system safety analysis. Dynamic quantitative analysis is proposed to confirm the dominant main and sub factors that influence system safety. The proposed system will enable us to comprehend accidents and to support the decision-making process for system safety.

Key words: Grey Relation Analysis, Chemical Plant, Accident, Cause & Consequence Analysis

[1]1. Introduction

Any system has many factors that influence its behavior. However, the relation between factors is usually complex, namely they show "grey" characteristic. In the past, regression analysis method was adopted for factors analysis, however such method was only used for a few linear factors, and it was not suitable for many nonlinear factors using such method[1)].

Considering above disadvantages, the underlying system is analyzed using grey relation analysis method, which considers quantitative change comparison analysis for development trend, comparing result with the quantitative change method and to find the relation degree between factors. Relation, as a kind of technology way, is a method of analyzing relation degree between factors in system or a quantitative change method of relation degree. Furthermore, because grey relation analysis is used to analyze systems according to development trend, sample quantity is not strictly required, the representative distributing rule is also not demanded, the counting work is a little and the analysis results are consistent with qualitative analysis results[2,3)].

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In chemical plants, calamity accidents have many impacts on plant process and the surroundings. In such accidents, there is almost infinitive information that are available, which made it difficult to conduct comprehensive system analysis with simple mathematical models. Grey system theory provides an effective way to analyze the impacts of such calamity accidents based on analytical and practical approach. In the proposed Grey theory, multidimensional reference lists are established for all impact factors of the underlying calamity accident and production system, followed by dominant analysis for all impact factors. This will enable us to classify and identify factors, such as main, sub, dominant, or non-dominant factors. In addition, it will enable us to confirm the degree of influence, sensitivity, and relation among these factors.

2. Grey Relation Analysis

2.1 Grey Relation Rnalysis

Grey relation is uncertain relation between things or system factors or factors and main action. The main task of grey relation analysis is to analyze and confirm influence degree between factors or contribution measuring degree of factors for main action based on microcosmic or macrocosmic geometrical approximation. However, grey relation space is the fundamentals of grey relation analysis[4)].

2.2 Referenced Data Column and Compared Data Column

To perform grey relation analysis, firstly, confirm referenced data column is used for the analysis and comparison. Where they are generally marked with $\{Y_0(k)\}$,k=1,2,…, n. While the compared data column with referenced data column are marked with $\{X_1(k)\}$, $\{X_2(k)\}$,… $\{X_i(k)\}$, k=1,2,…, n.

For the comparison of calamity accident influence factors of chemical plant, comparison data column is composed of the index calculated as the statistic values of each calamity accident influence factor. Referenced data columns contains calamity accidents which are calculated using explosion, fire calamity and eruption index data columns.

2.3 No Dimensionless Data Calculation

Generally, original statistic data columns can not be directly analyzed with grey relation analysis. The reason is that the data columns of different factors possibly have quantitative level and polarity differences, hence no dimensionless data calculation method is needed for each factor data column. The no-dimensional methods have data initialization, mean and data level difference, etc, data mean can de expressed as follows:

Original data set is $\{X_i(k)\}$(i=0,1,2,…, m; k=1,2,…, n), so:

$$X_i^{/}(k) = X_i(k) / \overline{X}_i \tag{1}$$

$X_i^{/}(k)$: The mean data column of No. i data column

$X_i(k)$: The No. i original data column

$\overline{X}_i$: The mean value of No. i data column

2.4 Calculation of Relation Coefficient

This relation represents the difference of geometry shape among curves, where the different values between curves are considered as the measure standard of relation, namely[5]:

$$\xi_i(k) = \frac{\min_{i,k}\left|Y_0^{/}(k) - X_i^{/}(k)\right| + \rho \max_{i,k}\left|Y_0^{/}(k) - X_i^{/}(k)\right|}{\left|Y_0^{/}(k) - X_i^{/}(k)\right| + \rho \max_{i,k}\left|Y_0^{/}(k) - X_i^{/}(k)\right|} \tag{2}$$

where

$\xi_i(k)$: The relation coefficient between $X_i(k)$ and $Y_0(k)$ at the k time

ρ: differentiating coefficient, generally, the value between [0, 1], is 0.5

$\min_{i,k}\left|Y_0^{/}(k) - X_i^{/}(k)\right|$ is the smallest difference of two levels

$\max_{i,k}\left|Y_0^{/}(k) - X_i^{/}(k)\right|$ is the largest difference of two levels

2.5 Calculation of Relation

Relation coefficient data has dispersed information, which made it difficult to conduct comparative analysis. So it is necessary to count relation coefficient in each time as one value and to calculate mean value. The mean value, on which so-called relation can be defined as follows:

$$r_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \tag{3}$$

r_i: The relation between compared data column $X_i(k)$ and referenced data column $Y_0(k)$

2.6 Confirm Order of Influence Effect

As known from the above analysis, the bigger the relation is, the nearer similitude degree between curves composed by compared data column and referenced data column is, correspondingly, and the clearer the effect of calamity accident influence factors is. So relation order from large to small is correspondingly effect order of calamity accident influence factors from domination to inferior.

3 Grey Relation Analysis of Calamity Accident

3.1 Calamity Accident Influence Factor is Grey

Grey relation analysis is as important part of the grey system theory which can resolve quantitative change problem of relation between factors. Calamity accident is the result of synthetically action of many factors which is called as the behavior characteristic quantity and calamity accident influence factor is called factor. behavior character and factors change with time transformation. The importance of relation analysis for calamity accident influence factors is to compare development trend of each factor and calamity accident, which defined as, the nearer change trend of calamity and factors with time is, the bigger influence degree.

3.2 Confirm Analysis Factors

Table 1 Data of Chemical Industry and Petroleum Manufacture From 1995~2002

Factor	1995	1996	1997	1998	1999	2000	2001	2002
Explosion accident Y_1	4	0	1	13	9	1	3	20
Fire accident Y_2	6	2	0	5	1	0	1	9
Eruption accident Y_3	4	1	1	1	2	0	0	2
People factor X_1	3	0	0	4	2	0	0	1
Structural factor X_2	4	2	0	4	1	0	0	9
Matter・ reflection factor X_3	2	1	1	2	3	0	1	9
Equipment・ device factor X_4	0	0	1	4	1	0	1	3
External factor X_5	3	0	0	0	1	0	0	0
Stimulation factor X_6	0	0	0	0	1	0	0	7
Uncertain factor X_7	2	0	0	5	2	1	2	2
Other factors X_8	0	0	0	0	1	0	0	0

According to the selected rule factors in relation analysis, influent factor can best reflect system character, "chemical accident database" (RISCAD) [7],which was developed by integrated institution of Japan industrial technology and rebound enterprise group of science technology (JST). In chemical and petroleum industry, during the period from January 1st 1995 to December 30th ,2002, 86 calamity accidents are analyzed and influence factors are selected: take people factor X_1, structure factor X_2, matter・reflection factor X_3, equipment・device factor X_4, external factor X_5, stimulation factor X_6, uncertain factor X_7, other factors X_8 as compared data column, and take Explosion accident Y_1, fire accident Y_2 and eruption accident Y_3 as referenced data column. The content of grey relation analysis in Fig 1. The data is shown in Table. 1.

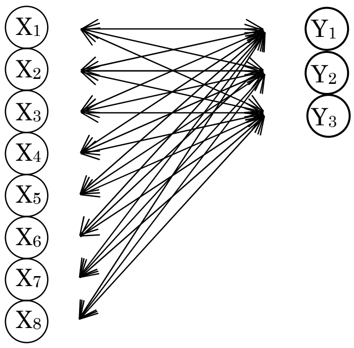

Fig. 1 Content of Grey Relation Analysis

3.3 Grey Relation Calculation

According to Eq.(1), mean original data, the calculating result is shown in Table 2.

According to Eq.(2), calculate relation coefficient of explosion accident, fire accident and eruption accident with each factor, respectively, the results are shown in Fig 2,3 and 4.

Table 2 The Result of Mean Disposal

Factor	1995	1996	1997	1998	1999	2000	2001	2002
$Y_1'(k)$	0.6275	0.0000	0.1569	2.0392	1.4118	0.1569	0.4706	3.1373
$Y_2'(k)$	2.0000	0.6667	0.0000	1.6667	0.3333	0.0000	0.3333	3.0000
$Y_3'(k)$	2.9091	0.7273	0.7273	0.7273	1.4545	0.0000	0.0000	1.4545
$X_1'(k)$	2.4000	0.0000	0.0000	3.2000	1.6000	0.0000	0.0000	0.8000
$X_2'(k)$	1.6000	0.8000	0.0000	1.6000	0.4000	0.0000	0.0000	3.6000
$X_3'(k)$	0.8421	0.4211	0.4211	0.8421	1.2632	0.0000	0.4211	3.7895
$X_4'(k)$	0.0000	0.0000	0.8000	3.2000	0.8000	0.0000	0.8000	2.4000
$X_5'(k)$	6.0000	0.0000	0.0000	0.0000	2.0000	0.0000	0.0000	0.0000
$X_6'(k)$	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	7.0000
$X_7'(k)$	1.1429	0.0000	0.0000	2.8571	1.1429	0.5714	1.1429	1.1429
$X_8'(k)$	0.0000	0.0000	0.0000	0.0000	8.0000	0.0000	0.0000	0.0000

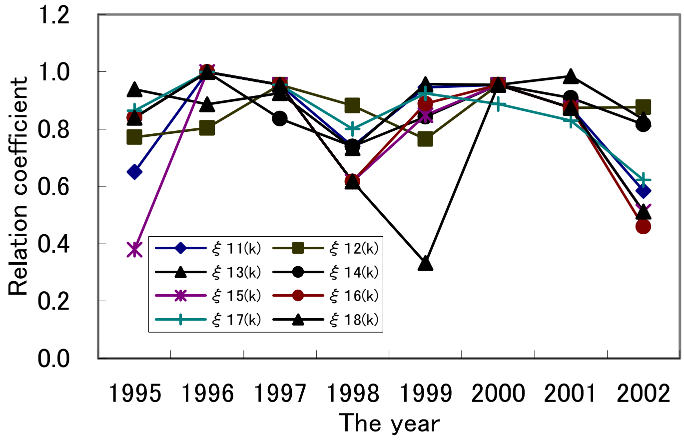

Fig. 2 The Relation Coefficient of Explosion Accident

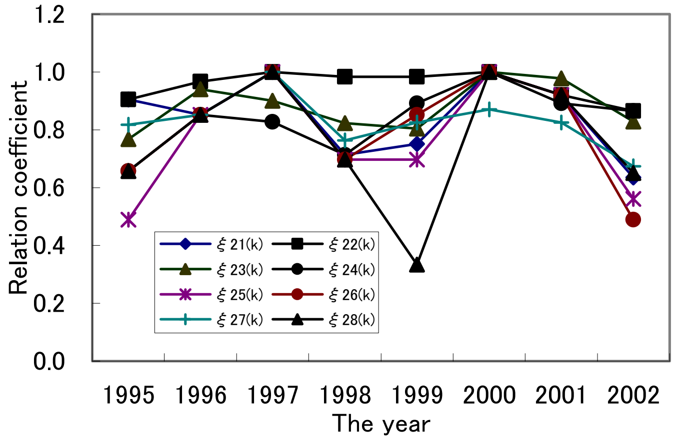

Fig. 3 The Relation Coefficient of Fire Accident

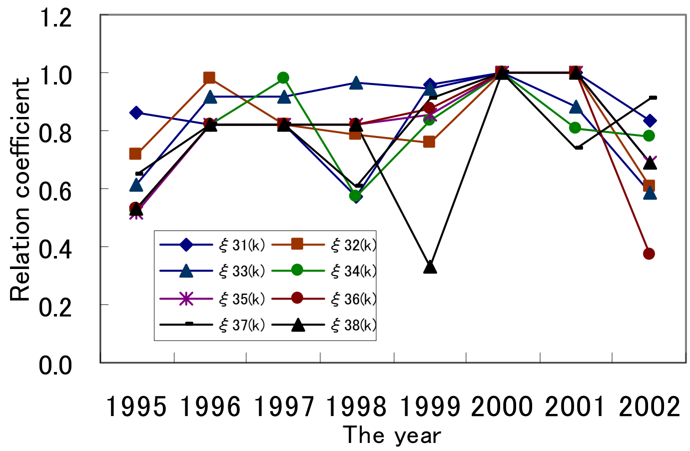

Fig. 4 The Relation Coefficient of Eruption Accident

According to Eq.(3), the relation results are shown in Table 3.

Table 3 The Relation of Calamity Accident

Factor	Explosion r_1	Fire r_2	Eruption r_3
People factor X_1	0.8381	0.8473	0.8578
Structural factor X_2	0.8606	0.9528	0.8326
Matter· reflection factor X_3	0.9020	0.8804	0.8528
Equipment· device factor X_4	0.8675	0.8373	0.7880
External factor X_5	0.7678	0.7770	0.8148
Stimulation factor X_6	0.8239	0.8084	0.7796
Uncertain factor X_7	0.8608	0.8284	0.8074
Other factors X_8	0.7609	0.7638	0.7512

The results of relation become matrix mode for easy analysis, that is:

$$R_1 = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{32} & r_{32} & r_{33} \\ r_{41} & r_{42} & r_{43} \\ r_{51} & r_{52} & r_{53} \\ r_{61} & r_{62} & r_{63} \\ r_{71} & r_{72} & r_{73} \\ r_{81} & r_{82} & r_{83} \end{bmatrix} = \begin{bmatrix} 0.8381 & 0.8473 & 0.8578 \\ 0.8606 & 0.9528 & 0.8326 \\ 0.9020 & 0.8804 & 0.8528 \\ 0.8675 & 0.8373 & 0.7880 \\ 0.7678 & 0.7770 & 0.8148 \\ 0.8239 & 0.8084 & 0.7796 \\ 0.8608 & 0.8284 & 0.8074 \\ 0.7609 & 0.7638 & 0.7512 \end{bmatrix}$$

Each row of the relation matrix R indicates the influent degree of a factor for each action characteristic quantity and each column indicates the influent degree of each factor for a action characteristic quantity.

4 Result Analysis

4.1 Column Analysis

(1) In the first Column, relation of explosion accident with matter·reflection factor, equipment·device factor and structural factor are all higher. At the second column, the relation of fire accident and structural factor, matter·feedback factor and personal factor are higher, respectively. At the third column, the relation of eruption accident and people factor, matter·reflection factor and structural factor are higher, respectively.

(2) Calculate mean value for each column of relation matrix, mean value is marked with $G_j(j=1,2,3)$, that is:

$$G_j = (\sum \gamma_i)/M(M=8) \tag{4}$$

G_j is the general relation of action characteristic quantity of a calamity accident with each influent factor. According to Eq.(4), the general relation is as follows:

G_1=0.8352, G_2=0.8369, G_3=0.8105

Obviously, $G_2 > G_1 > G_3$, which indicates the quicker responses of fire accident for each factor and is dominant root factor. The second is explosion accident and the last is eruption accident, at the same time, which also indicates the different influent degree of each influent factor for different accident.

4.2 Row Analysis

(1) In calamity accident, matter·feedback factor and equipment·device factor and exterior factor and stimulation factor have bigger influence for explosion accident. These factors have rather higher sensitivity to explosion accident. The structural factor and other factors have bigger influence for fire accident, which also has higher sensitiveness. The people factor and external factor are sensitive to eruption accident, which are also neglected in order to avoid sudden accident happen and great loss.

(2) In order to fully analyze the sensitivity of different calamity accident for each influent factor, use mean sensitive coefficient to weigh sensitivity. Calculate mean value for each row of relation matrix, which is marked with M_i(i=1,2,…,8), that is:

$$M_i = \left(\sum \gamma_i\right) / L (L = 3) \tag{5}$$

M_i is the general relation of a influent factor X_i for different calamity accident as mean sensitive coefficient of a factor $X_i(k)$ for all the calamity accidents, which indicates general reflection of a influent factor $X_i(k)$ for all the calamity accidents and sensitivity of different factors. According to Eq.(5), the mean sensitive coefficients of influence factor are as follows:

M_1=0.8477, M_2=0.8820, M_3=0.8784, M_4=0.8309,
M_5=0.7865, M_6=0.8040, M_7=0.8322, M_8=0.7586.

The order is:

$M_2 > M_3 > M_1 > M_7 > M_4 > M_6 > M_5 > M_8$

The results indicate that mean sensitivity coefficient is M_2, which is dominant child factor and the second is M_3, …, and the smallest is M_8. The structural factor has the greatest influence for accident. Also matter·feedback factor has remarkable influence for calamity accident. The external factor and other factors are within sensitive to calamity accident influence.

5 Conclusion

As shown from the general analysis of the relation matrix, general relation of fire calamity is the biggest which is dominant root factor for the occurrence of accidents. General relation of structural factor is the biggest, which is dominant child factor synthesis in general relation between each factor and calamity accidents. Relation between structural factor and fire calamity is biggest, which indicates that structural factor has the greatest influence for fire calamity and the relation is nearest in relation matrix.

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