Study on Logistics Warehouse Dynamic Fire Risk Assessment Based on Gustav Method

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Abstract: Modern logistics is a multi-faceted chain link comprised of storage, transfer, sorting, processing, and distribution. Logistics warehouses, regarded as the most significant infrastructures in the supply chain, have characteristics such as large building areas, multiple types, storage of miscellaneous goods, and fast goods flow. In recent years, there has been an increase in the frequency of logistics warehouses fires resulting in large socio-economic losses. Subsequently, a dynamic fire risk assessment method of logistics warehouses is needed. Firstly, 52 fire accidents implied that the fire of logistics warehouses generally destroyed large-destroyed areas, produced poisonous gases, spread rapidly, and led to the collapse of the warehouses. Secondly, the investigation of logistics warehouses showed that the different ribbons of the logistics chain had significant fire resources and risks. Thirdly, the fire risk analysis contributed to developing an index system of fire risk for modernized logistics warehouses with the parameter weights being decided by the AHP method and Delphi Method. Finally, a fire risk assessment method of modernized logistics warehouses was developed by using the Gustav method. The users' feedback ascertained that the new method is feasible and practical even to laymen of very little professional knowledge.

1 INTRODUCTION

Constructing logistics warehouses, which contributed to the high-speed transportation of goods between areas, became the most prevalent campaign because the least time cost of transportation means optimized social economics. COVIN-19 broke out the most serious public health crisis, bankrupted countless industries but boomed the logistics industry. Express delivery has become one of the necessary parts of our daily life. However, whether we under-evaluate some potential social risks?

1.1 Status Quo of Logistics Warehouses

News broadcasted many logistics warehouse fire accidents in recent years, including the Chinese Jingdong warehouse fire in 2016, Amazon UK logistics warehouse (BHX1) fire in 2017, Japanese transportation logistics warehouse in 2018, and Amazon American logistics center warehouse (TEB6) fire in 2020. Logistics warehouse fires always cause serious economic losses and casualties.

Logistics has been the tipping point of economic rise among modern industries and an integral parameter of financial evaluation. With the increasing demands of logistics, advanced technologies and transportation capacity, new automatic modernized logistics warehouses with a clearance height of over 14m are being developed. As the most substantial link within the logistics industry, how can we ensure its safety development? One efficient way is to develop a fire risk assessment method for modernized logistics warehouses. The structure of the article is shown in Figure 1.

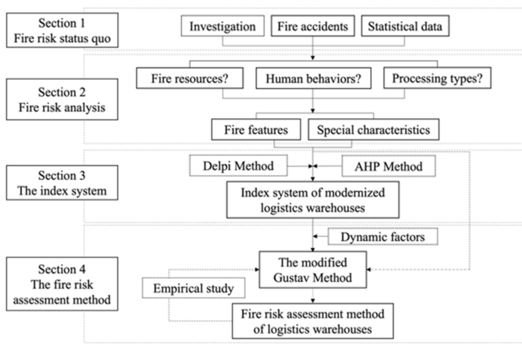

Figure 1: The structure of the article.

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1.2 Research Review

During the early years in the logistics industry, scholars focused more on how to optimize the layout of logistics warehouse based on the cost-benefit model, Melendez 0. et al (2001) and M.Dai.s C. (2010) suggested different optimization plans. These optimized plans were not enough to prevent the warehouse fire from occurring.

Subsequently, countries published their logistics warehouse regulations for various aspects, including the NFPA 230 Standard for the Fire Protection of Storage (2000), National Standard of Canada, The Building Code of Australia and Classification and Requirement of Logistics Park of China (2017). However, the regulations are hysteretic with the development of warehouses. The new types of logistics warehouses cannot satisfy the basic requirement of fire protection in the code. Wenhui J. (2017) chose nine typical logistics warehouses in China and studied the contradictions between real construction and fire department design requirements to make the fire protection investment more reasonable and feasible.

How can one value the risk of the logistics warehouse? This can be done through a risk evaluation method to ascertain the risk factors. Zang L.and Zhang J. established an index system for transportation warehouses using the fuzzy comprehensive analysis method and the Analytic Hierarchy Process (AHP). Wenhui J. (2016) developed the Event and Fault Tree Analysis method (EFTA) to explore the fire spread mechanism of various cotton logistics warehouses.

2 FIRE RISK ANALYSIS OF LOGISTICS WAREHOUSES

Fire risk analysis is an efficient tool to find the fire risk factors. The general and special characteristics should be analysed by fire accidents and features of different functions respectively.

For the common characteristic, 52 fire accidents, from 2005 to 2020, were collected with their complete information and investigation reports. There are four features of fire accidents in logistics warehouses, larger destroyed areas, abundant toxic and high-temperature smoke, faster spread speed at the early fire stage, and collapse.

For the special ones, it depends on the features of different processes. Warehouse types are defined by location, application, and automatic degree, which in effect lead to different fire characteristics. Generally, storing, sorting, and processing are the essential components of modernized logistics chains. Special fire risk analysis can be studied by comparing these three links.

2.1 Storing Area

Sorting has been the feature of the modernization of logistics warehouses. Investigations show that stochastic fluctuation of fire loads, complex combustion sources, and electrical failure are significant risk characteristics in the sorting area.

Although it is called 'zero storage' in the sorting center, the storage time is no more than 4 hours, the storage capacity randomly tips a peak every day as such making it difficult to predict the fire loads. Duo to its 'zero storage' nature, the sorting center is open to every person, unsafety behaviours, smoking or arson. This increases the propensity of a fire accident more readily. Even though automatic equipment is popular and advanced, its operation needs electricity. In the 52 fire accidents analysed, 30% was as a result of electrical failures, the highest of the loss.

2.2 Manufacturing Area

Manufacturing, including unpacking, thermoplastic, and repackaging order goods, is the most complex aspect of logistics warehouses. Lack of efficient fire separations and high-temperature manufacturing processes are the unique fire risks in this area.

To shrink the time interval between packing and transportation, storing area is always close to the manufacturing area, and the conveyor belts across the firewall may times. Even some warehouses illegally dismantle the fire separations. Thermoplastic needs high-temperature conditions. If the good with the high-temperature external surfaces, are put near inflammable things, a fire is likely to occur.

3 INDEX SYSTEM OF FIRE RISK ASSESSMENT FOR MODERNIZED LOGISTICS WAREHOUSES

Index system is a general method to evaluate logistics warehouses' fire risk. There exits quite a lot of index systems that is different in either warehouse categories or risk parameters. However, they cannot satisfy the modernized classification with high-tech and multi-function. Compared to the traditional warehouses, the modern ones have new fire risk sources and the context-specific fire characteristics ignored by any of the existed index systems. Therefore, a need to construct an updated version of the modernized logistics warehouse index system.

3.1 Construction Principle of Index System

The science and efficacy of the risk evaluation index system is dependent on whether the evaluation parameters are chosen reasonably. The effect between risk parameters of warehouses is complex enough as hinted by several principles always reminded us through the construction process.

Firstly, what is the main purpose of establishing an index system? It's to find out fire risk sources, distinguish risk factors, make sure fragile spots are eliminated or control the risks. Secondly, over-comprehensive should be avoided. Too many risk indexes may lead to an overlap of similar risk factors, and it may cause an over-evaluated risk level leading to a waste in fire protection investment. Unfortunately, it is not feasible for users to check out at first glance which fire risk should be eliminated without personalized characteristics being included. It is imperative therefore to consider special risk characteristics for developing warehouses. Fortunately, the research provides the basis for it.

3.2 The Parameters of the Index System

According to the theory of two types of hazards and the fire risk analysis, an optimized and multiple index system of modernized logistics warehouses is composed of four parameters in the first level, ten in the second level, and thirty-two in the third level, as shown in Figure 2.

There are four noteworthy points in the new index system. The first takes into account the risk of different process characteristics (B_2) into account. The second one is that it considers the risk of fire shutter in different parts, fire curtain at the firewall (C_{27}), and fire curtain near the conveyor belt (C_{28}). The third, safety management (B_5) considers whether the garbage materials cleaning is in time (C_{32}). The fourth, evacuation factors are omitted because the investigation showed that the workers in modernized logistics warehouses are few and familiar with the evacuation plans.

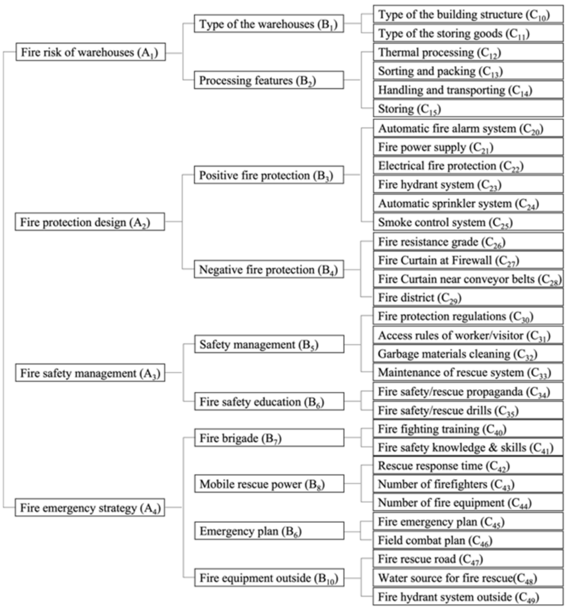

Figure 2: The index system of fire risk assessment of modernized logistics warehouses.

3.3 Weighted Parameters

Due to the lack of a database for logistics warehouses, it is scientific to calculate the weight of parameters in the index system was calculated using the AHP method and the Delphi method based on the fire risk analysis above. We invited more than ten renowned first safety Chinese experts.

Two methods were used to determine the weight of the judgment interval matrix, the relevant weight between indicators. We used MATLAB to calculate the weighted value of parameters and assess the consistency. The result of the consistency test of the judgment matrix is well, as is shown in Table 1.

Table 1: Consistency test of judgment matrix.

Judgment matrix	CR	Consistency test
$R_{P\leftarrow A}$	0.0440	Yes
R_{A_4C}	0.0191	Yes
R_{B_2C}	0.0415	Yes
R_{B_3C}	0.0257	Yes
R_{B_4C}	0.0428	Yes
R_{B_5C}	0.0191	Yes
R_{B_8C}	0.0036	Yes
$R_{B_{10}C}$	0.0036	Yes

4 THE MODIFIED GUSTAV METHOD FOR FIRE RISK ASSESSMENT OF LOGISTICS WAREHOUSES

When it is uncertain on which method to select amongst the many evaluation methods, the status quo and analysis of reasons should be considered. The status quo shows that the lack of historical data of logistics warehouse fire accidents excludes the quantitative methods, and the research goal of workers' evaluation method decides that the new method should be simple to learn and easy to operate.

4.1 Modified Gustav Method

Gustav method is a semi-quantitative risk analysis method. It separates fire risks into two aspects, the structure destroys of construction outside (GR) and property loss and casualties of construction inside (IR). The method constructs a rectangular coordinate system, x-axis defined as GR against the y-axis as IR. Two figures decide one point defined as risk level in the rectangular coordinate system. In this way, Gustav method could provide simple and feasible fire protection plan to companies, even those who don't have enough knowledge of fire prevention. However, the traditional Gustav method can only determine a fixable fire risk level. Considering the fire protection status quo and fire risks analysis in modernized logistics warehouses, it is necessary to modify the traditional version to consist with fire risk characteristics. So, we added dynamic factors into GR and IR to account for the dynamic assessment.

For GR, we added mobile fire loads and their inflammable degrees. We also considered the different links, similar to categorizing the special fire risks into storing, sorting and manufacturing areas.

$$GR = \frac{(Q_m \cdot \alpha + Q_i) \cdot S \cdot B \cdot T}{W \cdot R_i} \tag{1}$$

Q_m and Q_i, the mobile fire risk loads and fixable fire risk loads respectively; α, the inflammable degree of Q_m; S, the building area; B, the risk parameter of location; T, the function district parameter; W, the fire resistance degree; R_i, the competency of the fire protection system.

For IR, we added the number of people as the dynamic parameter of IR and multiplied it by 0.1 to shrink the maximum value of IR to fit with the figure interval of the x-axis.

$$IR = 0.1F \cdot (H \cdot \varphi) \cdot D \tag{2}$$

F, toxic degree of gases; H, the risk degree; φ, the number of people; D, the loss degree of property.
All value of each parameter above obeys some regulations. The original parameters values are same as the traditional Gustav method, while the figures of adding parameters are according to the status quo of building codes or other regulations. The details of the figures are available on request.

4.2 The Procedure of Dynamic Fire Risk Assessment of Modernized Logistics Warehouses

The research above establishes a dynamic fire risk assessment to fit modernized logistics warehouses. Assessors should therefore know how to use it, and the procedure of the method illustrates as follow.

Firstly, the assessor should investigate the basic data of an assessed warehouse. At the same time, the assessor should record the fire risk resources and hidden hazards. In this step, the assessor can determine some values of fixable parameters in the modified Gustav method.

Secondly, the assessor should choose an area to record the data of dynamic parameters at least two days (without maximum limitation), including the mobile fire loads, the number of workers. This helps to bring out average value of each dynamic parameter comes out.

Thirdly, the value of each parameter in the modified Gustav method should be multiplied with the corresponding weighted value in the index system, to bring out the fire risk level comes out.

4.3 Empirical Study

The sorting center of JingDong Gu'an Logistics warehouse was chosen. It is 20762.28m^2, separated into three fire compartments, and installs automatic sorting equipment. This warehouse is used to sort electronic household appliances, mobile phones, laptops, foods, and some wine.

We chose 15-time points every day to record the data of the mobile fire loads and the number of people, and the recording work continued for one week. Three periods, 01:00 to 7:00, 11:00 to 14:00, and 18:00 to 21:00 were deleted because workers rested during these periods. It was assumed that there was no fluctuation of fire risk, although some few parts continued working actually.

According to the investigation of the sorting center of the logistics warehouse, by adding data from the record, each parameter's value, the average value of one week's records, in the modified Gustav Method could be determined, as the table 2 shows.

Table 2: The value of GR & IR in Jingdong sorting center of logistics warehouse.

Time	GR	IR	Time	GR	IR
7:00	0	0	17:00	3.99	2.16
8:00	0.35	2.16	18:00	5.32	1.08
9:00	1.24	2.16	21:00	3.11	2.16
10:00	1.95	2.16	22:00	3.73	2.16
11:00	2.57	2.16	23:00	2.84	2.16
14:00	2.75	1.08	00:00	1.15	2.16
15:00	2.40	2.16	01:00	0.53	2.16
16:00	3.19	2.16	—	—	—

Putting all the figures into x-axis and y-axis respectively, a graphic, implying the fluctuation of fire risk in sorting center of logistics warehouse, is shown as Figure 3.

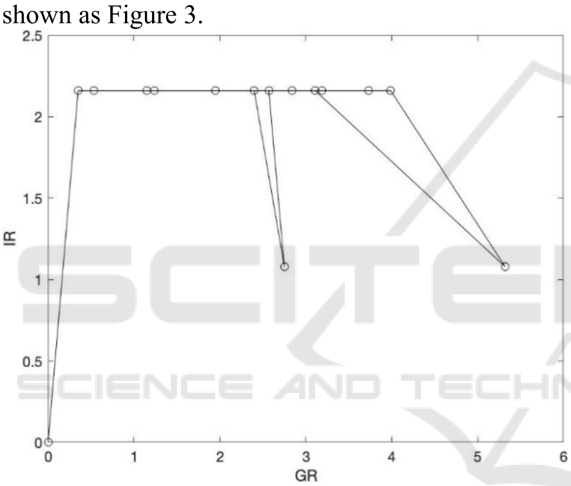

Figure 3: The fluctuation of fire risk level in sorting center of logistics warehouse.

According to Figure 3, three points are lower than others, respectively corresponding to 7:00, 14:00, and 18:00. It is obvious that when the sorting center is operating, the fire risk is higher. However, comparing the three lower points, the fire risk at night is still higher relative to the morning. The manager said that the reason might be that some orders, paid through the e-commerce platform, were at night. When the worker picked out the goods and transported them to the sorting center, the workers had to work overtime, but the extra time was excluded from the record.

5 CONCLUSIONS

The research develops a dynamic fire risk assessment method based on the Gustav method.

Firstly, based on investigations of fire accidents and reports of modernized logistics warehouses, the research implies the status quo of fire safety, analyses the fire features, and concludes special characteristics for different links in logistics warehouses.

Secondly, the research constructs a new index system of modernized logistics warehouses, and emphasizes the effect of warehouse types, packing garbage, operating processes, and fire roller shutters.

Thirdly, the research modifies the Gustav method by adding dynamic fire risk factors, mobile fire loads, and the number of workers. Through the assessment of the fire risk in Jingdong Gu'an sorting center of logistics warehouses, the result validates the reliability and efficacy of the new assessment method.

When reviewing the research, we think some aspects could be improved. In the empirical study, the type of the function area is too single to make a comparison, and the time length of the record is too short to find enough routines of fluctuation. And the research started on a general workday, not on a special days like shopping festivals, which may raise the peak figure of the mobile fire loads. Moreover, the new method could be modified to be a quantitative, provided enough data of logistics warehouses and change the method of calculating the weight of parameters. Other details pertaining to investigation and calculation that were not presented in this paper are available on request, if needed.

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