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A quantitative judgement method for safety admittance of facilities in chemical industrial parks based on G1-variation coefficient method

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Abstract

This paper aims to introduce a new quantitative method for safety admittance of facilities based on G1-variation coefficient method in chemical industrial parks. As is known, at present mass incidents resisting the hazards of chemical facilities were happened in China frequently. In order to alleviate such prominent contradictions, from the perspective of safety admittance of facilities in chemical industrial parks, the judgement criteria and indexes were put forward. Then the subjective G1 method and the objective variation coefficient method were used to determine the weights of criteria and indexes. And the quantitative judgement model was established. At last, an empirical research was conducted. The results show that the judgement criteria and indexes proposed in this paper include four criteria and nine indexes. And the weight of environment bearing is higher based on subjective evaluation, complying with the people’s risk perception of chemical facilities’ hazards. While the weights of economic effect and safety management are higher than others based on objective evaluation, in line with the current situation that how chemical industrial parks to choose the suit facilities for entering.

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Keywords: chemical industrial park; safety admittance; algorithm; quantitative judgement; G1 method; variation coefficient method

1. Introduction

With the growth of the national economy, the quantity of chemical industrial park in China is climbing quickly. At the same time, China's urbanization process accelerating, the chemical industrial parks originally built far away

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from the cities are closer to people now. But compared with the increasing number of chemical industrial parks and economic effects, more attention was paid to numerous safety and environmental issues.

In 2007, 105 CPPCC members suggested relocating Xiamen PX chemical project, and the citizens stop boycotting until the Xiamen municipal government announced the suspension of the project; In July 2012, an event that people protested against the prince paper was happened in Qidong, Nantong, Jiangsu province, and the event caused a massive demonstrations. Many large-scale mass incidents of boycotting chemical hazards show that in the process of chemical industrial park to choose chemical projects at present is more of government leading action [1], lack of consultation with the social groups. Moreover, now there are not specifical relevant laws and regulations for safety admittance of facilities in chemical industrial parks. And relevant evaluation technology is relatively scarce.

At present, the domestic studies on safety admittance of facilities in chemical industrial parks are concentrating in the theoretical framework and the application process [1, 2]. Relevant scholars put forward some safety admittance methods based on regional risk assessment or safety capacity of chemical industrial park [3]. On the other hand, more attention is paid to land-use planning (LUP) in the researches abroad [4−7]. The methods based on the accident consequences or risks are the two main research methods and the latter is widely used. Britain, the Netherlands, Singapore, Australia and other countries have made the individual risk acceptance criteria to guide the construction of chemical industrial parks [8]. However, throughout the home and abroad related researches, their studies only focus on single side like regional risk bearing or the security capacity and failed to put forward quantitative methods. In this paper, according to the combination of subjective and objective ideology, the subjective G1 method and objective variation coefficient method are used to assign weights and establish a quantitative calculation method to provide foundation support for safety admittance of facilities in chemical industrial parks.

2. Safety admittance

The definition of safety admittance in Chemical industrial park is given in literature [1]. The goal is to guarantee the safety of the whole park, personnel and the environment around. From the requirement of regional risk and the function division, combined with the influencing factors of overall risk of chemical industrial park, the capacity of risk bearing is calculated according to the actual situation of chemical industrial park. Then good construction, installation, production enterprise are chose into the park.

But, in this paper the definition of safety admittance is more focusing on the safety criteria and indexes which influence choosing facilities. And through the combination of subjective to objective assessment, appropriate facilities will be chose into the park.

3. Judgement for safety admittance of facilities

3.1. Criteria and indexes

How to judge some facility whether an appropriate one to be chosen, it is necessarily a multi-criteria decision making problem and contains two aspects of subjective and objective. In reference [1], the judgement of safety admittance is based primarily on composite risk assessment, such as location selection, overall planning, regional economic, safety management, environmental capacity, pollution emissions and other aspects. In reference [2], the judgement of safety admittance includes location, overall layout and safety management. In reference [9], the analytic hierarchy process (AHP) is used to study safety admittance. And the rule layer is divided into economic effect, social effect, resource consumption and environmental impact. Based on the consideration of relevant research results and chemical industrial park data, the judgement of safety admittance in chemical industrial park is summarized as the following 4 criteria and 9 indexes, as shown in the Table 1.

3.2. Evaluation program

The evaluation program of safety admittance in chemical industrial park can be divided into the following four steps:

- Some facility applies for entrance.

- The applicant is evaluated under different criteria and indexes.
- To calculate the applicant's comprehensive score results.
- To judge the applicant with the judgement value of the chemical industrial park.

The above four steps are shown in the Fig. 1.

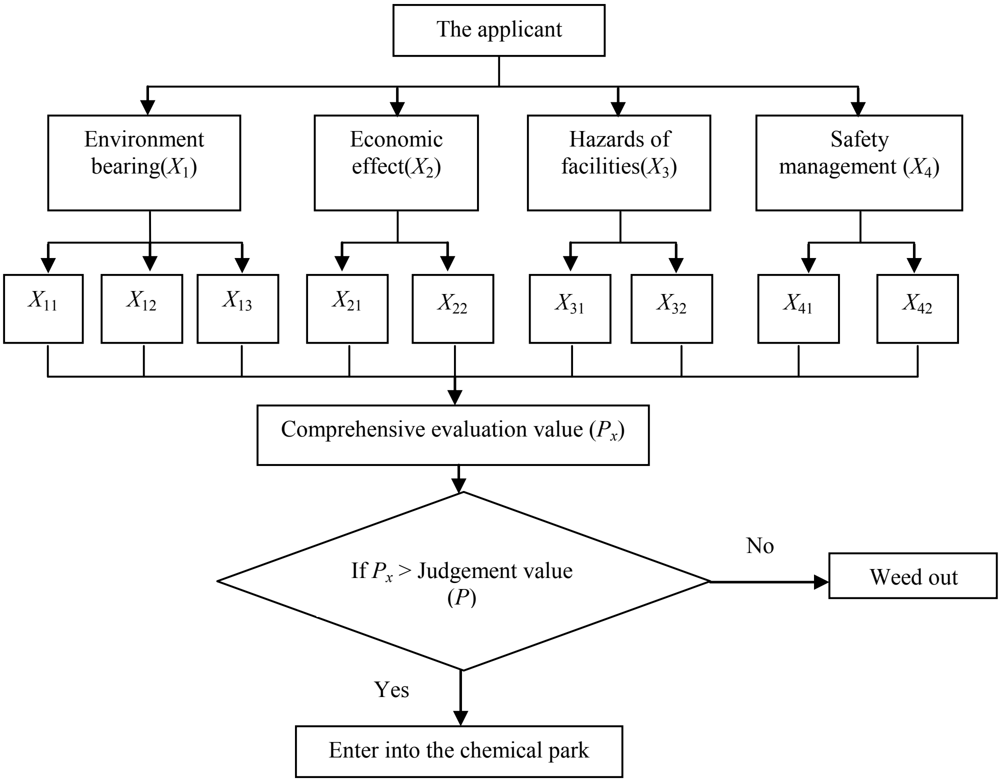

Fig. 1. Evaluation program of safety admittance.

Table 1. Criteria and indexes of safety admittance.

Criterion	Index	Content description
Environment bearing(X_1)	Wastewater quantity(X_{11})	Emissions of wastewater (t)
	Exhaust value (X_{12})	Emissions of SO_2 and NO_X (mg/m^3)
	Amount of solid waste (X_{13})	Emissions of hazardous solid waste (t)
Economic effect(X_2)	Ratio of output and consumption (X_{21})	Output (10 thousand RMB) / Consumptions of water, electricity and steam(10 thousand RMB)
	Return on investment(X_{22})	Output (10 thousand RMB) / Total assets (10 thousand RMB)
Hazards of facilities(X_3)	Major hazards(X_{31})	Assessment value of major hazards
	Stock of hazardous substances(X_{32})	Total storage capacity of hazardous chemicals (t)
Safety management (X_4)	Ratio of safety managers(X_{41})	Number of safety managers / Number of staffs
	Ratio of safety input and output(X_{42})	Safety input (10 thousand RMB) / Output (10 thousand RMB)

4. Quantitative evaluation model of safety admittance

4.1. Standardization process of indexes data

For the convenience of comparison and calculation, the original data are standardized to eliminate the influence of the dimension with the following formula.

$$D_x = \frac{\left|I_x - m(I)\right|}{\max I - \min I} \tag{1}$$

where D_x denotes the dimensionless value of I_x; *max I* is the maximal value of index *I*, and *min I* is the minimal value of index I; *m(I)* represents the *min I* when index *I* is positive index, and *m(I)* represents the *max I* when index *I* is reverse index; I_x is the actual value of index *I*.

4.2. Calculation of the comprehensive weights

1. Subjective method-G1 method

G1 method is a subjective method put forward by Chinese scholars Guo Yajun recently [10]. The weights of indexes are determined on the basis of importance of every index. This method overcomes the large amount of calculation and consistency check of analytic hierarchy process (AHP).

(1) To determine the importance of the evaluation indexes

$$X_1 \succ X_2 \succ \cdots X_k \quad k=1,2,\cdots,m$$

where $\succ$ represents the index on the left side of the symbol is more important than the index on the right.

(2) The importance assignments (r_k) of adjacent indexes

$$r_k = \omega_{k-1}^s / \omega_k^s \quad k=m,m-1,\cdots,3,2$$

The importance assignments of adjacent indexes are shown in Table 2.

Table 2. The important degree between adjacent indexes.

r_k	Instruction	r_k	Instruction
1.0	Index X_{k-1} and X_k have the same importance	1.1	Between same and slightly more important
1.2	The index X_{k-1} is slightly more important than index X_k	1.3	Between slightly more important and obviously more important
1.4	The index X_{k-1} is obviously more important than index X_k	1.5	Between obviously more important and strongly more important
1.6	The index X_{k-1} is strongly more important than index X_k	1.7	Between strongly more important and extremely more important
1.8	The index X_{k-1} is extremely more important than index X_k		

(3) To calculate the weights of indexes

$$\omega_m^s = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1} \tag{2}$$

$$\omega_{k-1}^s = r\omega_k^s \tag{3}$$

where ω_m^s denotes the weight of index *m*; ω_{k-1}^s represents the weight of index *k–1*; ω_k^s is the subjective weight of index *k*.

2. Objective method- variation coefficient method

The variation coefficient method calculates index data directly to obtain the objective weight of index, and avoids the interference of subjective factor [11].

(1) The coefficient of variation index

$$V_k = \sigma_k / \bar{X}_k \qquad k=1,2,\cdots,m \tag{4}$$

where V_k denotes the variation coefficient of index k; σ_k represents the standard deviation of index k. $\bar{X}_k$ is the arithmetic mean of index k.

(2) The weight of variation coefficient

$$\omega_k^o = V_k \Big/ \sum_{k=1}^{m} V_k \qquad k=1,2,\cdots,m \tag{5}$$

where ω_k^o denotes the weight of variation coefficient.

3. Comprehensive weights of indexes

Comprehensive weights of indexes are the linear combination of subjective and objective weights and could be calculated by the formula below.

$$\omega_k^{so} = \beta\omega_k^s + (1-\beta)\omega_k^o \qquad k=1,2,\cdots,m$$

where β is the proportion of subjective weight in comprehensive weight; ω_k^{so} represents the comprehensive weight of index k.

To achieve the best combination of the two kinds of weights, mathematical optimization problem method was used to solve the optimal value of β. It means to minimize the sum of the squares of deviations between comprehensive weights with subjective weights and objective weights. And the optimal solution is 0.5 which represents the subjective weight and objective weight each accounted for 50% of the combination weights. Therefore, the best combination of the index k weights as follows.

$$\omega_k^{so} = 0.5\omega_k^s + 0.5\omega_k^o \tag{6}$$

4.3. The evaluation model of safety admittance based on combining weights of indexes

According to the chemical park safety admittance evaluation criterion, the safety admittance evaluation model was built (i.e., linear comprehensive weight evaluation formula).

$$P_x = \omega_1^{so} p_{x1} + \omega_2^{so} p_{x2} + \cdots + \omega_m^{so} p_{xm} = \sum_{k=1}^{m} \omega_k^{so} p_{xk} \tag{7}$$

where P_x denotes the comprehensive score of the applicant which wants to enter the chemical park, and the score is between 0 and 1. Also if P_x is larger, the applicant will be easier to be accepted. P_{xk} represents the applicant's standardization value of evaluation indexes.

Finally, the comprehensive score P_x calculated by formula (7) is compared with the set judgement value P. If $P_x > P$, the applicant can enter the chemical industrial park; If the $P_x \leqslant P$, the applicant will be eliminated. The judgement value P should be set according to the actual situation of different chemical industrial parks. High judgement value P represents the high standard for the applicant, and it is difficult to be accepted.

5. An empirical research on a fine chemical industrial park in south of Jiangsu provinces

5.1. Sample data acquisition

Through the spot investigation, the specific data of 29 facilities in the fine chemical industry park were gained, and they are shown in Table 3.

Table 3. The original data of the chemical industrial park in south of Jiangsu provinces.

Facility	Index								
	X_{11}	X_{12}	X_{13}	X_{21}	X_{22}	X_{31}	X_{32}	X_{41}	X_{42}
1	32878	1.19	1392	62000/1035	62000/35000	0	1690	3/350	72.94/62000
2	168000	1.3	4147	142000/6236	142000/29000	139.11	1349	4/220	108.25/142000
3	0	4.8241	3	56000/1057.45	56000/29700	12.22	892	3/95	62.3/56000
4	580	14.22	5	62102/171.75	62102/4048	0	803	2/72	55.02/62102
5	4000	0.03	100	15371/255.49	15371/11389	1.74	677.3	3/91	56/15371
6	3000	49.03	20	10000/202.15	10000/4400	0	450	1/30	38/10000
7	54700	0.43	431.24	25050/253.32	25050/10260	0	350	3/137	56.8/25050
8	500	0.5173	10	18000/315	18000/5169	21.53	211.65	2/66	62.1/18000
9	2131.62	0	3.8	1800/10.54	1800/200	0	185.1	2/11	24.7/1800
10	3930	0.1	20	1981/954	1981/2681	4.12	146.05	13/97	21.6/1981
11	6120	0	28	13850/182.8	13850/6264.2	0	143.8	6/175	66.2/13850
12	850	0.9	2	3000/110.5	3000/795	51.80	140	3/46	22.3/3000
13	360	0	5	6163/29	6163/1565	0	128.3	4/30	39.4/6163
14	1200	0	17	3003/131.9	3003/4200	0	128	2/28	28.84/3003
15	3740	0.029	8	2883/85.2	2883/930	0	126.5	2/66	21.2/2883
16	3590	4.518	217	23547/584.7	23547/4288	1.23	114.5	3/192	86.1/23547
17	640	0	2	1500/8.4	1500/1500	0	50.9	2/44	18.3/1500
18	1150	0.83	0.05	6198/455.6	6198/724	0	51	1/52	48.55/6198
19	1200	0	12.5	1743/284.7	1743/984	0	47	2/34	18.5/1743
20	2100	0.002	7.65	7500/252.66	7500/5000	15.83	47	5/47	32.3/7500
21	1060	0.593	3	2300/23.8	2300/1882	0	40.3	3/30	23.5/2300
22	10000	0	136	7096/224.3	7096/2214	0	40	2/85	36.4/7096
23	1255	0	15	6500/10.2	6500/2200	0	25.25	2/110	35.7/6500
24	54000	0.43	4.84	580/29.9	580/410	12.00	23	2/17	17.56/580
25	1900	0	9	6000/21.3	6000/4000	0	21	1/50	28.5/6000
26	9000	1.7	22.2	19000/540.4	19000/5000	9.60	10	2/85	51.73/19000
27	6000	6.06	6	2100/229.5	2100/1200	0	5	3/60	23/2100
28	6580	0	23	11776/312	11776/4607	0	5.7	9/253	103.6/11776
29	800	0	1.5	8000/117.5	8000/5000	2.78	3.9	1/20	41.53/8000

5.2. *The comprehensive weights of criteria and indexes*

1. To standardize the data

Among the 9 evaluation indexes given in the table above, X_{21}, X_{22}, X_{41} and X_{42} are positive indexes, while X_{11}, X_{12}, X_{13}, X_{31} and X_{32} are reverse indexes. According to formula (1), the dimensionless value of each index was calculated, and the results are shown in Table 4.

2. To calculate subjective weights by G1 method

(1) The rule layer of safety admittance

Integrated experts' opinions, importance sequence and relative importance assignment of the environment bearing(X_1), economic effect(X_2), hazards of facilities(X_3) and safety management(X_4) were determined.

$X_1 \succ X_2 \succ X_3 \succ X_4$

$r_2=X_1/X_2=1.4$； $r_3=X_2/X_3=1.2$； $r_4=X_3/X_4=1.1$

Then the weight of rule layer X_4 was calculated by formula (2), as shown in the formula below.

$$\omega_4^s = \left(1 + \sum_{k=2}^{4} \prod_{i=k}^{4} r_i\right)^{-1} = 0.1898$$

And the weights of X_3, X_2, X_1 were calculated by formula (3), ω_3^s =0.2088, ω_2^s =0.2506, ω_1^s =0.3508.

(2) The indexes of safety admittance

Integrated experts' opinions, importance sequence and relative importance assignment of the wastewater quantity(X_{11}), exhaust value (X_{12}) and amount of solid waste (X_{13}) were determined under the rule layer X_1.

$X_{11} \succ X_{12} \succ X_{13}$； $X_{11}/X_{12}=1.2$； $X_{12}/X_{13}=1.2$

Then, the weights of X_{11}, X_{12}, X_{13} were calculated by formula (2) and formula (3), the results were 0.3956, 0.3297, 0.2747.

Similarly, the weights of other indexes under their own rule layer would be calculated.

(3) The final weights of each evaluation index

According to the calculation results of (1) and (2), the final weight of evaluation index X_{11} could be calculated by the formula below.

$$\omega_{11}^s = 0.3508 \times 0.3956 = 0.1388$$

Similarly, the weights of other indexes could be calculated, and the results are shown in Table 4.

3. To calculate objective weights by variation coefficient method

According to the standardized data of 9 evaluation indexes, the arithmetic mean $\overline{X}_k$ and standard deviation σ_k would be calculated. And the variation coefficient weights of each index could be gained through formula (4) and formula (5). The specific calculation results are shown in Table 4.

4. To calculate comprehensive weights

According to the formula (6), subjective weight and objective weight both account for 50%. And the comprehensive weights of indexes can be calculated based on the subjective weights and objective weights. The specific calculation results are shown in Table 4.

5.3. The safety admittance in chemical industrial park

1. To calculate the comprehensive score P_x of the applicant

For the applicant to get the permission, feasibility demonstration, energy-saving evaluation and safety pre-assessment should be conducted before application. In this series of project evaluation, the actual data of the 9 indexes mentioned in Table 1 will be obtained and can be standardized with the formula (1) and the original data of 29 facilities in Table 3. The calculation formula is shown below.

$$p_{xk} = \frac{\left|I_{xk} - m(I)\right|}{\max I - \min I} \quad i=1,2,\cdots,9 \tag{8}$$

where p_{xk} denotes the standardized data of index k and I_{xk} denotes the original data of index k; *max I* and *min I* represent the maximum and minimum data of index k among the 29 facilities' data; *m(I)* represents the *min I* when index I is positive index, and *m(I)* represents the *max I* when index I is reverse index; At the same time, when index I is positive index, and if $I_{xk}>maxI$, $p_{xk}=1$; if $I_{xk}<minI$, $p_{xk}=0$. When index I is reverse index, and if $I_{xk}>maxI$, $p_{xk}=0$; if $I_{xk}<minI$, $p_{xk}=1$.

At last, according to the formula (7), comprehensive evaluation score P_x can be calculated.

2. To set the judgement value P of the chemical industrial park

With the comprehensive weights of the 9 indexes and the standardized data of the 29 chemical facilities, the comprehensive evaluation score of each facility can be calculated and the results are shown in Table 5.

Table 4. The standardized data and weights of judgement indexes.

Facility	X_1			X_2		X_3		X_4	
	X_{11}	X_{12}	X_{13}	X_{21}	X_{22}	X_{31}	X_{32}	X_{41}	X_{42}
1	0.8043	0.9757	0.6643	0.0910	0.0722	1.0000	0.0000	0.0000	0.0140
2	0.0000	0.9735	0.0000	0.0326	0.2859	0.0000	0.2022	0.0555	0.0000
3	1.0000	0.9016	0.9993	0.0801	0.0800	0.9122	0.4733	0.1328	0.0119
4	0.9965	0.7100	0.9988	0.5660	1.0000	1.0000	0.5261	0.1109	0.0042
5	0.9762	0.9994	0.9759	0.0914	0.0434	0.9875	0.6006	0.1408	0.0976
6	0.9821	0.0000	0.9952	0.0746	0.1065	1.0000	0.7354	0.1429	0.1029
7	0.6744	0.9912	0.8960	0.1524	0.1180	1.0000	0.7947	0.0769	0.0510
8	0.9970	0.9894	0.9976	0.0867	0.1892	0.8452	0.8768	0.1254	0.0911
9	0.9873	1.0000	0.9991	0.2656	0.5664	1.0000	0.8925	1.0000	0.4391
10	0.9766	0.9980	0.9952	0.0000	0.0016	0.9704	0.9157	0.7241	0.3436
11	0.9636	1.0000	0.9933	0.1160	0.1023	1.0000	0.9170	0.1484	0.1361
12	0.9949	0.9816	0.9995	0.0395	0.2091	0.6276	0.9193	0.3270	0.2260
13	0.9979	1.0000	0.9988	0.3313	0.2204	1.0000	0.9262	0.7201	0.1908
14	0.9929	1.0000	0.9959	0.0326	0.0000	1.0000	0.9264	0.0070	0.2996
15	0.9777	0.9994	0.9981	0.0500	0.1631	1.0000	0.9273	0.1254	0.2233
16	0.9786	0.9079	0.9477	0.0601	0.3266	0.9912	0.9344	0.0407	0.0981
17	0.9962	1.0000	0.9995	0.2779	0.0195	1.0000	0.9721	0.2129	0.3875
18	0.9932	0.9831	1.0000	0.0181	0.5364	1.0000	0.9721	0.0615	0.2396
19	0.9929	1.0000	0.9970	0.0064	0.0722	1.0000	0.9744	0.2901	0.3338
20	0.9875	1.0000	0.9982	0.0435	0.0537	0.8862	0.9744	0.5646	0.1201
21	0.9937	0.9879	0.9993	0.1489	0.0347	1.0000	0.9784	0.5277	0.3204
22	0.9405	1.0000	0.9672	0.0465	0.1702	1.0000	0.9786	0.0863	0.1480
23	0.9925	1.0000	0.9964	1.0000	0.1531	1.0000	0.9873	0.0555	0.1603
24	0.6786	0.9912	0.9988	0.0273	0.0478	0.9137	0.9887	0.6296	1.0000
25	0.9887	1.0000	0.9978	0.4402	0.0537	1.0000	0.9899	0.0660	0.1351
26	0.9464	0.9653	0.9947	0.0521	0.2109	0.9310	0.9964	0.0863	0.0664
27	0.9643	0.8764	0.9986	0.0111	0.0708	1.0000	0.9993	0.2391	0.3453
28	0.9608	1.0000	0.9945	0.0562	0.1259	1.0000	0.9989	0.1559	0.2723
29	0.9952	1.0000	0.9997	0.1039	0.0605	0.9800	1.0000	0.2391	0.1501
σ_k	0.1967	0.1902	0.1927	0.2122	0.2106	0.1950	0.2497	0.2562	0.1959
$\overline{X}_k$	0.9217	0.9390	0.9447	0.1483	0.1757	0.9326	0.8406	0.2446	0.2072
V_k	0.2134	0.2026	0.2039	1.4301	1.1991	0.2091	0.2970	1.0474	0.9458
ω_k^o	0.0371	0.0352	0.0355	0.2488	0.2086	0.0364	0.0517	0.1822	0.1645
ω_k^s	0.1388	0.1156	0.0964	0.1367	0.1139	0.1094	0.0994	0.0994	0.0904
ω_k^{so}	0.0880	0.0754	0.0659	0.1927	0.1612	0.0729	0.0755	0.1408	0.1275

Table 5. The comprehensive evaluation score of each chemical facility.

Facility	Comprehensive score	Facility	Score sorting(↓)
1	0.2920	9	0.7077
2	0.1488	23	0.6215
3	0.3726	4	0.6061
4	0.6061	13	0.5970
5	0.3998	24	0.5706
6	0.3452	21	0.5240
7	0.3918	10	0.5127
8	0.4324	17	0.5113
9	0.7077	18	0.5029
10	0.5127	25	0.4958
11	0.4449	20	0.4781
12	0.4588	19	0.4712
13	0.5970	28	0.4616
14	0.4167	12	0.4588
15	0.4521	29	0.4584
16	0.4423	27	0.4563
17	0.5113	15	0.4521
18	0.5029	11	0.4449
19	0.4712	16	0.4423
20	0.4781	22	0.4361
21	0.5240	8	0.4324
22	0.4361	26	0.4294
23	0.6215	14	0.4167
24	0.5706	5	0.3998
25	0.4958	7	0.3918
26	0.4294	3	0.3726
27	0.4563	6	0.3452
28	0.4616	1	0.2920
29	0.4584	2	0.1488

According to Table 5 and the relatively saturated situation of this chemical industrial park at present, strictly requirements should be set for the applicants. As a result, the lowest score among the top 50% of the 29 chemical facilities' comprehensive score was chose to be the judgement value P, $P = 0.4588$.

3. Safety admittance of the chemical industrial park

The comprehensive evaluation score P_x calculated by formula (7) is compared with the set judgement value P. If $P_x>P$, the applicant can enter the chemical industrial park; If the $P_x \leqslant P$, the applicant will be eliminated.

6. Conclusions

(1) Four judgement indexes are put forward in this paper. They are environment bearing, economic effect, hazards of facilities and safety management. And nine judgement indexes are presented, such as wastewater quantity, exhaust value, amount of solid waste, ratio of output and consumption, return on investment, major hazards, stock of

hazardous substances, ratio of safety managers and ratio of safety input and output. At the same time, the judgement process of the facilities which want to enter the chemical park is established.

(2) Through the subjective method (G1 method) and the objective method (variation coefficient method), the comprehensive weights of all the judgement criteria and indexes are calculated. With subjective evaluation, the weight of environment bearing is higher. And through objective evaluation, the weights of economic effect and safety management are much higher.

(3) According to the established quantitative judgement model, an empirical research on a fine chemical industrial park in south of Jiangsu provinces was conducted successfully. Weather the applicant can be accepted depends on the evaluation score of its own. If it is larger than the judgement value, the applicant can enter the chemical industrial park; If it is less than the judgement value, the applicant will be eliminated.

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