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Fire Risk Analysis and Emergency Evacuation Study on Large Comprehensive Building

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Abstract: To prevent and control the fire risk of large comprehensive building, taking Jianye shopping plaza as an example, with the analytic hierarchy process (AHP) to establish large comprehensive building fire risk evaluation index system, the final evaluation index and fire risk level of Jianye shopping plaza is calculated by using the security check points and weight of the cumulative. Crowd evacuation time is simulated by using FDS, which can conclude that, in the ideal state, emergency evacuation time is 150 s and 3500 people are evacuated completely. In actual running state investigation, however, it is concluded that researchers were completely evacuated after the 450 s, while only 1500 people have been evacuated in 150 s. Finally, trajectory intersection theory is put forward in two aspects of the fire risk and emergency evacuation measures. Suggestions and measurements are proposed in order to prevent fire in reality and improve the possibilities timely as well as effectively in crowd evacuation after the fire, which are able to guarantee the safety of people.

Keywords: Fire Disaster, Emergency Evacuation, Large Comprehensive Building, Risk

1. Introduction

With the deepening of China's openness and the increasing of economic level, all kinds of large-scale integrated construction emerge such as commercial buildings, supermarkets and so on [1], but, at the same time, large-scale integrated building fire has happened constantly. Only in terms of commercial building in large comprehensive building, its area in 2012 is already greater than 112.4 million m^2 with approximately 13.1% average growing rate. And the single area of commercial buildings is growing with each passing year. In these buildings, cardinal numbers of personnel are large with big densities. Data displays that in some hot sell area, the densities often reach over 0.5 person per m^2. [2]

According to related data, only in 2014, the death toll in personnel intensive place reaches up to 307 people, accounting for 16.9% of the total number of deaths, which the accident caused incalculable economic losses [3]. To analyze large comprehensive building fire risk, according to the results of analysis of the fire emergency evacuation study [4], it is an urgency that put forward the corresponding targeted improvement measures and Suggestions.

In recent years, domestic and foreign scholars focused more on the application of accident causation theory and fuzzy mathematics in fire risk analysis of buildings, in order to establish the evacuation model for fire protection and evacuation performance of buildings with evaluation and analysis through the simulation. The analytic hierarchy process is mainly used in this article to systematic analyze the main reasons and features of fire risk. Quantitative process is distinct and calculation results are simple, clear understandable and practical. Using simulation software to simulate evacuation, the comparison of each evacuation time is more focused, which can provide more intuitive simulation results and comparison of the evacuation effect in the real large comprehensive buildings. On the basis above, trajectory intersection theory is used to analyze and countermeasures put forward are also more practical.

2. Risk Statistical Analysis

2.1. Accident Statistics on Large Comprehensive Building Fire Accidents

By collecting possible fire accidents in the large comprehensive buildings, according to the consequences of and the cause of fire accidents to do statistical analysis [5].

During the past two years, statistics of fire accidents is shown in table 1, and the cause is shown in table 2.

Table 1. *Statistical table of fire disastersin 2013-2014.*

Item	amount	deaths	injuries	direct economic losses (millions)	Burned construction areas(m^2)	Affected buildings
Shopping mall	2016	24	21	41135.1	219253	1135
supermarket	1580	14	6	9720.1	66378	630
Indoor market	1312	36	35	9694.2	78958	1050
hotel	1947	21	36	2836.5	41354	530
entertainment venues	1485	24	59	4749	55074	430
Total number	8340	129	184	68179.9	461017	3775

Table 2. *Statistical table of the cause of fire disasters in 2013-2014.*

	firing	electric	Production operation	Careless use of fire	smoke	Playing with fire	Spontaneous combustion	lightning stroke	static electricity	other
Shopping mall	45	1065	107	190	68	29	11	2	0	269
supermarket	30	885	31	179	57	31	7	1	2	277
Indoor market	16	732	46	140	41	16	8	1	0	222
hotel	58	859	95	320	141	34	4	0	0	340
entertainment venues	31	804	63	159	78	13	13	2	0	249
Total number	180	4345	342	988	385	123	43	6	2	1457

2.2. Causes and Characteristics of Large Comprehensive Buildings Fire

From the perspective of the statistics causes of fire disasters of the large-scale integrated constructions in nearly two years, electric accounted for the highest percentage in the causes of the fire, followed by careless use of fire, production operation and smoke, and the least amount of the causes of the fire as a proportion is for firing, playing with fire, and spontaneous combustion [6].

From the perspective of the statistics of fire disasters of the large-scale integrated constructions in nearly two years, large-scale integrated buildings have huge number of fire accidents; more and more casualties and economic losses caused by fire accident are becoming more serious, and the burned and affected building areas more also have a great number. It may be because of the inventory or goods and commodities with large quantities in and out in places such as shopping malls and supermarkets [7], and they are located in the downtown area with crowded and heavy traffic, once there happen fire, it will spread quickly, prone to stampede, burns and other accidents of deaths and casualties with great number of persons [8].

3. Fire Risk Assessment

3.1. Fire Risk Assessment Index System and Its Weights

The author mainly uses the analytic hierarchy process (AHP) to establish large comprehensive building fire risk evaluation index system. The main evaluation content are five parts including construction factor, fire using expert scoring method to mark all levels of indicators factors according to the impact of accidents' consequences, calculating the various evaluation index for the relative weight value of evaluation content, and finally concluding that the lowest level indicators for cumulative weight value. For example, matrix of grades, in the first part in figure is table 3. [9]

Table 3. *First level index matrix table of decision-making layer A.*

construction factor	A1	A2	A3	A4
construction characteristic A1	1	-	-	-
fire-resistant rating A2	2/3	1	-	-
Fireproofingzone A3	2/3	1	1	-
Area A4	1	2/3	3/2	1

Control facilities factor, product factor, safety evacuation factor and factor of safety management, five parts including construction factor, fire using expert scoring method to mark all levels

Obtain the large-scale integrated building fire risk assessment index system and relative weight value and the accumulative weight value of indexes at all levels by calculation, and the results is shown in table 4.

Table 4. *Fire risk assessment index system and relative weight value.*

criterion layer	first level assessment indicator	relative weight	second level assessment indicator	relative weight	cumulative weight value
Factor A 0.150	construction characteristicA1	0.200	architectural scaleA11	0.200	0.006
			Used service year A12	0.450	0.02025
			building altitudeA13	0.350	0.0105
	fire-resistant rating A2	0.300	fire-resistant rating of building altitude A21	0.500	0.0375
			fire-resistant rating of decorative materialA22	0.500	0.0375
	Fireproofingzone A3	0.300	Horizontal Fireproofing zone A31	0.500	0.0375
			vertical Fireproofing zone A32	0.500	0.0375
	Characteristic of areaA4	0.200	fire lane A41	0.250	0.0075
			The fire interval between buildingsA42	0.200	0.006
			the distance from the fire brigade A43	0.250	0.0075
			Traffic conditionA44	0.300	0.009

3.2. Fire Risk Analysis of Jianye Shopping Plaza

Taikang county Jianye shopping plaza limited company is located in intersection Construction Road and Zhinong road in Taikang county, zhoukou city in Henan province. Safety checks for Jianye shopping plaza to mark according to the security level is shown in the table 4[10], then to calculated the final evaluation index fire risk level of Jianye shopping plaza by using the security check points and weight of the cumulative security evaluation level as shown in table 5.

Table 5. *Security evaluation level table.*

Evaluation rating	Good	preferably	general	Relatively bad	Bad
Grade	[90,100]	[75,90]	[60,75]	[45,60]	[0,45]

The fire risk assessment of the Jianye shopping plaza is made and the final result is shown in table 6.

Table 6. *Jianyeshopping plaza fire risk assessment.*

serial number	Index	Assessment content	Points	The cumulative weight value	Index points
1	architectural scale A11	Is it a architectural scale	70	0.006	0.42
2	Used service year A12	Whether in service year	85	0.02025	1.72125
3	building altitude A13	Is it a high-rise buildings	50	0.0105	0.525
4	fire resistance rating of building structure A21	Whether to conform to the specifications or specific requirements	76	0.0375	2.85
5	fire-resistant rating of decorative materialA22	Whether accord with standards	70	0.0375	2.625
6	Horizontal Fireproofing zone A31	Whether over or accord with standards	70	0.0375	2.625
7	vertical Fireproofing zone A32	Whether over or accord with standards	70	0.0375	2.625
8	fire lane A41	Whether accord with standards or whether be blocked or occupied	50	0.0075	0.375
9	Whether accord with standards	Whether accord with standards	40	0.006	0.24
10	the distance from the fire brigade A43	arriving in five minutes as standards	70	0.0075	0.525
11	traffic condition A44	Average of free, crowd and blocked value	50	0.009	0.450
Total					56.73075

Finally the score of Jianye shopping square is calculated: 56.73075. According to the levels of stipulations of index evaluation and scoring, the square level is less. So the possibility of a fire is higher. The main hidden trouble in the following areas:

(1) The mall fire channel had occupied and blocking phenomenon. During the holiday, fire channel was occupied because of the overmuch personnel cars unable to park.

(2) The unit paid little attention to the useof fire explosion protected electrical apparatus. Fire-resistant cable did not wear a buried pipe line processing, which is extremely easy to fire accident.

(3) Electrical ground handling situation was not ideal, and part of the appliance did not handle.

(4) Fire interval between buildings was short, not conforming to the relevant provisions of the state.

(5) Exit was shut down. There is no guarantee that the emergency evacuation channel unobstructed.

4. Emergency Evacuation

4.1. Evacuation Parameters of Jianye Shopping Plaza

According to statistics of marketing and security department of the Jianye shopping plaza, personnel composition situation as shown in table 7, the weekday traffic statistics as shown in figure 1, traffic statistics on weekend as shown in figure 2.

Table 7. *Staff composition in Jianye shopping plaza.*

staff composition	male	female	The aged	children
ratio	37.2%	47.6%	7.3%	7.9%

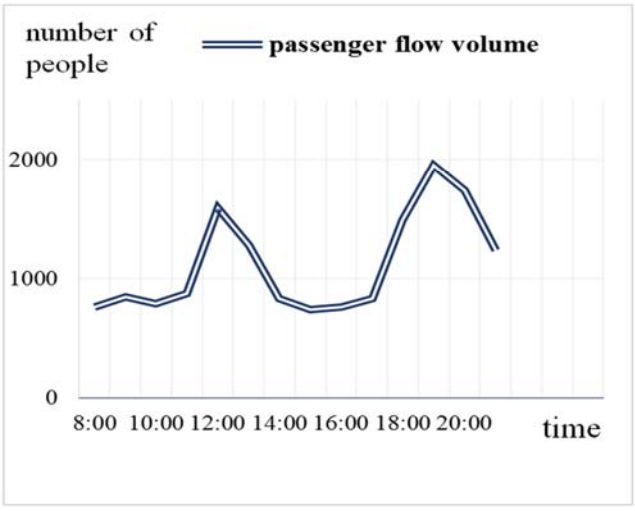

Figure 1. *The weekday traffic statistics.*

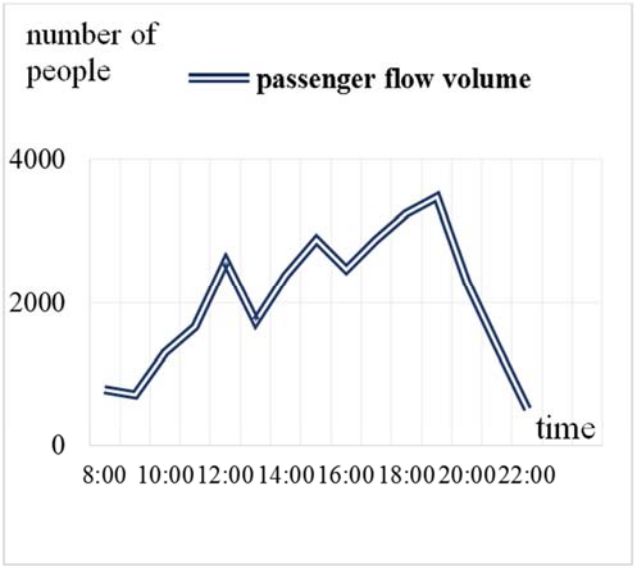

Figure 2. *Traffic statistics on weekend.*

4.2. FDSEvacuation Simulation

The author does the emergency evacuation study to Jianye shopping square model, setting up the fire for the shopping plaza happening during the evening peak at 19:00-18:00. Passenger flow volume is 3500 people, setting up by staff composition as women, men, children and the aged, respectively 1666, 1302, 256 and 276. To compared the analysis of running state of idealstate and the actual work of Jianye shopping plaza simulation [11]. Purple part in figure 1 is store mobile shelves. Shopping malls have five exports, which have two store front and side and the remaining three exits for connecting the warehouse. In the field research and practice, locations of mobile shelves, corridors and public area displayed on the map; Store front and side were occupied by a vehicle jam or other staffs; Connection of warehouse three exit regularly closed and locked. Therefore, to do the emergency evacuation study of Jianye shopping plaza with simulation analysis in realistic operating conditions. There are two kinds of state simulation analysis below, figure 35,7, 8shown as the actual running state and 4, 6 as the ideal state.

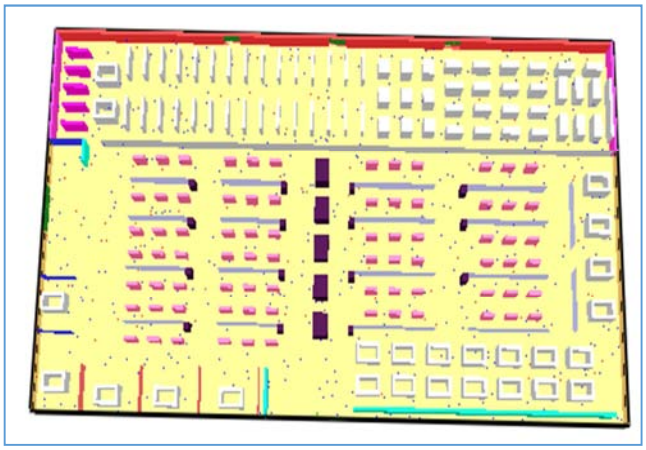

Figure 3. *The actual running stateof 0S personnel distribution of shopping mall.*

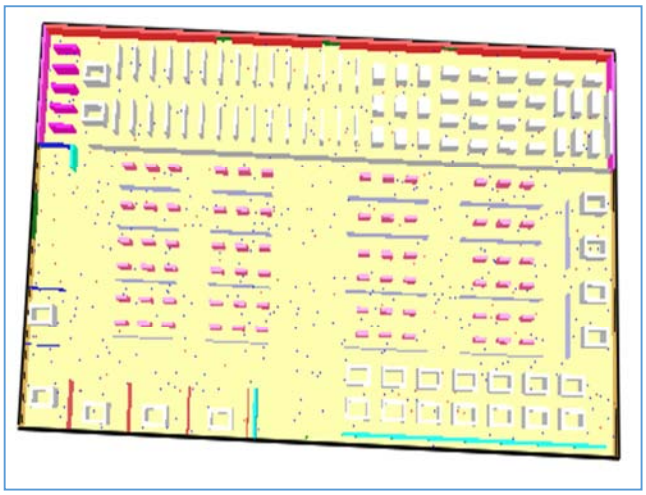

Figure 4. *Theideal stateof 0S personnel distribution of shopping mall.*

Figure 5. *The actual running stateof 150S personnel distribution of shopping mall.*

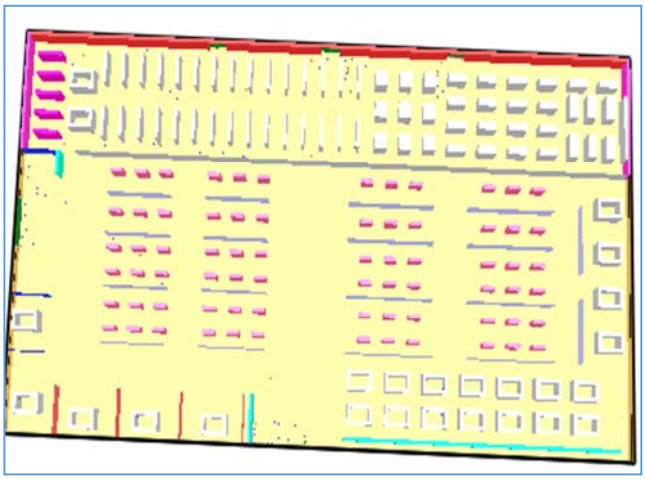

Figure 6. *The ideal running stateof 150S personnel distribution of shopping mall.*

Figure 7. *The actual running state of 320S personnel distribution of shopping mall.*

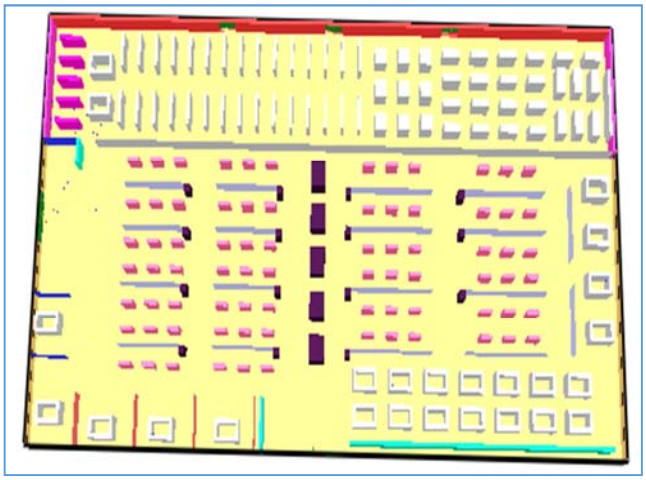

Figure 8. *The actual running stateof 450S personnel distribution of shopping mall.*

According to simulation analysis of emergency evacuation in ideal state and the actual running state of Jianye shopping plaza, it is concluded that, in the ideal state, emergency evacuation time is 150 s and 3500 people are evacuated completely. In actual running state investigation, there are conditions including occupied the corridor on the public area with obstacles such as mobile shelves, closed exit, occupied fire engine access with other vehicles, and so on (details seen as the attachment). It is concluded that researchers were completely evacuated after the 450 s in actual running state. Only 1500 people have been evacuated in 150 s. For the above situation the following control measures are put forward:

(1) Fire channel exists conditions like blocked or occupied, etc., special warning label should be set up on fire channel. Once conditions like occupied or jam have been found, related personnel should be arranged immediately to take.

(2) Exits must keep unobstructed, and not be closed or occupied by the other goods jams.

(3) Because there are mobile shelves and other items on mall's corridor between, causing fire prevention spacing decreases, so the mobile shelves on the corridor should be removed. Or the counter should be widened.

5. Risk Control Measures

By studying the fire risk and emergency evacuation of large-scale integrated buildings, according to the theory of trajectory cross as shown in figure 9, improvement measures of large-scale integrated building fire are put forward respectively from two aspects of fire risk and emergency evacuation. [12]

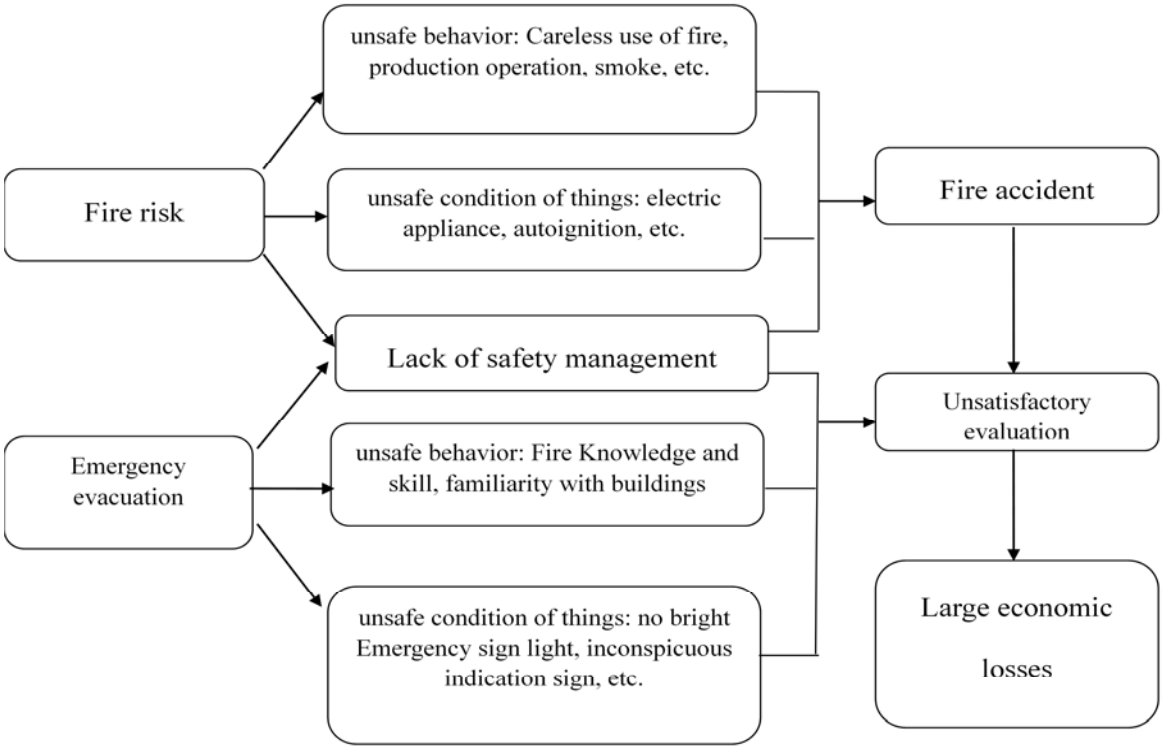

Figure 9. *Orbit Intersecting Theory model.*

5.1. Fire Risk

By trajectory intersection theory, itcan be seen that they are human unsafe acts, unsafe state of objects and the lack of safety in fire manage to cause fire accidents. Therefore, measurements are put forward on the aspects of fire risk control.

(1) Electrical equipment must be bought or used observing the rules and regulations grimly, and fire-resistant wire must be embedded or poling or circuit grounding.

(2) Materials easy to spontaneous combustion need special handling, without placing together with combustible or inflammable ones.

(3) The firefighting equipment, such as fire extinguisher and fire hydrant facilities needs prophylactic repair as well as timely replacement, should be ensured the normal use of equipment, automatic alarm system, automatic sprinkler system design and construction in accordance with the relevant provisions of the state, regularly inspecting and replacing.

(4) When the production operation, staffs have to should be, after passing safety educations and trainings, in strict accordance with the rules and operation process before operations, finally mounting guard after qualified inspections. For special equipment operating personnel executing in strict rotation with employment with certificates institution, staffs should wear personal protective equipment by rules.

(5) Placing no smoking signs in each public place of a large comprehensive buildings, safety management personnel and workers should be discouraged while finding smoking.

(6) With enacting impeccable relative administrative rules and institutions, executing and practicing in strict rotation with safety production responsibility system, explicit ranges and contents of each post, building relative safety administrative department and institution needs related qualified personnel who pass the strict safety training to be in charge.

5.2. Emergency Evacuations

With orbit intersecting theory, it can be seen that unsafe behaviors and conditions and lacks of safety managements in emergency evacuations are able to enlarge fire accidents.

(1) Specifications and locations of emergency equipment like emergency indicator light and applied floodlight should be set up by relative rules of the state and prophylactic repairing in order to well function.

(2) Exits should be unobstructed, not being allowed to occupy or block.

(3) Public areas shouldn't be occupied by commodities or campaign materials. Corridors shouldn't be put with moving goods shelves or promotion items, in order to ensure that there are unblocked personnel paths.

(4) Exits graphs of this building should be put in the building entrance. Employees in mall should pass safety trainings to be familiar with emergency evacuation routes and master the fundamental firefighting knowledge.

(5) To provide advertise paper about evacuation and activities in aspect of evacuation to the customers.

6. Conclusions

Large comprehensive building's fire could easily cause serious personal casualties and property losses. Because of the economic level continually rising and the high population density, it is vital to look for main causes and characteristics of large comprehensive buildings fire and to reduce and avoid the catastrophic accidents through prevention and emergency evacuation measurements. In this article, research is carried on large comprehensive building fire in three parts-- analysis of fire risk, emergency evacuation simulation and countermeasures and suggestions. The following is main conclusions:

1. From the perspective of the statistics causes of fire disasters of the large comprehensive buildings in nearly two years, electric accounted for the highest percentage in the causes of the fire, followed by careless use of fire, production operation and smoke [6]. Targeted preventing buildings from those causes of the fire, especially the electrical fire, can effectively reduce fire accidents.

2. The severe accident consequences of large comprehensive buildings may be because of the inventory or goods and commodities with large quantities in and out in places, and the location in downtown area with crowded and heavy traffic. Once there are on fire, the fire will spread quickly, prone to stampede, burns and other crowded group death and injury accidents, which could have serious casualties. [8].

3. Taking Jianye plaza as an example, the main hidden troubles are: occupation and clogging phenomenon, lack of maintenances and managements for fire and explosion preventions, unsatisfactory electrical grounding, short fire interval, obstructed emergency evacuation channel.

4. By ideal and the actual situation of emergency evacuation simulation analysis on Jianye plaza, there are great differences of evacuation effect between ideal state and actual state. To rectify and improve the firefighting accesses, exits and shopping corridors can well improve this situation.

5. The occurrences of large comprehensive buildings fire are mainly owing to the improper management of safety evacuation passageways, items, placements and electrical equipment in buildings. Measurements on two aspects of equipment and management can effectively reduce the fire risk of large comprehensive buildings.

6. When large comprehensive buildings are on fire, reasonable emergency evacuation plans and good emergency equipment are the key to reducing losses and casualties. And based on the employee's safety trainings and safety knowledge in public for people can reduce or avoid the crowd panics caused by fire.

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