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Hazardous Chemical Transportation Inputs and Optimization Based on Linear Programming Model

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The development of society and economy has made the commodities circulate more frequently than usual. According to the statistics from the Logistics Information Center, the transportation plays a very important part in the logistics industry, especially for dangerous things, the logistics security inputs have certain complexity and continuity. How to develop effective strategies for distribution ration of inputs to maximize economic benefit has become the great challenge in modern logistics transportation. Here, the factors affecting the logistics security can be divided into several types such as hazardous goods, transportation, warehousing, personnel and equipment. A linear programming theory is used to build a linear programming model that can maximize the economic benefits of security inputs. Positive analysis accesses the optimal distribution for security inputs as percentage of the total, namely, the transportation security cost accounts for 55%; the dangerous goods security input is 20%; the storage and personnel security input is 10%; and the equipment security input is 5%.

1. Introduction

After opening and reformation, China has gained access to a huge and growing economy, and the commodities in domestic and overseas markets have been circulated at an unprecedented rate. The logistics industry has experienced a fast track of development, which provides speedy transit services for all walks of life, and contributes much to the transformation of business models and the burst in growth of social and economic benefits. Although the management and organization in the logistics industry continue to be optimized and upgraded in terms of informationization, specialization, systemization in the whole journey (Tyworth and Zeng, 1998; Hall, 1985; Lahti, 1990), logistics incidents often occur and have become a bottleneck in the development of the logistics industry. Especially for the dangerous chemicals, the accidents cause the most serious losses, for example, the explosion outbroken in dangerous goods warehouses in Tianjin Binhai New Area has become a class of particularly important accident involving production security responsibilities.

The logistics business process is complex, consisting of transportation, loading and unloading, storage, package, processing, etc., while the security problem may appear in any subprocess, especially in transportation process where the geographical span is long, and there are many unstable factors (Lu and Koufteros, 2014; Leroux et al., 2013; Doll et al., 2014), so that there are many potential risks. How to ensure the security of logistics activities has aroused wide concern of experts and scholars at home and abroad. The balance between security risks and economic input benefits has become the focus of businesses.

Now it is optimistic about the domestic logistics security issues (Koc et al., 2013; Feng and Chen, 2013; Hartmann-Wendels et al., 2011). According to the statistical analysis of accident data and the weight subject to the economic benefits, we know that, the dangerous products and the special industry are most likely to cause security accidents, as shown in Figure 1.

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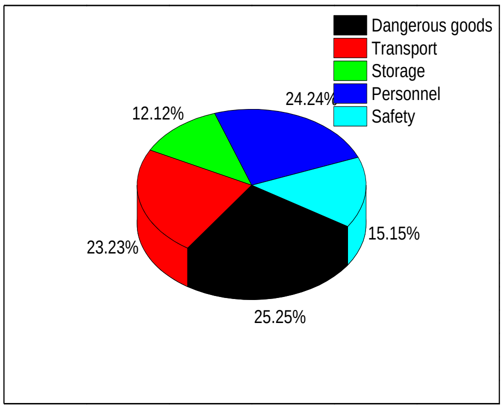

Figure 1: Risk factor contribution rate weight proportion distribution

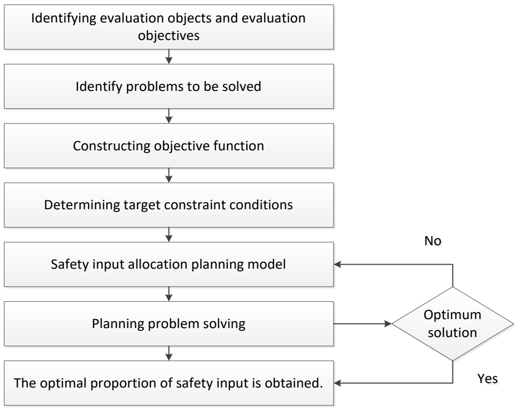

Figure 2: Linear programming model for optimal allocation of security input

In order to achieve a healthy, rapid and stable development in China's logistics industry and improve the economic benefits, this paper focuses on the transportation of dangerous chemicals, explores the security inputs and the program optimization. A linear programming model is then built to optimize the strategies on security inputs. An example is cited to provide theoretical basis and rationalized proposals for optimal allocation of logistics security resources, thereby eventually getting the clues to developing the business strategies, improving the business efficiencies and logistics quality.

2. Building the model

Company A with a relatively mature management system is chosen as a study case. According to the identification of security risk factors, the security works in the Company A are groomed, and the expenditures relevant to security production are divided into six types, equipment, transportation, warehousing, personnel and others, as shown in Table 1.

Table 1: Details of logistics A companies' security input over the years

Unit: 10000 yuan								
Cost category	2006	2007	2008	2009	2010	2011	2012	2013
Safety facilities	18.20	10.30	11.00	11.80	6.40	5.90	11.70	8.20
Transport safety	2.30	8.45	2.80	2.15	2.80	7.45	2.80	2.15
Storage safety	1.90	1.60	2.40	1.60	2.40	1.60	2.40	1.60
Dangerous goods	8.10	7.40	7.30	4.70	4.90	4.15	5.00	4.70
Personnel safety	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
Other	2.10	2.15	2.15	2.15	2.15	2.15	2.15	2.15
Total	34.7	32.00	27.75	24.50	20.75	23.35	22.55	21.90

Table 2: Total security input simulation forecast correction results

Time	Total safety input	Analog value				Predicted value
		Observation value	Fitting value	Error	%	
2006	34.70	——	——	——	——	
2007	32.00	32.03	31.89	0.517	1.836	
2008	27.75	31.25	28.87	2.040	7.178	
2009	24.50	27.82	28.72	-1.184	-4.811	
2010	20.75	22.30	25.55	-3.508	-17.215	
2011	23.35	25.77	24.04	0.678	2.858	
2012	22.55	23.51	24.55	0.894	3.726	
2013	20.90	23.69	23.05	0.600	2.861	
2014						19.995
2015						18.855

Above data is predicted and corrected by the Data Processing System (DPS), and the total security inputs in 2014 and 2015 were 19.995 and 18.855, respectively, as shown in Table 2.

2.1 Initial linear programming equations

According to the variable proportionality coefficient, the linear programming coefficient matrix is: value vector C=(25,24,23,15,12), decision vector X=(x_1,x_2,x_3,x_4,x_5), where x1,…,x5 are hazardous chemicals, personnel, transportation, equipment and warehousing.
Mathematically, the linear programming of economic benefit Z of security inputs can be expressed:

$$\text{Max } Z = 25x_1 + 24x_2 + 23x_3 + 15x_4 + 12x_5$$

$$\text{s.t}\begin{cases} a_{11}x_1+a_{12}x_2+\cdots+a_{1n}x_n\le b_1 \\ a_{21}x_1+a_{22}x_2+\cdots+a_{2n}x_n\le b_2 \\ a_{31}x_1+a_{32}x_2+\cdots+a_{3n}x_n\le b_3 \\ a_{41}x_1+a_{42}x_2+\cdots+a_{4n}x_n\le b_4 \\ a_{51}x_1+a_{52}x_2+\cdots+a_{55}x_5\le b_5 \\ x_j\ge 0\ (j=1,2,\ldots,5) \end{cases} \tag{1}$$

2.2 Decision vector and constraints

Thanks to the rapid development of the economy, in light of the security inputs of Company A, the constraints to be considered are:

3.2.1 The total security inputs is lower than the aggregate limit

From the above analysis, it is known that the total limit is RMB 199.95 million.

3.2.2 The transportation security cost as percentage of the total increases

According to the statistics from the Logistics Information Center, the logistics transportation cost in various industries accounts for more than 45%, higher than that of Company A, as shown in Figure 3. Therefore, in order to reduce the probability of transportation accidents, it is required to increase the transportation security cost.

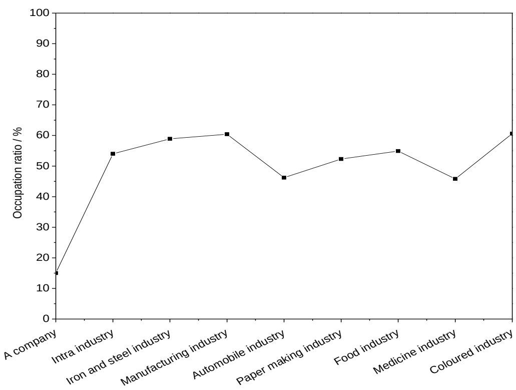

Figure 3: Percentage of transportation cost of key enterprises in logistics industry

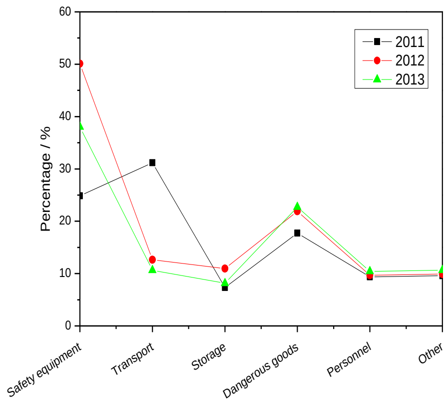

Figure 4: Trend of expenditure ratio in recent three years

3.2.3 Consolidated inputs for personnel and equipment

After various expenses in Company A in the past three years are compared, it can be found that the security equipment outlay as percentage of the total is significantly higher than the personnel training expenditure. Most expenses are used for propaganda, etc. Little attention has paid to personnel skills, so that it is necessary to consolidate equipment and personnel inputs. As shown in Figure 4.

3.2.4 Any security inputs are not greater than zero.

2.3 Linear programming model

According to the above analysis, the constraint conditions are digitized, and a linear programming model can be obtained as follows:

$$\text{Max } Z = 25x_1 + 24x_2 + 23x_3 + 15x_4 + 12x_5$$

$$\text{s.t}\begin{cases} x_1+x_2+x_3+x_4+x_5\le 20 \\ x_2\ge 2 \\ x_3\ge 11 \\ x_4\ge 1 \\ x_5=2 \\ x_j\ge 0\ (j=1,2,\ldots,5) \end{cases} \quad (2)$$

The model is solved and an operation table is created, as shown in Table 3. According to Table 3, the calculation area is built. The pure linear programming solution function runs, and the operation results are shown in Table 4.

Table 3: Initial data of model

Objective function coefficient	25	23	12	24	15		
Decision variables	1	1	1	1	1		
Constraint condition						Restricted left side term	Restricted right end item
1	1	1	1	1	1	5	20
2	0	1	0	0	0	1	11
3	0	0	0	1	0	1	2
4	0	0	0	0	1	1	1
5	0	0	1	0	0	1	2
Objective function value	99						

Table 4: Model operation results

Objective function coefficient	25	23	12	24	15		
Decision variables	4	11	2	2	1		
Constraint condition						Restricted left side term	Restricted right end item
1	1	1	1	1	1	20	20
2	0	1	0	0	0	11	11
3	0	0	0	1	0	2	2
4	0	0	0	0	1	1	1
5	0	0	1	0	0	2	2
Objective function value	440						

2.4 Model operation analysis

It is known from the above operation results that the initial and final values of security economy benefit of Company A are 99 and 400, respectively, which implies that the economic benefit increases after redistributing the security cost of hazardous chemicals with the linear programming model. The coefficients of decision variables at this time are 4, 2, 11, 1, 2. It is converted into an input ratio, and the results are shown in Table 5.

Table 5: Optimization results of A company security input ratio prediction in 2014

Input project	Dangerous goods	Transport	Warehousing	Personnel	Equipment
Optimal proportion	20%	55%	10%	10%	5%

As shown in Table 5, the transportation security cost is the highest, reaching 55%; the second is the dangerous goods, up to 20%; the warehousing and personnel security input is 10%, moderate as percentage of the total; the lowest is the security equipment input, similar to the accident rate of each risk factor. It is showed that the prediction optimization result is reliable.

The total sum of security inputs predicted in 2014 reached RMB 199,953. It is known that the input value corresponding to each risk factor is shown in Table 6.

Table 6: Forecast results of A company security input in 2014

Input project	Dangerous goods	Transport	Storage	Personnel	Equipment	Fixed expenditure	Total input
Safety input forecast value	3.53	9.805	1.765	1.765	0.98	2.15	19.995
Actual input in 2013	4.70	2.15	1.60	2.10	8.20	2.15	21.90

The security inputs predicted in 2014 is compared with the practical inputs in 2013, as shown in Figure 5. Company A's total input in 2014 is slightly higher than that in 2013, and there is a big difference in transportation and equipment security. According to the optimized distribution results, transportation security inputs should be intensified and the equipment security inputs should be cut down.

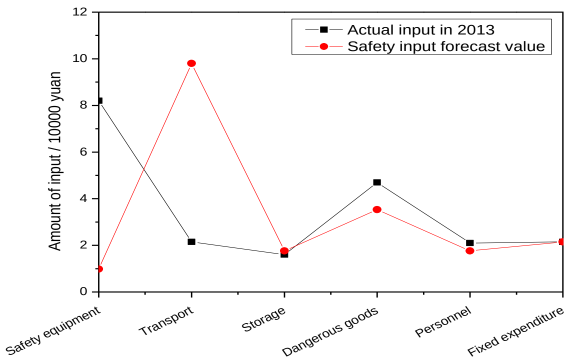

Figure 5: Comparison chart of predicted optimal allocation results

In addition, as the industry development has undergone dramatic changes, it is required to flexibly adjust the percentage of inputs in special cases based on the predicted distribution results. In terms of the security of dangerous goods, it should be determined based on the business volume of dangerous goods, and the control ration is about 20%; in terms of transportation security, the security of transportation should be absolutely guaranteed, since the transportation is the core process of logistics services. It should be controlled as 55% or so. In terms of warehousing security, it should depend on the types of commodities, and can be adjusted according to the special level of the commodities. The control ration is about 10%. In terms of personnel security inputs, it mainly aims at the personnel education and training, and is sustainable. The control ration is about 10%; in terms of equipment security inputs, it has bearing on the security awareness of personnel and the equipment maintenance condition, and the control ration is about 5%.

3. Conclusion

The rapid development of the logistics industry has contributed to speedy increase in e-commerce and the burgeoning of social economy, but it also has raised a range of security issues, especially for the security of dangerous chemicals where major accidents occur from time to time. In order to reduce the security risks, many logistics companies have established appropriate security management system and institution, but the security investment strategies are not sufficiently scientific, security precautions are not in place, and security inputs cannot maximize the benefits. How to effectively predict and optimize the security inputs and maximize the benefit of economic inputs of businesses is still a challenge that plagues us in the business development today. Based on the premise of theoretical analysis, this paper decomposes the risk factors in security inputs, establishes a linear programming model, and applies the model to distribute security resources, thus providing the clues to the security inputs.

(1) The analysis of logistics security, a total of six risk factors are identified, i.e. dangerous goods, transportation, warehousing, people and equipment. Risk contribution rate is also determined for each factor, including dangerous chemical: people: transportation: equipment: warehousing = 25:24:23:15:12.

(2) The linear programming theory is introduced into the analysis of logistics security inputs to analyze the variables, decision vectors and constraints. Take security input data from Company A as an example, a linear programming model is built for maximizing economic benefits.

(3) The linear programming model with the maximum benefit of security investment is used to make a prediction, the optimal allocation of security resource inputs can be obtained, that is, the transportation security cost as percentage of the total inputs accounts for 55%; the security input of dangerous goods is 20%; the warehousing and the personnel security inputs are 10%, respectively; the equipment security input is 5%.

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