

Risk Analysis of Fire Disaster in Modern Warehousing System Based on The Data of Idealized Transit Warehouse

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Abstract. In the modern logistic system, the modern warehouse plays an important part in it, affording more functions than just storage. Fire disaster is one of the most common disasters in the modern warehouse, causing huge problems. It is necessary to protect the security of the modern warehouse by specific measures. This study takes a modern logistics transit warehouse as an example, and mainly discusses the fire risk probability in the different areas and the total fire disaster risk assessment using the total probability formula and Gustav civil fire risk analysis method. This study uses the actual data of the warehouse itself and some quantitative methods to calculate parameters indicating the fire risk of goods and people in the Gustav method, and puts them together for a final assessment. Results show that the main storage area have the highest risk for both facilities and stuff, even though the whole warehouse is relatively safe. Finally, this study gives out some practical suggestions for this kind of warehouse, mainly in the aspects of the completeness of fire warning system and installation of fire-fighting facilities.

Keywords: Warehouse, Gustav Method, Fire Risk Analysis, Simulation, Probabilities.

1. Introduction

Since the early 2000s, online shopping has become a new trend in the circulation and exchange of goods. To match the requirements of transportation capacity, a modern logistic system comes into being. The warehouse is an important part of the logistic system, and needs to afford more functions like calculation, transshipment, packaging, and monitoring. That is to say, more facilities and space are required. So, the risk and harm of fire disasters in the modern warehouse are higher than before.

The analysis and prevention of fire disasters in the modern warehouse are necessary. Usually, risk analysis of fire disasters requires the use of qualitative analysis methods. However, there is a half-qualitative analysis method called Gustav method. It not only considers empirical qualitative analysis, but also contains quantitative grading analysis. That is to say, compared with other methods, Gustav method is more accurate and objective. So, this research chooses this method to make some quantitative supplements and corrections.

This research takes a modern logistics transit warehouse as a research object. With the use of the corrected and supplied Gustav method, it offers the analysis, assessment, and prevention suggestions for fire disasters in the modern logistic warehouse.

2. Background of the warehouse

The warehouse is an idealized transit warehouse design combined with forklift AGV (automated guided vehicle) and robots in cargo palletizing and depalletizing. The total area of the warehouse is 29296.7558 m². In the main storage area, there are 648 cargo units (Figure 1). Since it is a modern logistics transit warehouse, the cargo units are in a state of flux in the main storage area.

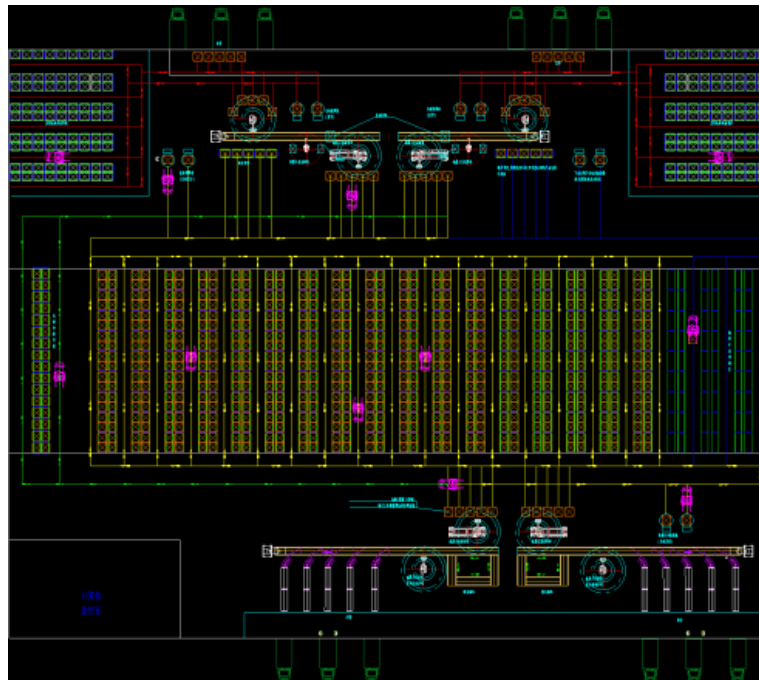


Figure 1. General map of idealized transit warehouse

According to the function of different areas in the warehouse, the whole warehouse is divided into 10 basic areas (Figure 2). Areas 1,3 and 4 are shipping plates storage shelves areas. Areas 2 and 10 are outbound and inbound areas with facilities including image recognition robots in cargo palletizing, depalletizing and automatic equipment for labeling, scanning, and wrapping. Areas 5,6 and 7 are the main storage areas. Area 8 is the bulk cargo storage area. Area 9 is the computer monitoring room. Areas 1-8 and 10 are for forklift AVG for cargo shipping.

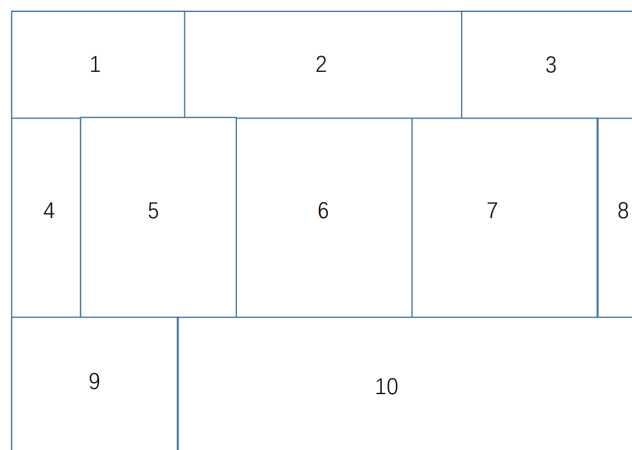


Figure 2. Simplified zoning map of the warehouse

3. Methods

3.1 Gustav Method

Gustav method is a fire risk analysis method that calculates the risk degree and fire loss of the building structure and people or material inside the building respectively to give suggestions, it also focuses more on staff's fire awareness and fire-fighting action [1].

The calculation formula of building fire risk (GR) is:

$$GR = \frac{(Q_M C + Q_i)SL}{WR_i}$$

Where Q_m is the transportable fire load factor; C is the flammability factor; Q_i is the fixed fire load factor; S is the fire area; L is the location factor; W is the building fire factor; R_i is the fire risk reduction factor.

Fire risk inside buildings (IR) stands for the fire risk of material and people inside the building.

$$IR = k \cdot H \cdot D \cdot F$$

Where k is the personnel feature factor; H is the personnel risk factor; D is the property risk factor; F is the smoke factor.

Tables 1 and 2 show the calculation parameters related to the Gustav Method.

Tao has given a formula for comprehensively calculating GR and IR, introducing two non-dimensional coefficients [2]:

$$R = f(GR, IR, C) = \frac{\eta GR + \mu IR}{C}$$

$$\eta_i = \frac{z_i}{S_i} \quad \eta = \frac{\sum_{i=1}^n \eta_i}{n}$$

$$\mu_i = \frac{P_i}{S_i} \quad \mu = \frac{\sum_{i=1}^n \mu_i}{n}$$

Table. 1. Calculation parameters for the Gustav Method

Year	Death	Injured	Life loss (10,000 CNY)	Material loss (10,000 CNY)	Fire loss (10,000 CNY)	μ_i	η_i
1999	45	97	2580.0	18059.7	20639.7	0.125	0.875
2000	37	100	2425.0	8949.5	11374.5	0.213	0.787
2004	39	74	2085.0	6334.3	8419.3	0.248	0.752
2006	12	45	975.0	7740.7	8715.7	0.112	0.888
2008	39	30	1425.0	41969.0	43394.0	0.033	0.967

Table. 2. Primary and secondary indexes for the Gustav Method

Primary Index	Secondary Index	Scoring criteria			
		1.0	1.5	2.5	3.0
Personnel features (0.199)	Number of people	<5	5~25	25~50	>50
	Familiarity with the firefighting facilities	Very familiar	Familiar	Not	Not at all
	Conduct of fire drill status	>Once/month	>Once/season	>Once/half a year	Else
Automatic fire alarm system (0.453)	Whether the system design conforms the requirement	Totally conform	Most of them are conform	Few of them conform	Not conform
	Whether the facilities are in good condition	Good	Most of them are good	Few of them are good	Not good
Evacuation capability (0.348)	Whether the building safety evacuation designs are in standard	In standard	Most of them are in standard	Few of them are in standard	Not in standard
	Whether the safety evacuation	Effective	Most of them are effective	Few of them are effective	Not effective

	signs are effective				
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3.2 Total probability formula

Total probability can be used to calculate the expectation of GR in the structure.

$$P(B) = \sum_{i=1}^n P(A_i)P(B|A_i)$$

3.3 Normal distribution

In the storage area, the case of the goods on the space of each shelf is a random event. This study defines the event “There is a case of goods on this space at any given moment” with the value of 1, its opposite event has the value of 0. It is assumed that the probability that there is a case of goods on this space follows a normal distribution.

3.4 Stochastic simulation method

According to Tong’s research, there should be 30 forklifts in the warehouse, and each forklift can lift two units of goods [3]. So this can be equal to a mathematical model of picking a random number of units-picking up 60 units in a total of 648 units. After a certain number of simulations, the distribution of goods at any one time can be concluded.

3.5 Python simulation code

```
import random
l = [i+1 for i in range (648)] + [1]
for i in range (30)
    a = []
    n = [1 for i in range (648)]
    for j in range (30)
        r = random.randint (0,647)
        while n[r] == 0:
            r = random.randint (0,647)
        a.append ([l[r], l[r+1]])
        n[r] = 0
    print (a)
```

4. Results

According to the working time regulation, the study defines 10 hours as the edge. If the cargo is on its location for more than 10 hours, it shows that there is a case of cargo today. So the probability that there is a case of cargo is 0.6826, and the probability of its opposite event is 0.3174. According to the CAD graphic, the area proportions of Areas 5,6,7,8 are calculated. The probabilities of Areas 5, 6, 7 are 0.1516, and the one of Area 8 is 0.0253. The GR values of Areas 5, 6, 7, 8 are 0.3955, 0.4069, 0.3857, 0.2565, respectively. The E(GR) is calculated as 0.4127. The conformity of IR is the same as GR, and thus E(IR) is 26.398. According to the formula combining GR and IR, the result f(GR, IR, C) is 0.266375.

Table 3 shows the result of the Python simulation, indicating the distribution of cargo units quantity. In Area 5, the distribution results in the range of 180-216, 170-180, and 166-170 are 0.7123, 0.2498, and 0.0034, respectively. Those in Area 6 are 0.6945, 0.2652, and 0.0076, respectively. Those in Area 7 are 0.6429, 0.2718, and 0.0027, respectively. Compared with the theoretical percent distribution in Table 4, the results are reasonable. It means that those results can be adapted in subsequent calculations.

Table. 3. The results of Python simulation

Cargo units quantity range	Area 5	Area 6	Area 7
180-216	0.7123	0.6945	0.6429
170-180	0.2498	0.2652	0.3075
166-170	0.0034	0.0076	0.0047

Table. 4. Cargo units quantity range percent distribution

Cargo units quantity range	Theoretical percent distribution
180-216	0.6826
170-180	0.2718
166-170	0.0027

Based on the results in Tables 3 and 4, Table 5 shows the values of Qm in different areas of the warehouse. Since the Qm is flexible and is an important parameter for the calculation of GR, once this study gives out the value of Qm, the study gives out the calculation results of GR in different areas (Table 6). Results show that GR is higher in Areas 5, 6, 7 (average of 0.693) than in other areas (average of 0.468).

Table. 5. Qm in different area of the warehouse

Area	1	2	3	4	5	6	7	8	9	10
Qm	1.6	1.2	1.6	1.6	2.8/2.4/2.0	2.4/2.0/1.6	2.4/2.0/1.6	1.2/1.4/1.6	1.0	1.2

Table. 6. GR in different area of the warehouse

Area	1	2	3	4	5	6	7	8	9	10
GR	0.564	0.452	0.564	0.564	0.692	0.712	0.675	0.450	0.236	0.452

According to the values of Qm and GR, the IR calculation results in different area can be calculated (Table 7). Results show that IR of Areas 5, 6, 7, 8 are the highest (average of 28.45), followed by Areas 9 and 10 (average of 24.42), and Areas 1, 2, 3, 4 are the lowest (average of 17.94). Combined GR and IR, the risk analysis of the whole warehouse can be concluded.

Table. 7. IR in different area of the warehouse

Area	1	2	3	4	5	6	7	8	9	10
IR	16.10	24.34	16.10	15.25	28.02	27.58	29.95	28.26	24.50	24.34

5. Discussion

5.1 Risk Estimation evaluation of GR and IR

The standard line is a subjective reference index according to the value of rather safe parameters in GR and IR, indicating the key fire prevention areas in the warehouse.

Yang set the standard value of GR and IR according to the score of the safer indicators in the Gustav formula in the E-commerce logistics warehouse; while Tao drew the fire hazard distribution map through the distribution of the GR and IR of different areas and set the standard line distinguishing areas with significantly higher risk values. This study picks the rather safe indicators in the formula based on the expectation of Qm of total areas (1.6), considering the density of distribution for the areas on the map. The standard value of GR is 0.6111, and the standard value of IR is 25.

Setting the standard line and a fire hazard distribution map is obtained (Figure 3).

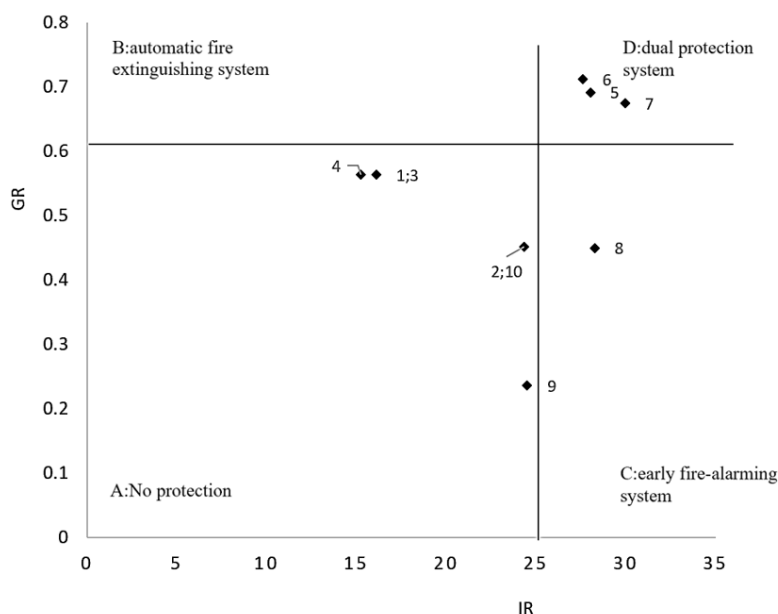


Figure 3. Fire hazard distribution map of idealized transit warehouse

Considering the protection method based on the comprehensive risk evaluation of Gustav method, this study divides the 10 areas of the warehouse into four zones A, B, C, D corresponding to four protection methods through the relationship of location between the area and the standard line.

When the GR and IR values are in different zones, the fire prevention measures are different. When the GR is high, it is recommended to use an automatic fire extinguishing system to strengthen the building's self-rescue ability. When the IR is high, it is recommended to use an early fire-alarming system. When both the GR and IR are high, a dual protection system is recommended.

According to Figure 3, Areas 1-4 and 9-10 are in zone A, indicating safe. Area 8 is with high IR value, which is in zone C, and thus is still in need of the early fire-alarming system. Areas 5, 6, 7 are with both high GR and IR values in zone D, and need dual protection including an early fire-alarming system and an automatic fire extinguishing system.

5.2 Reasons for risk

For the safe areas including 1-4 and 9-10, the Areas 1, 3, 4 are mainly for the storage of shipping plates, with less flammable objects and staff members. These areas are with lower fire risk for both GR and IR. Areas 2, 10 are outbound and inbound areas depositing facilities including image recognition robots in cargo palletizing and depalletizing along with automatic equipment for labeling, scanning, and wrapping, with few cushioning shelves for temporary cargo storage and small quantities of cargo under processing. Both areas are with low transportable fire load factor and flammability factor, the IR value is also low considering its automatic feature. Area 9 is the computer monitoring room which is with few staff and no cargo involved, which both indicate the low fire risk.

Areas 5, 6, 7, 8 are cargo storage areas, with complex sorting and transshipment facilities and a larger number of staff. The personnel hazard is higher than standard, which leads to high IR values. Areas 5, 6, 7 are the Centralized cargo storage areas (Figure 2), with a high amount of goods, the removable fire load factor is higher than in other areas, which led to the high GR value. Area 8 is the bulk cargo storage area, it is occupying less area and with lower density for cargo storage, highly evaluability, and fewer cargo values, which leads to the low GR value.

5.3 Limitation of measures

The analysis through Gustav's method is with a guiding significance towards transit warehouses, however, the practical usage is still limited by its idealization. It could lead to differences in structure areas and function zoning between the idealized warehouse and practical modern warehouses.

In addition, the transit warehouse design is based on a highly automated system with forklift AGV and image recognition robots in cargo palletizing and depalletizing. For traditional warehouses based on personnel resources, the increase of IR value should be considered.

5.4 Suggestions

According to the fire hazard distribution map of the idealized transit warehouse (Figure 3), four suggestions are provided to avoid risk by analyzing the data of GR and IR along with the reason for fire risk based on the function of 10 areas.

Considering the protection method based on the comprehensive risk evaluation of Gustav method, it is suggested to complete the protection system to improve the safety level, with the alarming system in Area 8 while both alarming system and firefighting system in Areas 5, 6, 7.

For the enterprise, the fire prevention plan based on the actual warehouse situation and number of employees needs to consider disabled employees [4]. It is necessary to review the plan annually, update it as required, and redistribute it. Making the list of accumulations of flammable and combustible waste materials is also an important process, getting them into control.

For the employees, the employees' training towards major working fire hazards and procedures to follow in fire emergencies should be enhanced. Meanwhile, regular fire drills should be settled and firefighting activities such as firefighting knowledge competitions could be held by the related enterprise. According to the "2-8" rule which is 20% of people lead to 80% of hazards [5], employees with weak firefighting knowledge and awareness should be mainly noticed and educated. At the same time, the enterprise should also improve the system of reward and punishment accordingly. Arranging employees responsible for the equipment maintaining and controlling fuel source hazards, and providing regular training are in need as well.

For the facility improvement, the exit signs are needed to be well-restored and be suitably settled in various prominent positions [6]. At least two exit routes should be planned in a distant position of the warehouse, and make sure all exit routes are unobstructed at all times by improving the regularly monitoring system. Hazardous facilities such as extension cords are supposed to be prohibited. Meanwhile, the electrical cords along with the electrically operated items should be inspected regularly to avoid the rising hazard of wear or damage.

6. Conclusion

This study chooses a warehouse and applies some quantitative methods to evaluate its fire risk. Results show that the studied warehouse is overall safe. However, according to the GR and IR values, the main storage areas still face a high risk of a heavy-loss fire disaster both for the structure of the warehouse and the property and staff safe. More alarm systems and fire-fighting facilities are needed.

Areas 5, 6, 7 mainly afford the function of the main storage area. Cargo units and stuff are too concentrated in these three parts. The values of GR and IR are relatively high. The fire warning facilities and firefighting facilities should be devoted more money and manpower. Also, some flexible facilities such as forklift trucks should be maintained to avoid the risk of movement and diffusion of the fire source.

Areas 4, 8 afford the function of the storage of loose items, since these two parts have the same function as Areas 5, 6, 7 with smaller scale and fewer quantities. So, the measure can be the same as those in Area 5, 6, 7, but the measure can be more casual.

Areas 1, 3 afford the function of the storage of wooden pallets for forklifts. Since the fire source is wooden and too concentrated, some specific firefighting facilities should be set.

Areas 2, 9, 10 contain a lot of high-tech equipment, the loss of these facilities will not harm the structure of the warehouse and cause collapse, but the loss of them cannot be afforded in the category of property. So fire alarming system will be more important in these two parts.

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