Optimization of Multi-Objective Dispatching for Emergency Rescue in Chemical Enterprises

Haoxue Wang(✉)

College of Business Administration, Liaoning University of Engineering and Technology, Huludao 125105, China
853279221@qq.com

Abstract. With the continuous development of chemical industry, the number and scale of chemical enterprises are increasing, but it also leads to the frequent occurrence of chemical accidents, and the complexity and specificity of the production environment makes it easy for the domino effect to occur after the accident, thus causing derivative accidents. Therefore, it is of great significance for chemical enterprises to establish an efficient and reasonable emergency material dispatching strategy. In order to enhance the scientific nature of the enterprise emergency material dispatching strategy after an accident, effectively reduce the loss of the enterprise after an accident and enhance the comprehensive competitiveness of the enterprise. This paper takes enterprise emergency material dispatching as the research object and uses the multi-criteria decision-making method to study the enterprise emergency material dispatching strategy. The specific process is as follows: according to the problem of the enterprise emergency dispatching model, the emergency material dispatching model to maximize time, demand and cost satisfaction is constructed, and the dispatching optimization analysis is carried out in combination with the typical accident of the enterprise, and the comparison with the original processing results of the enterprise shows that the results of the model constructed in this paper are substantially better than the results of the enterprise in terms of time, demand and cost satisfaction. It is beneficial to prevent the occurrence of the enterprise's derivative accidents and effectively guarantee the dispatch of the enterprise's emergency materials.

Keywords: emergency supplies · prioritization · scheduling optimization · multi-objective planning · particle swarm algorithm

1 Introduction

Since the 1990s, China's chemical companies have grown rapidly, including the country's overall chemical output accounting for 40% of the global market in 2018, ranking first in the world [1]. With the continuous development of the chemical industry, most of the chemical enterprises are concentrated and distributed to form chemical parks, and now, chemical parks have become the mainstream of chemical enterprise clusters. There are many enterprise industrial chains [2], concentrated production of hazardous chemicals, the existence of production plants, storage tanks and processing devices and other

S. H. B. D. M. Zailani et al. (Eds.): ICMSEM 2023, 259, pp. 797–806, 2024.
https://doi.org/10.2991/978-94-6463-256-9_80

dangerous sources inside the enterprises, if an accident occurs in such a dense chemical enterprise of hazardous chemicals, it will lead to serious consequences [2] If an accident occurs in such a dense chemical enterprise, it will lead to serious consequences.

As there are many hazardous sources in chemical parks, it is very easy to produce domino effect when an accident occurs, leading to a chain of secondary accidents [2], therefore, how to ensure the safety production in chemical parks has attracted extensive attention from domestic and foreign research scholars. Shen Kexin et al. [4] In order to effectively avoid the occurrence of domino accidents, Zhao Yan [7] the accident risk analysis of China's petrochemical industry. In foreign countries, Sklet et al. [8] proposed the concept of safety facilities by preventing accidents and mitigating their consequences through human means in 2006; Tugnoli [9] in response to the characteristics of chemical parks, which are highly prone to domino secondary accidents, an index system was established for assessing their hazard level, and an evaluation index of safety facilities was proposed in combination with the research of Sklet et al.; Reniers [12] gridded the park, assessed the safety risks in the park, and made recommendations for safe production. Among them [2], the reserve of emergency materials is a key part of emergency preparedness and an important criterion for measuring emergency rescue capability.

In view of this, for enterprises, the effect of accident rescue is closely related to the dispatching strategy of emergency [12] materials, and a scientific and reasonable distribution strategy of emergency materials directly affects the level of risk resistance of enterprises. Reasonable and effective dispatching of emergency supplies [12] can make it possible to reduce losses in case of accidents and thus ensure the rapid resumption of safe production.

2 Emergency Supplies Dispatch Model Construction

2.1 Problem Description

When an incident occurs the decision maker has to determine both which distribution center to send supplies from to each incident point and which distribution center to dispatch the various resources. The abstraction diagram of the dispatching process is shown in Fig.

To emergency rescue time as the shortest as the first goal [12], at the same time to meet as much as possible each accident point should therefore maximize the satisfaction of emergency needs as the second goal [12], and consider the waste of resources under the rescue process to absorb the smallest transport costs as the third goal.

Assumptions.

(1) The cost of vehicle transport per unit distance is known;
(2) Known inventory levels of various materials at each distribution center;
(3) The distances from each distribution center to each incident point are known;
(4) The speed at which the vehicle is moving is known;
(5) Independence of the distribution centers from each other;
(6) A situation where 1 distribution center is allowed to supply to multiple incident sites and 1 incident site receives material from multiple distribution centers;

2.2 Time Analysis

The emergency supplies are divided into two categories in the chemical park emergency rescue, which are *p* class supplies that can go to the accident site alone and can be delivered at one time, such as supply trucks, rescue trucks, etc. and other *q* class supplies that need to be transported separately by transport vehicles. For category p materials, there is no need to load and unload emergency materials and they can go directly to the accident site, so only the transportation time can be considered, while for category q materials, the materials need to be loaded and then transported, so the material preparation time and transportation time need to be considered.

$$T_j = \sum_{j=1}^{n} \max_i (t_z + t_y)$$

where: T_j: emergency response time; t_z: material preparation time; t_y: material transportation time; t_z and t_y are calculated as follows.

$$t_z = p_i Y_{ij}$$

$$t_y = t_{ij} * Z_{ij}$$

Eq: p_i $(i = 1, 2, \ldots\ldots, m)$; Y_{ij}: the number of trucks needed to transport q materials from the distribution center B_i to the incident site A_j $(i = 1, 2, \ldots\ldots, m)$ $(j = 1, 2, \ldots\ldots, n)$; t_{ij}: the time from the distribution center B_i to the incident site A_j $(i = 1, 2, \ldots\ldots, m)$ $(j = 1, 2, \ldots\ldots, n)$; Z_{ij}: whether to send materials from the distribution center B_i to the incident site A_j $(i = 1, 2, \ldots\ldots, m)$ $(j = 1, 2, \ldots\ldots, n)$.

Eq. Equation indicates the actual emergency rescue time, followed by the preparation time as well as the transportation time are calculated separately.

Shipping time.

q Classes of emergency supplies (medical kits, etc.) have both transport time and preparation time.

$$Z_{ij} = \begin{cases} 1 \sum_{t=1}^{r} xp_{ijt} > 0 \text{ and } \sum_{k=1}^{s} xq_{ijk} > 0 \\ 0 \sum_{t=1}^{r} xp_{ijt} = 0 \text{ and } \sum_{k=1}^{s} xq_{ijk} = 0 \end{cases}$$

Transportation time t_{ij} Calculated from equation:

$$t_{ij} = \frac{d_{ij}}{v}$$

In Equation, t_{ij} represents the travel time from the distribution center B_i to the incident point A_j, the distance from the distribution center B_i to the incident point A_j is represented by d_{ij}, and v represents the speed at which the vehicle is traveling.

Total transit time is:

$$t_y = t_{ij} * Z_{ij}$$

Vehicle preparation time.

In addition to the transportation time, for q type of material, the preparation time also needs to be calculated. The prerequisite for calculating the lead time is knowing the number of transport vehicles to be dispatched, which is calculated by the formula shown in Equation:

$$Y_{ij} = ceil(\sum_{k=1}^{s} \alpha_k * xq_{ijk})$$

$$\alpha_k = \frac{volume_{qk}}{V}$$

$$t_z = p_i Y_{ij}$$

In equation, a_k is the ratio of the volume occupied by the kth material to the volume of each transport vehicle. $volume_{qk}$: The volume of the k material of the q material category. VXq_{ijk} indicates the distribution center B_i is the incident point A_j the quantity of the kth material of the q material category. q B_i A_j q Multiplying the volume of a material by the space factor of the transport vehicle, the total space of the transport vehicle occupied by the material is obtained. q Then multiply the lead time p_i of each truck in the distribution center B_i with Y_{ij} obtained above to get the lead time to each incident point.

Finally, add up the travel time of the incident point A_j with the preparation time, and the preparation time of the material of the category p is 0. From all the exit rescue points that deliver the material to the incident point A_j, select the time of the distribution center with the longest emergency rescue time and take it as the latest moment when the incident point A_j reaches the demand, and then add up the latest moment of each incident point to get the time spent on the whole emergency rescue process.

2.3 Demand Analysis

In the process of dispatching emergency supplies, whether the distribution point's distribution of supplies to the incident point meets as well as the demand for supplies at the incident point greatly affects the efficiency of dispatching emergency supplies, therefore, the demand analysis is conducted.

Let the required material requirement for each incident point be D_j, as shown in Equation.

$$D_j = \sum_{k=i}^{s} Dq_{jk} + \sum_{t=i}^{r} Dp_{jt}$$

And the amount of material distribution required at the incident point is X_j, as shown in Equation.

$$X_j = \sum_{i=1}^{m}\sum_{t=i}^{r} Xp_{ijt} + \sum_{i=1}^{m}\sum_{k=i}^{s} Xq_{ijk}$$

In the actual distribution, the degree of satisfaction of emergency supplies should be ensured as much as possible. Therefore, the quantity of material demand minus the quantity of material distribution is used to indicate the quantity of failure to satisfy the demand, and if it is less than 0, it means that the actual delivery quantity is greater than the quantity of material demand and satisfies the demand.

$$D_c = \begin{cases} D_j - X_j & D_j > X_j \\ 0 & D_j \le X_j \end{cases}$$

where: D_c denotes the number of supplies not delivered on demand at the incident point

For D_c, smaller means that the material transported meets the demand of the incident site, if $D_c \le 0$, it means that the actual delivered material fully meets the demand of the incident site.

2.4 Cost Analysis

And the cost function is obtained by multiplying three items: the vehicle transportation cost per unit distance, the distance between each distribution center to each incident point, and the number of vehicles dispatched from each distribution center to each incident point. The number of vehicles sent from each distribution center to each incident point consists of two parts, one part is the number of vehicles sent from the distribution center B_i to the incident point A_j for p type materials, i.e. the number of vehicles. The other part is the number of transport vehicles required to transport category materials.

$$C_j = \sum\nolimits_{j=1}^{n} \sum\nolimits_{i=1}^{m} (f * d_{ij} * (\sum\nolimits_{t=1}^{r} xp_{ijt} + Y_{ij}))$$

where, C_j: Transportation cost from distribution center i to incident point j. f represents the transportation cost per unit distance of vehicle, and d_{ij} represents the distance from distribution center i to incident point j.

2.5 Integrated Scheduling Model

A multi-objective optimization model is developed and transformed into a single-objective problem by a weighting method, and the time, demand, and cost functions are de-quantized. The time satisfaction function, demand satisfaction function and cost satisfaction function are obtained by fuzzy normalization of the time, demand and cost functions.

Time satisfaction

Let the emergency material rescue time be $[T_{\min}, T_{\max}]$, if the emergency material arrives before $T_{\min}$, it will not cause secondary loss and satisfy the time demand by default, if the emergency material arrives within $[T_{\min}, T_{\max}]$, it will lead to the occurrence of loss, if the emergency material arrives late with $T_{\max}$, it means such scheme is wrong, as shown in Equation, $f(t)$ is the time satisfaction function.

$$f(t) = \begin{cases} 1 & T_j \leq T_{\min} \\ \frac{T_{\max} - T_j}{T_{\max} - T_{\min}} & T_{\min} < T_j < T_{\max} \\ 0 & T_j \geq T_{\max} \end{cases}$$

Demand Satisfaction

For demand satisfaction, more specifically, if all demands are satisfied, then $D_{c\omega} = 0$. Therefore, it is sufficient to linearly normalize $D_{c\omega}$ to

$$f(d) = 1 - \frac{D_{c\omega}}{\sum_{k=i}^{s} \omega_{jk} Dq_{jk} + \sum_{t=i}^{r} \omega_{jt} Dp_{jt}}$$

where: $\sum_{k=i}^{s} \omega_{jk} Dq_{jk} + \sum_{t=i}^{r} \omega_{jt} Dp_{jt}$ represents the product of priority and material requirements, if demand is fully met, $D_{c\omega} = 0$, then demand satisfaction is 1. If no demand is met and transportation is 0, then $D_{c\omega} = \sum_{k=i}^{s} \omega_{jk} Dq_{jk} + \sum_{t=i}^{r} \omega_{jt} Dp_{jt}$, then demand satisfaction is 0.

Cost satisfaction

The cost satisfaction expression is shown in Equation:

$$f(c) = \begin{cases} 1 & C_j \leq C_{j\,\min} \\ \frac{C_{\max} - C_j}{C_{j\,\max} - C_{j\,\min}} & C_{j\,\min} < C_j < C_{j\,\max} \\ 0 & C_j \geq C_{j\,\max} \end{cases}$$

Among them:

$$C_{j\,\max} = 1.2C_j \quad (j = 1, 2, \ldots\ldots, n)$$

$$C_{j\,\min} = 0.8C_j \quad (j = 1, 2, \ldots\ldots, n)$$

The multi-objective problem solution is transformed into the single-objective problem solution shown by the linear weighting method:

$$MaxF = \alpha f(t) + \beta f(d) + \gamma f(c)$$

3 Example Analysis

Chemical enterprise was selected to analyze the emergency dispatch mode under a typical accident. Among them, a fire occurred in a plant, which caused a domino effect, resulting in accidents in five plants next to chemical enterprise, and the basic information of the accident point is shown in Table 1.

Table 1. Basic information on six disaster sites

Serial number	Number of people affected (people)	Area covered by the disaster area (km^2)	Accident Type
1	510	3.4	Ethylene fire
2	420	2.7	Aromatic fires
3	310	5.6	Aromatic explosion
4	456	4.1	Propylene poisoning
5	321	2.2	Propylene fire + leak
6	556	3.5	Ethylene explosion + leak

The enterprise has five material distribution centers with certain material reserves, which can meet the degree of demand at the accident point with reasonable transportation, and its basic information and distance from the accident point are shown in Table 2.

The five emergency centers have a certain distance from the accident point, as shown in Table 3.

Table 2. Material reserves of 5 material distribution centers

Distribution center material volume	1	2	3	4	5
First aid kit (/100 people)	307	304	308	219	40
Material truck (/100 people)	25	40	22	36	35
Extinguishing agent (/km^2)	244	167	204	213	149
Rescue vehicle (/km^2)	17	17	16	19	14
Firefighting equipment (/100 people)	143	241	236	231	218
Neutralizing materials (/km^2)	16	12	15	14	8

Table 3. Distance between the emergency distribution center and the accident point

First Aid Kit	1	2	3	4	5
1	28	50	18	37	43
2	20	67	37	10	34
3	26	10	49	31	70
4	10	10	10	55	10
5	16	39	34	23	48
6	80	80	69	80	80

Table 4. Four options versus four satisfaction outcomes

Algorithm name	Demand Satisfaction	Time satisfaction	Cost satisfaction	Overall satisfaction
Particle swarm algorithm with adaptive inertia weights and shrinkage factor improvement	0.97	0.90	0.92	0.93
Adaptive inertia weighted particle swarm algorithm	0.88	0.90	0.91	0.89
Particle swarm algorithm	0.86	0.86	0.64	0.86
Original transportation solution for W Enterprises	0.51	0.77	0.46	0.64

The above results in Table 4 show that the emergency rescue solution proposed in this paper is much better than the original transport solution of enterprise W in terms of demand, time and cost analysis.

4 Conclusion

Once a hazardous chemical accident occurs, it is very likely to trigger a domino effect. As the core part of emergency rescue and disposal, emergency material dispatching is directly related to the development of emergency rescue work and rescue effect. Therefore, in order to improve the emergency material dispatching system of the enterprise, a multi-objective emergency material dispatching model that maximizes time, demand and cost satisfaction is constructed. The main findings are as follows:

(1) The analysis shows that the effect of accident rescue is closely related to the dispatching strategy of emergency materials. Reasonable and effective dispatching of emergency materials can make it possible to reduce losses in case of accidents and thus ensure the rapid resumption of safe production.
(2) Based on the analysis of the existing dispatching model of the enterprise, we found its problems and constructed a multi-objective emergency material dispatching model that maximizes time, demand and cost satisfaction for its problems. The features of the model: First, it is improved and optimized in combination with the enterprise's dispatching strategy to make it more meaningful in practice.

(3) Simulation calculation by example, using particle swarm algorithm to solve, and concluded that the optimization model established in this paper has better results than the original results, and optimized the enterprise emergency material dispatching system.

References

1. Shi Lichen. Research on the problems and countermeasures of chemical park safety development [J]. China Safety Production Science and Technology, 2021, 17(S1): 128–134.
2. Qu Chongchong, Wang Jing, Yu Jiahao. Research on post-disaster emergency logistics decision model and algorithm based on grid-based management perspective [J]. Operations Research and Management, 2022, 31(01): 75–79.
3. Zhang, Yifei, Fu, Liyang, Bi, Jun, (et al.). Study on the risk assessment system of environmental emergencies in Jiangsu industrial park [J]. Environmental Pollution and Prevention, 2020, 42(11): 1430–1435.
4. Shen Kexin, He Zhichao, Weng Wenguo. Coupling between physical effects in chemical domino accidents [J]. Journal of Tsinghua University (Natural Science Edition), 2022 (05): 1–12.
5. Jiang Yongqing. Evolutionary game analysis of local government's safety supervision of chemical enterprises: the example of the "3-21" explosion in Reshui, Jiangsu Province [J]. Journal of Beijing University of Aeronautics and Astronautics (Social Science Edition), 2021, 34(05): 58–69.
6. Guo, Zhonghua, Jiang, Hu, Gong, Chang. Research on the identification of risk factors and network evolution mechanism of chemical explosion accidents [J]. Industrial Engineering and Management, 2022(05): 1–13.
7. Zhao Yan, Xu Jianhua. Analysis of accident risk in China's petrochemical industry [J]. Journal of Peking University (Natural Science Edition), 2018, 54(04): 857–864.
8. Sklet S. Safety barriers: Definition, classification, and performance [J]. Journal of Loss Prevention in the Process Industries, 2006, 19(5): 494–506.
9. Tugnoli A, Khan F, Amyotte P, Cozzani V. Safety assessment in plant layout design using indexing approach: implementing inherent safety perspective Part 1-Guideword applicability and method description [J]. Journal of Hazardous Materials, 2008, 160(1): 100–9.
10. Cozzani V, Tugnoli A, Salzano E. The development of an inherent safety approach to the prevention of domino accidents [J]. Accid Anal Prev, 2009, 41(6): 1216–27.
11. Reniers G. An external domino effects investment approach to improve cross-plant safety within chemical clusters [J]. Journal of Hazardous Materials, 2010, 177(1–3): 167–74.
12. Reniers G L L, Sorensen K, Khan F, Amyotte P. Resilience of chemical industrial areas through attenuation-based security [J]. Reliability Engineering & System Safety, 2014, 131: 94–101.