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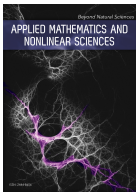

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Statistical analysis of typical elevator accidents in China from 2002 to 2019

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Abstract

By utilising data from official sources, a statistical analysis was made on the elevator accidents that occurred in China during the period 2002 to 2019 on five aspects namely elevator type, occurrence stage, casualty's identity, accident type and accident causes. The main purpose is to use the frequency and correlation among related factors to evaluate crucial causes, and to prevent similar accidents among technicians and users. Based on the statistical results and discussion, some proposals were put forward to the management of the responsible authorities for accident investigation and prevention of similar elevator accidents in the future.

Keywords: elevator; accident; casualty; statistics; safety

1 Introduction

Elevators have become indispensable transportation equipment nowadays, and their safety is closely related to people's life safety, and safety of elevators has also gradually become an important part of urban public safety. Elevators refer to mechanical and electrical equipment driven by a power whose boxes move along the rigid guide rail or steps that move along the fixed line to carry people and goods by lifting or parallel movements [1]. Currently, China is the largest country in terms of the usage, annual output and annual increment of elevators [2]. To ensure the safe operation of elevators and to reduce accidents, the safety supervision systems of elevators were implemented in China since mid-1980s [3]. However, elevator accidents that often occur recently indicate

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that elevator safety risks still exist. Therefore, statistically studying of occurred elevator accidents including analysing the reasons for the accidents, and summarising experiences and lessons, etc. are very critical for China for accident prevention and safety management of elevators in the future.

The analysis and understanding of historical accidents are very important for accident prevention. Similarly, it is necessary to study historical elevator accidents to prevent elevator accidents effectively. Some researchers have conducted statistical investigations of elevator accidents. For example, O'Neil et al. [4] analysed the elevator accidents among children in America for the period 1990 to 2004, concluded that the elevator door striking or hitting a body part during its closing operation was the most frequent cause of injury, and advised the government to supervise children on or near elevators. Steele et al. [5] investigated the statistical characteristics of elevator accidents among the elderly in the United States from 1990 to 2006, which shows that elevator accidents for the elderly are often related to slipping, tripping, or falling, and so older adults should be careful when stepping on or off an elevator. Zarikas et al. [6] conducted a statistical analysis of elevator accidents in Greece for 1998 to 2009, and believe that 65% of the accidents were mainly due to improper operation of installation and maintenance staff, and advised the responsible authorities to strengthen data collection and analysis to prevent the recurrence of similar accidents.

However, so far, few systematic statistical investigations have been conducted on the characteristics of typical elevator accidents in China in the past two decades. To address that, this study attempts to characterise the accidents of elevators including lifts, dumbwaiters and escalators (passenger conveyors included) in China from 2002 to 2019. Analyses were made according to the number of accidents, deaths, and injuries. For the three above different types of elevators, we analysed the differences of elevator accidents in the aspects of occurrence stage, casualty identity, accident type, accident cause and so on. Finally, some possible countermeasures and suggestions to prevent elevator accidents were proposed.

2 Data and methods

2.1 Data collection and preprocessing

The data of typical elevator accidents in China used here were obtained from the Special Equipment Safety Supervision Bureau of State Administration of Market Regulation. Interested readers can find the detailed introduction of the State Administration of Market Regulation (SAMR) of China in [7]. The Special Equipment Safety Supervision Bureau is a subordinate department of the SAMR, which is responsible for supervising the safety of special equipment (such as drawing up the catalogue of special equipment and safety technical specifications, supervising and inspecting the implementation of relevant legal standards for special equipment, supervising and administering special equipment inspection institutions and inspection personnel, organising the investigation and handling of special equipment accidents and conducting statistical analysis, etc.). It is the most common and official source of statistical data for special equipment accidents in China.

However, during data collection and collation, some information on the historical data was missing in the database. To facilitate the statistical analysis of the related data, we filled in the missing information based on the description of the accident process and other existing information, and deleted the cases in which the missing information cannot be analysed based on the existing information, and also deleted the factors containing a large amount of missing information including the industry and the age of the casualties. Eventually, this study collected the data of 412 typical elevator accidents in China for the period 2002 to 2019, each of which has more than one casualty. Thus, the sample's information of these 412 accidents used for the analysis is as follows:

- Date
- Province
- Elevator type
- Accident type
- Occurrence stage

- Injuries
- Deaths
- Identity
- Accident causes
- Accident description

2.2 Sample description

The parameters and their possible states of the accident samples are shown in Table 1.

Table 1 Parameters and their possible states.

Parameter	Possible states
Date	Year-Month-Day
Province	
Elevator type	Lift, Escalator (passenger conveyor included), Dumbwaiter (Only for goods. Also calls service lift [8].)
Accident type	Fall: The type of accident in which casualties were caused by a person falling from an elevator shaft. Extrusion: The type of accident in which casualties were caused by extrusion. Shear: The type of accident in which casualties were caused by shear. Collision: An accident type of one moving object or person striking violently against another. Tumble: An accident type in which casualties were caused by people suddenly tumbled from the steps of an escalator. Winding: A type of escalator (passenger conveyor included) accident in which people were entangled by steps and involved in equipment resulting in casualties. Reversal: In escalators (passenger conveyors included) accidents, the type of accident in which casualties were caused by equipment reversal. Electric shock: The type of accident in which people were injured or dead by electric shock. Trap: The type of accident in which people were locked up in elevator cars and cannot come out.
Occurrence stage	Installation, Use, Maintenance, Rescue, Reconstruction, Disassembly
Injuries	1, 2, 3, . . .
Deaths	1, 2, 3, . . .
Identity	Installer, Maintainer, Passenger, Operator, Rescuer, Property manager, Others
Accident causes	Unsafe behaviour Defective equipment Inadequate safety management
Accident description	The process of the accident is recorded in detail, including the time, place, people, causes, and results.

2.3 Methods

This study made a statistical analysis on the data of typical elevator accidents in China for the period 2002 to 2019. After sorting out the data provided by the Special Equipment Safety Supervision Bureau of SAMR, the basic information of the accidents was preprocessed, and the relevant factors shown in Table 1 are obtained. Analyses were made according to the number of accidents, deaths and injuries. Moreover, we adopted the method of descriptive statistics to study the differences between different types of elevators in the typical elevator accident data using occurrence stage, casualty's identity, accident type and accident causes. The results of the descriptive statistical analysis were shown in Section 3. In Section 4, the statistical results were discussed in detail, and some countermeasures and suggestions to prevent similar accidents were proposed. Conclusions were drawn in Section 5.

3 Results

As shown in Figure 1, the number of elevators in China is increased at a double-digit growth rate annually (from 0.346 million in 2002 to 7.0975 million in 2019). But with the growing number of elevators in China, elevator accidents often occur resulting in great loss of human lives and properties, even though the number of elevator accidents is increased year-on-year, the accident rate per 10,000 equipment decreased steadily.

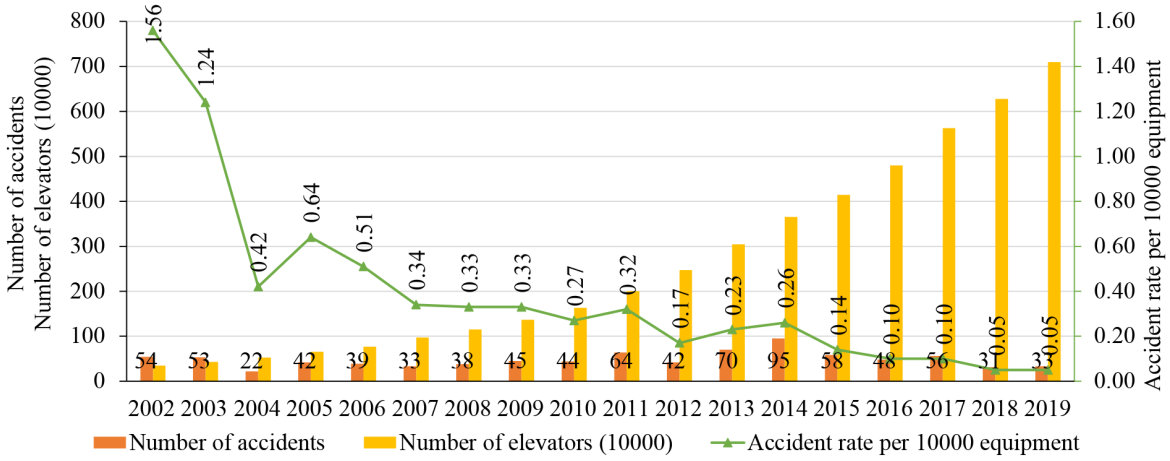

Fig. 1 Accidents and the existing quantity of elevators in China from 2002 to 2019.

3.1 Elevator types

According to the classification of elevators in the 'Catalogue of Special equipment' [1], the 412 elevator accident cases could be classified into three categories namely lifts, dumbwaiters and escalators (passenger conveyors included). Lift is a compartment mounted on a shaft to raise and lower people or goods to different floors or levels. A dumbwaiter is utilised to carry things from one floor of a building to another. It can only be utilised for carrying goods. Escalator is a moving staircase, which consists of a cycle belt of steps driven by a motor and utilised to transport people between the floors of a public building. The passenger conveyor, which transports people at a horizontal or tilt angle of less than 12° has a similar structure like the escalator, was categorised as an escalator here.

Figure 2 shows categorisation of the 412 elevator accidents:347 occurred in the lift, accounting for 84.22%; 44 accidents occurred in escalator or passenger conveyor, accounting for 10.68%; and 21 accidents occurred in dumbwaiter, accounting for 5.10%. This is similar to the proportion of various types of elevators used by China

over the years [3]. According to [9], due to the limited operating areas, the escalators (passenger conveyor included) are mainly used in shopping malls, subway stations and other large-scale public places with large passenger flow. Furthermore, compared with lift, escalators adopt an open working mode, which can reduce the probability of accidents in terms of running speed and equipment characteristics. As for the dumbwaiter, because it is only utilised to transport goods, the frequency of accidents with casualties is even lower. Therefore, the frequency of accidents of above three types of elevators such as high to low lifts, escalators (passenger conveyors included) and dumbwaiters is shown here.

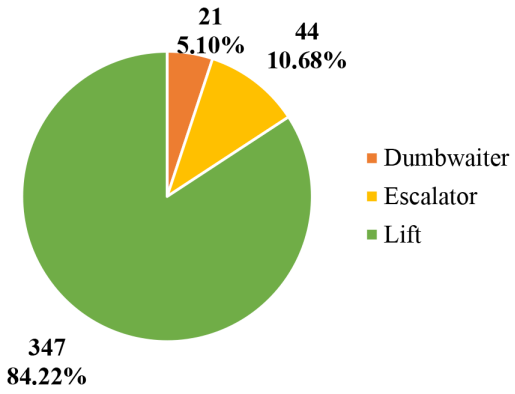

Fig. 2 Statistic of elevator types in the 412 accidents.

The 412 elevator accidents analysed here caused a total of 527 casualties, of which 331 died, accounting for 62.81% of the total casualties while 196 were injured accounting for 37.19%. The details are shown in Figure 3. Overall, dumbwaiter has the most serious consequences, with a high death ratio (Deaths/Deaths+Injuries) of 0.95, followed by lift with a death ratio of 0.66 and escalators (passenger conveyors included) with a death ratio of 0.22. Based on the above statistical analysis, although the frequency of dumbwaiter accidents is not high, the consequences are serious, while the frequency of lift accidents is high, but its consequences are serious.

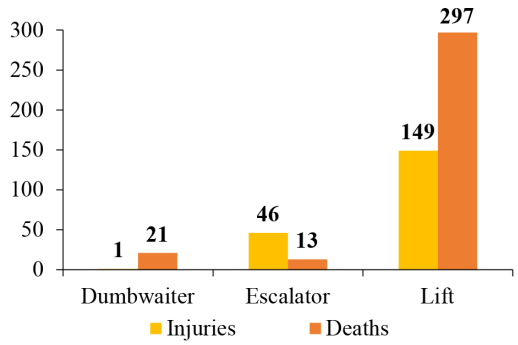

Fig. 3 The casualties of different elevator types in the 412 accidents.

3.2 Occurrence stages

The whole life cycle of an elevator includes the stages of design, manufacture, installation, maintenance, use, disassembly, etc. In this study, the 412 elevator accidents can be categorised under six stages of occurrence: installation, use, maintenance, rescue, reconstruction and disassembly. The statistical results are shown in Table 2.

The statistical results show that the most accidents (n=238) occur at the use-stage, accounting for 57.77% of

Table 2 Statistics on the occurrence stages of elevator accidents and the number of casualties.

Occurrence stage	Cases	Percentage (%)	Deaths	Percentage (%)	Injuries	Percentage (%)	$\frac{\text{Deaths}}{\text{Deaths+Injuries}}$
Use	238	57.77	168	50.76	161	82.14	0.51
Maintenance	93	22.57	78	23.56	23	11.74	0.77
Installation	61	14.81	64	19.34	8	4.08	0.89
Rescue	12	2.91	12	3.63	2	1.02	0.86
Reconstruction	6	1.46	6	1.81	1	0.51	0.86
Disassembly	2	0.48	3	0.90	1	0.51	0.75
Total	412	100	331	100	196	100	–

the total number of accidents, contributing 50.76% of deaths and 82.14% of injuries. Besides, accidents during use, maintenance and installation stages caused the most casualties. It shows that the probability of injury in the use, maintenance and installation of elevators is high, and the protection of personnel in these stages is the top priority of elevator safety technology and management requirements.

To find out the reasons for the frequent accidents in the above three stages, we checked the official accident reports. It is found that the occurrence of elevator accidents in use stage is mainly related to incorrect use of elevators (n=62), improper self-rescue disposal of people trapped in elevators (n=25), inadequate guardians (n=21), unconfirmed status of elevators before use (n=17), elevator failures (n=80) and improper management (n=45). According to the official accident report, during elevator installation and maintenance, unsafe phenomena such as improper operation (n=94, 61.04%) and failure to take effective safety protection measures (n=31, 20.13%) occur from time to time have become important reasons for the frequent occurrence of elevator accidents in these two stages. For example, on August 2, repairman did not open the 'overhaul' lever while repairing an elevator, resulting in his death in the elevator shaft by an upward moving elevator in a community in Zhejiang province [10]. On November 26, 2017, during the installation of an elevator in a hotel in Anhui Province, elevator installers failed to follow the installation procedure provided by the elevator manufacturer, and installation was done improperly without protective measures such as scaffolding, resulting in the death of four installation workers [11].

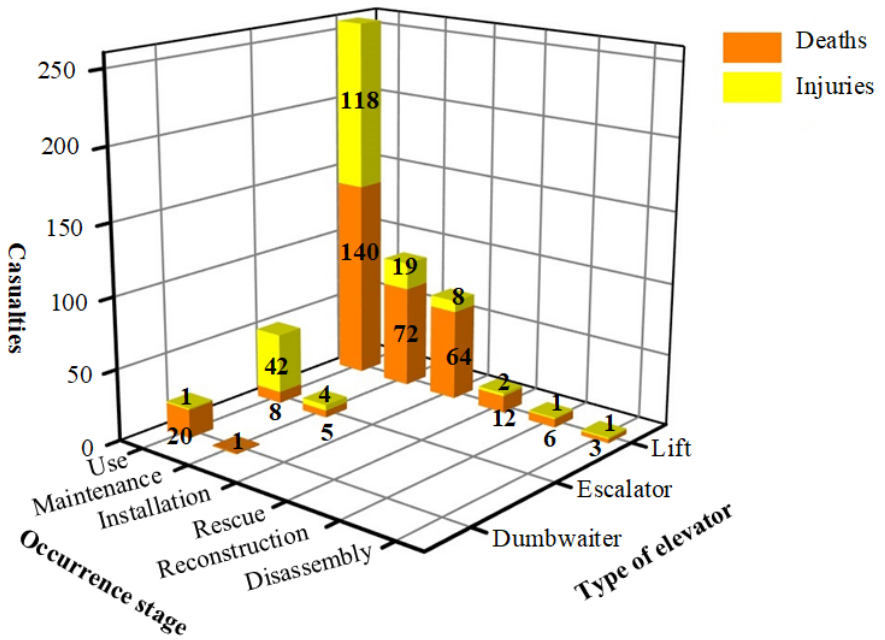

Fig. 4 Statistics of casualties due to accident occurrence stages.

Figure 4 shows the distribution of stages involved in different types of elevator accidents. As shown in Figure 4, the lift accident involves all six stages, whereas the dumbwaiters and escalators (passenger conveyors included) accidents only involve two stages which are use and maintenance, and this is related to the structural characteristics and use-environment of elevators. Compared with lifts, the installation environment of dumbwaiters and escalators (passenger conveyors included) is safer [9], so accidents do not easily occur as easily as in lifts during construction. While in the maintenance and use stages (cases=65, deaths=34, injuries=47), accidents can be caused by inadequate guardian supervision (n=19, 29.23%), improper operation (n=15, 23.08%), equipment failure (n=13, 20.00%), unlicensed work (n=8, 12.31%) and other factors. Therefore, the safety management of dumbwaiters and escalators (passenger conveyors included) should focus on the use and maintenance stages. As for lifts, as shown in Figure 4 and Table 2, the accident occurred during the installation process of lifts is the most serious one, with a death ratio of 0.89, followed by the rescue stage and reconstruction stage, both with a death ratio of 0.86. And the death ratio of accidents in the disassembly stage is 0.75. According to the accident description in our lift accident sample, the high death ratio was caused by falling (n=204). This is because the use environment of lift is generally high-rise buildings, and more safety protection is required in the installation and reconstruction process. When the workers do not take effective safety protection measures, such as not wearing a full-body safety harness, most of them may die in a falling accident [12]. The results show that the accident consequences in installation, rescue, reconstruction and disassembly of lifts are more serious, and emphasis should be placed on these stages in lift safety management.

3.3 Casualty's identity

To analyse which people are easily injured and killed in elevator accidents, we have made a statistical analysis of the identity of the victims, as shown in Figure 5. The identity statistics of casualties are basically consistent with the occurrence stages of accidents. Individual inconsistent cases are due to non-maintenance or non-installation personnel mistakenly entering the elevator car or shaft during installation or maintenance, and the casualties in such accidents are called others.

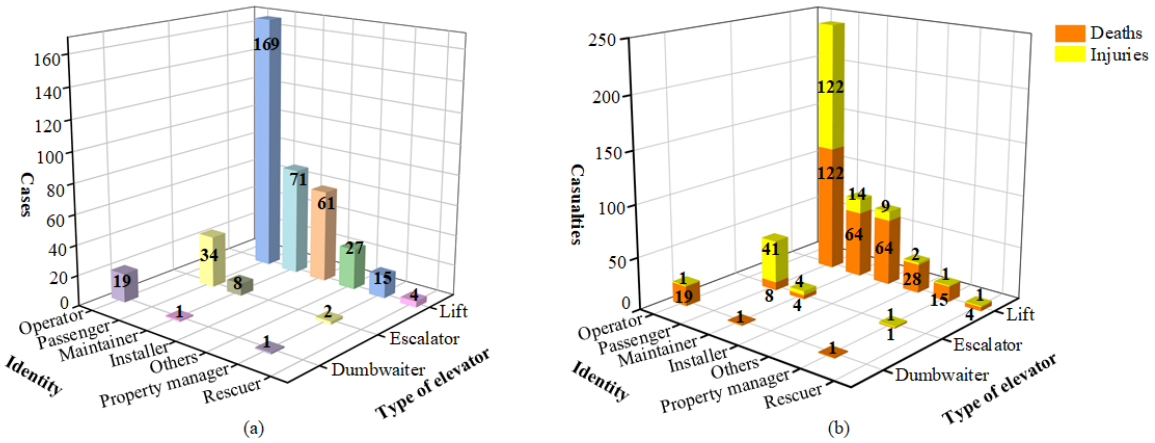

Fig. 5 Identity distribution of casualties. (a) The number of accidents according to the identity of the casualty and elevator type. (b) The number of casualties according to the identity of the casualty and elevator type.

Figure 5 shows the number of casualties is highest for passengers in lift accidents, with the death of 122 people in total and 122 injured in 169 accidents, which is followed by maintainers and installers. Among them, 71 lift accidents resulted in the death of 64 maintainers and 14 getting injured, and a total of 64 installers getting killed and 9 getting injured in 61 lift accidents. In escalator accidents, passengers are also the ones with the largest number of casualties (34 escalator accidents resulted in 41 injuries and 8 deaths). But the statistical results of dumbwaiter accidents are unusual. The results show that dumbwaiter accidents mainly lead to casualties of

operators (n=20, 90.91%). This is because dumbwaiters are only used for carrying goods. According to the accident description in the dumbwaiter accidents sample, the main causes of injury or death of operators are due to the illegal ride in dumbwaiters (n=7, 36.84%), improper operations (n=5, 26.32%) and equipment failures (n=5, 26.32%).

3.4 Accident types

The mechanical structure of the elevator is complex, and the operating environment is quite at high altitudes. Thus, there are many types of elevator accidents. According to the official accident reports, these 412 elevator accidents can be classified into five types: fall, extrusion, collision, shear and others (including electric shock, trapped, tumble, winding and reversal), as shown in Table 3.

Table 3 Statistical investigation of elevator accident types.

Accident types	Cases	Percentage (%)	Deaths	Percentage (%)	Injuries	Percentage (%)	$\frac{\text{Deaths}}{\text{Deaths+Injuries}}$
Fall	208	50.49	188	56.80	56	28.57	0.77
Extrusion	141	34.22	108	32.63	35	17.86	0.75
Collision	32	7.77	17	5.13	76	38.78	0.18
Shear	21	5.10	13	3.93	9	4.59	0.59
Others	10	2.42	5	1.51	20	10.20	0.20
Total	412	100	331	100	196	100	–

Table 3 shows that 'Fall' occurred most frequently, and caused the largest number of casualties, reaching 244, constituting 46.30% of the total casualties, followed by 'Extrusion'. The accident death ratios of fall and extrusion were 0.77 and 0.75, respectively, indicating that the fall and extrusion accidents exhibit not only high probability but also serious consequences which are the two major characteristics of casualties in elevator accidents.

The accident type is closely related to the elevator type, such as reversal and winding, and other accident types only occur in the escalator. Therefore, Figure 6 shows statistics on the accident types according to the elevator category. The overall statistical results are consistent with Table 3. However, there are unexpected findings:

Figure 6 (b) shows that the frequency of winding accidents in escalators is not high, but the consequences are very serious (death ratio=50%). According to [13], the main causes of winding accidents are step or pallets sagging guard damage of escalators, missing steps, or failure of safety devices.

Figure 6 (c) shows that the type of accident with the most serious casualties caused by dumbwaiter is extrusion (n=16, 72.73%), rather than fall, which is related to the function of dumbwaiters. According to the description of accidents, the casualties in dumbwaiter are mainly related to the illegal use of it to carry people (n=7, 33.33%), improper operation (n=6, 28.57%) and equipment failure (n=5, 23.81%).

Figure 6 (d) shows that the electric shock does not often occur in the lift accident types, but the accident consequences are very serious (the only electric shock accident resulted in one death). For trap accidents, there will be no casualties when passengers are trapped in elevators. But in this work, there are two cases in which the accident type is a trap. According to the original data of the two cases, the main reason is the failure of the elevator emergency rescue alarm function, which leads to the delay in emergency rescue, and if the passenger(s) is not found trapped in time, it will result in the injury and death of the trapped passenger(s).

3.5 Accident causes

The occurrence of accidents is usually the result of the interweaving and interaction of many factors, but there is still a direct cause [14]. Based on the official accident report, the direct cause of the 412 cases could be divided according to people, equipment and safety management. The statistical results are shown in Table 4.

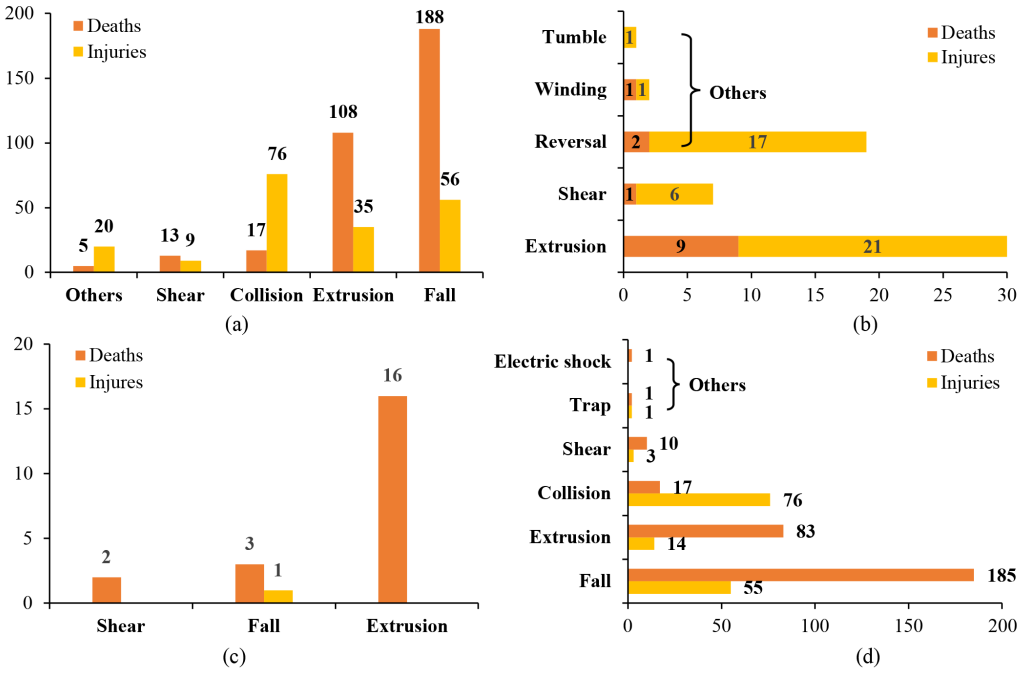

Fig. 6 Statistical investigation of elevator accident types. (a) The statistics of accident types for all types of elevators. (b) The statistical investigation of elevator accident types in escalators (passenger conveyors included). (c) The accident type statistics of dumbwaiters. (d) The accident type statistics of lifts.

Table 4 Statistics on the causes of typical elevator accidents in China from 2002 to 2019.

Accident causes	Lift	Escalators	Dumbwaiter	Percentage (%)
People's unsafe behaviours	211	28	11	60.68
Defective equipment	83	9	4	23.30
Inadequate safety management	53	7	6	16.02
Total	347	44	21	100

Table 4 shows that the largest number of accidents is caused by people's unsafe behaviours, accounting for 60.68% of the total accidents. And nearly 40% of accidents are caused by elevator defects and inadequate safety management. Then, the specific forms of these causal factors in different types of elevator accidents are counted.

3.5.1 People's unsafe behaviours

This work has conducted statistics on the unsafe behaviour information of different personnel, and the results are listed in Table 5.

Table 5 shows that the unsafe behaviour by passengers usually includes taking the wrong self-rescue behaviour (n=31), not confirming the state of the elevator before using (n=27), not taking care of the child (n=27), illegal use of triangular keys (n=6) and overload (n=4). When riding the escalator (passenger conveyor included), the main passengers' errors are as follows: children take the escalator alone or play on the escalator, and the guardian is not in place to monitor the children (n=21). The unsafe behaviour of maintainers and installers are as follows: no enclosure or safety warning signs are set at the worksite (n=10), the improper wearing of labour protection equipment (n=21) and improper operation (n=112). According to the data sample, the illegal use of dumbwaiters to carry people (n=7) is the primary unsafe behaviour by operators. Besides, unsafe behaviour also involves property managers and rescuers. Their unsafe behaviours in the case sample chiefly include the illegal use of triangle key (n=2), unauthorised lending of triangle key (n=1), and unprofessional and incorrect rescue

Table 5 Unsafe behaviour information.

Detailed behaviour		Type of elevator		
		Lift	Escalator	Dumbwaiter
Unsafe behaviour by passengers	Wrong self-rescue behaviour	31	0	–
	Didn't confirm the status of the elevator before using	27	0	–
	The guardian did not take care of the child	6	21	–
	Illegal use of triangular keys	6	0	–
	Overload	4	0	–
Unsafe behaviour by installers	Improper operation	53	0	0
	Improper wearing of labour protection equipment	14	0	0
	Didn't follow the installation guidelines	4	0	0
	No safety warning signs are set on the worksite	2	0	0
Unsafe behaviour by maintainers	Improper operation	59	8	5
	No safety warning signs are set at the worksite	8	3	1
	Improper wearing of labour protection equipment	7	2	1
Unsafe behaviour by operators	Illegal use of dumbwaiter to carry people	–	–	7
	Improper operation	–	–	5
	Didn't confirm the status of the elevator before using	–	–	2
Unsafe behaviour by property managers	Illegal use of triangular key	2	0	0
	Unauthorised lending of triangle key	1	0	0
Unsafe behaviour by rescuers	Unprofessional and incorrect rescue operations	7	0	0

operations (n=7) when people are trapped in elevators.

The manifestations of these unsafe behaviours can be summarised as conscious unsafe behaviours and unconscious unsafe behaviours. According to [15, 16], human errors are caused by weak safety awareness, insufficient safety knowledge, insufficient training, bad behaviour habits and limited physical or mental capabilities. Therefore, the government and relevant management departments should strengthen the promotion of elevator safety and the training of employees to reduce or even avoid the occurrence of such accidents.

3.5.2 Equipment malfunction

To determine the unsafe states of different types of elevators, this study has conducted statistics on the fault information of equipment components that caused elevator accidents, as shown in Table 6.

In this study, the unsafe state of lift mainly includes failures such as door lock (n=56), brake (n=23), hoist rope (n=8), speed governor (n=7), inspection switch (n=6), and emergency alarm device (n=2). Among them, the failure of the door lock mainly includes the failure of the electrical safety device of the verification layer door and car door closure (n=34), the damage of the mechanical parts of the door lock (n=17) and the meshing depth of the door lock is not enough (n=5). Brake faults are mainly manifested due to insufficient braking force (n=12), mechanical jam failure of brake components (n=4), the incomplete opening of the brake arm (n=4) and failure of the brake control circuit (n=3). The main faults of escalators are damage to the step chain wheel (n=3), loosening of the floor plate (n=2), failure of step or pallets support (n=2), fracture of the drive chain (n=2), lack of steps (n=1) and the handrail and step running speed are not synchronised (n=1). The unsafe state of

Table 6 Defective equipment component information.

Detailed failure components		Detailed fault information	Number of accidents
Lift	Door lock	Electrical safety device fails	34
		Damage to mechanical parts	17
		Shallow meshing depth	5
	Brake	Insufficient braking force	12
		Mechanical jam	4
		Incomplete opening of the brake arm	4
		Brake control circuit failure	3
	Hoist rope	Hoist rope breaks	8
	Speed governor	Speed governor fault	7
	Inspection switch	Inspection switch failure	6
	Emergency alarm device	Emergency alarm device fault	2
Escalator	Step sprocket	Damaged step chain wheel	3
	Floor plate	Loose floor plate	2
	Step or pallets sagging guard	Step or pallets support failure	2
	Drive chain	Drive chain broken	2
	Step	Missing escalator steps	1
	Handrail speed monitor	Handrail and step running speed are not synchronised	1
Dumbwaiter	Door lock	Damage to mechanical parts	4
		Electrical safety circuit fault	3
		Lack of electrical safety device	3

dumbwaiters is mainly manifested due to the damage of the mechanical parts of the door lock (n=4), the failure of electrical safety circuit of door lock (n=3) and noninstallation of electrical safety device to monitor the closure of the door (n=3).

By the statistical analysis of the unsafe state of elevators, the components that often fail in different types of elevators can be identified. In the future maintenance works, accidents caused by equipment failures can be effectively prevented by focusing on the inspection of these components.

3.5.3 Inadequate safety management

The safety management problems of related enterprises are summarised in Table 7.

Table 7 shows that the management problems of elevator manufacturers, which include producing and manufacturing elevators without qualification (n=7), lax quality control of key components (n=3), flawed design (n=1) and failure to provide maintenance guidance documents (n=1). The main management problems of elevator owners are using unqualified or uninspected elevators (n=22) and not hiring a full-time elevator safety administrator (n=22). And failure to obtain a licence to use the elevator (n=10), illegal use of faulty elevators (n=9), hiring unlicensed personnel to operate dumbwaiters (n=8) and using illegally manufactured elevators (n=7) are also management problems of elevator owners. The safety management problems of the elevator installation company are manifested in insufficient safety training for employees (n=45), the ineffective implementation of the safety management system of the worksite (n=41) and not following the installation diagram during the instal-

Table 7 Safety management-related information.

Related enterprises	Detailed safety management problem	Number of accidents
Manufacturer	No production qualification	7
	Lax quality control of key components	3
	Flawed design	1
	Not provide maintenance guidance documents	1
Owner	Elevators are unqualified or uninspected	22
	Didn't hire a full-time elevator safety administrator	22
	Did not go through the registration for use	10
	Illegal use of faulty elevators	9
	Employ unlicensed personnel to operate dumbwaiters	8
	Using illegally manufactured elevators	7
Installation company	The safety training of employees is not enough	45
	The safety management system of the worksite has not been effectively implemented	41
	Construction is not following the installation drawings	5
Maintenance company	The safety training of employees is not enough	69
	The safety management system has not been implemented	16
	Employ unlicensed personnel to maintenance elevators	9
	Incomplete safety management system	5
	Maintenance is not on a schedule	2

lation (n=5). 'The safety training of employees is not enough' (n=69) being the primary management problem of the elevator maintenance company.

Given these management problems, the relevant departments should strengthen their understanding, strictly abide by the 'People's Republic of China special equipment safety law' [17] and the 'Regulations on safety supervision of special equipment' [18], and engage in the management of the production, installation, maintenance and use of elevators. At the same time, safety training for staffs working in the companies must be emphasised.

4 Discussion and suggestion

In our current study, most of the accidents occurred in the use stage, followed by the installation and maintenance stage. Statistics on the direct causes of the 412 accidents show that most accidents are caused by unsafe behaviour such as overloading when taking the elevator, taking a wrong self-rescue behaviour, illegal or improper operation during installation or maintenance elevators and so on. For the unsafe behaviour of passengers when taking the elevator, intelligent video surveillance technology should be used to monitor the dangerous behaviour of elevator passengers, and through the identification and alarm of dangerous behaviour, the accidents caused by improper use of equipment can be reduced. In fact, in recent years, many researchers [19–23] have made some achievements in video-based human behaviour recognition. The practical application of these research results needs to be promoted and implemented by relevant industries. Moreover, the relevant departments should popularise the methods of safe use of and emergency rescue operation in elevators to the public through the media and brochures, etc. When installing and maintaining elevators, in this study, the unsafe behaviour of workers

is mainly related to the failure to take correct safety protection measures. Therefore, companies responsible for the installation and maintenance of elevators should strengthen safety and skills training for employees, such as installers and maintainers, as well as the safety supervision and management of the construction site. And the effectiveness of safety and skills training can be tested by holding elevator safety knowledge competitions, vocational skills competitions and so on.

In this work, the analysis of the cause of the accident is mainly focused on the direct cause, but the occurrence of an accident is often the result of the interweaving and interaction of many factors [14]. Therefore, to prevent the occurrence of elevator accidents, it is necessary not only to strengthen the monitoring mechanism of people but also to monitor the running status of the elevator and strengthen the establishment of an effective elevator safety management system. The results of this paper show that many accidents are caused by elevator equipment failure. As elevators have many different operating states, the relevant departments should refer to the corresponding standards and specifications to correctly understand and test the operating status and reasonable safety of elevators. The method of using the internet of things (IoT) technology to monitor the running status of elevators [24] and using artificial intelligence (AI) technology for elevator fault diagnosis and prediction [25] is very important to ensure the safe operation of elevators. When the failure of the elevator is predicted, the components that may fail can be replaced or repaired before the failure of the elevator, to achieve predictive maintenance and keep the elevator in a safe state. This paper summarises some key components directly related to elevator accidents, which can be monitored when monitoring the status of elevators, such as real-time detection of the elevator door opening, closing and fault status [26]. And the product standards of elevators in accord with China's national conditions should be established.

Improper safety management is often closely related to the weakness of people's security and legal awareness. Therefore, it is necessary to strengthen safety training and law popularisation. And the problem of untimely elevator rescue can be solved by promoting the use of an elevator rescue application in elevator emergency management. At the same time, accessible and analytical form of information on history accidents [27], and data-driven safety [28] approaches can be used to prevent recurrence or occurrence of new accidents. In the era of big data, it is necessary to develop an elevator safety management system to collect data in the process of elevator safety management. Elevator safety management based on big data will be a major research trend in the future. The above countermeasures are summarised in Figure 7.

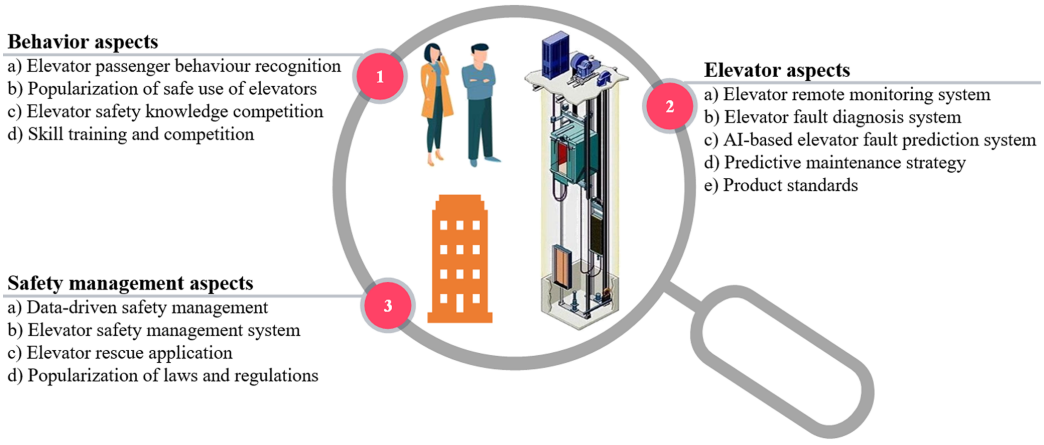

Fig. 7 Some countermeasures and suggestions for reducing elevator accidents.

Furthermore, the data samples used in this study show that the investigation on the causes of elevator accidents in the official accident report of China is not deep enough. For example, in our sample, many accidents are attributed to illegal or improper operation. But fundamentally, people's illegal or improper operation is closely related to improper management and the degree of the intrinsic safety of the equipment. In this regard, the

proposal that the elevator accident investigation should make a more in-depth analysis of the equipment causes of the accident to help improve the essential safety of the elevator has been put forward.

5 Conclusions

This study analysed typical elevator accidents in China from 2002 to 2019 and formed the following conclusions: (i) accidents that occurred in the dumbwaiters usually have serious consequences (death ratio 0.95); (ii) most accidents occurred in the use stage (57.77%); (iii) the accidents that occurred during the installation process of lifts are the most serious, with a death ratio of 0.89; (iv) 'Fall' and 'Extrusion' are the two major characteristics of casualties in elevator accidents; and (v) most of the accidents are mainly caused by unsafe behaviours. To address that, some corresponding countermeasures and suggestions are given here: (i) dumbwaiters should be strictly supervised and managed to reduce the probability of accidents; (ii) intelligent video surveillance technology can be applied to monitor and identify the dangerous behaviours of elevator passengers; (iii) conducting some competitions to consolidate the effect of safety and skills training is required; (iv) the use of IoT technology is necessary to monitor the elevator running status, and AI technology contributes to elevator fault diagnosis and prediction; (v) the data-driven elevator safety management system should be developed for safety management improvement; and (vi) the accident investigation of elevators should have a more in-depth analysis of the equipment causes of accidents. This paper summarises all key components directly related to elevator accidents, hoping to provide a useful reference for future elevator fault detection.

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