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# Fatal accident patterns of building construction activities in China

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ABSTRACT

Fatal accidents occur frequently in building construction activities due to inherently hazardous nature. This paper aims to explore the fatal accident patterns in China's building construction activities by using frequency analysis, correlation coefficient analysis and variance analysis. The data presented in this study come from short reports of accidents published by the Ministry of Housing and Urban-Rural Development. The results are obtained by analyzing the factors related to *month, day of week, time interval of day, province, type of accident, and severity of accident*. It's mainly found that more fatal accidents occur (1) in July and August, (2) on Monday and (3) during the time intervals 10:00–11:00 and 15:00–16:00, and excessive laboring hours still exist in building construction activities. It's also notable that relatively underdeveloped provinces have experienced higher mortality rate per hundred million yuan of gross domestic product in the building industry, especially Qinghai, Hainan and Heilongjiang. Moreover, fall is the predominant type of fatal accidents, accounting for more than 55% overall. There exists the significant correlation between the types of accidents and the severities of accidents, and each collapse and hoisting damage can cause more fatalities compared to other types. The corresponding recommendations are ultimately put forward to prevent fatal accidents of building construction activities. The patterns found in this paper can provide valuable direction for formulating accident prevention strategies.

## 1. Introduction

With the continuous economic development in China, Gross Domestic Product (GDP) in the construction industry has an astonishing increase and annually accounts for about 25% of GDP nationwide (National Bureau of Statistics of China, 2017a), which is twice as much as the world average (Amiri et al., 2017). As the main subsector of construction industry, the building industry shares over 64% of GDP in the construction industry in recent five years and has laid a solid foundation for the urbanization in China (National Bureau of Statistics of China, 2017a).

The urbanization is, to a large extent, characterized by the increase of people who move from rural areas to cities or towns (Fan et al., 2017). As an important employment channel, the building industry has accelerated the movement by attracting a large number of rural surplus labor (Fung et al., 2010). The growth of urban population in developing regions is annually expected to be 53 million during 2007–2025, as in China alone the number is about 21.1 million (He et al., 2013). Until 2015, China's urban population had reached 771 million, with an urbanization rate of 56.1% (Fan et al., 2017). With the rapid growth of urban population, a great amount of building construction projects (e.g., commercial buildings, multifamily dwellings, single family or duplex dwellings) are required to meet the increasing needs of people's life, especially the residential need (Sang and Carlson, 2014). Moreover, some developed cities have to keep the increasing number of building construction projects due to the increasingly ageing buildings (Gangolells et al., 2014).

Unfortunately, the construction industry is notorious for its reputation as being at a high risk in many countries (Im et al., 2009; Kang et al., 2017; Rubio-Romero et al., 2013). As a result of uncertain and harmful nature, construction accidents usually cause lots of negative consequences, such as absenteeism, project delays, permanent disability (Fung et al., 2010; Hu et al., 2011; Unsar and Sut, 2009). Particularly, fatal accidents not only cause heavy loss of casualties, but also cause huge personal, social and financial costs (Forteza et al., 2017; Peng et al., 2015; Sa et al., 2009). As shown on the Ministry of Housing and Urban-Rural Development (MHURD) website (MHURD, 2017), over 2850 construction workers died from building construction

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activities during 2012–2016 with an average of 1.57 fatalities each day, as in the US the number is about 2 (Macario et al., 2015). Thanks to continuous efforts from the academia and practitioners, the safety situation in the building industry has been improved steadily in recent years (Zhou et al., 2015), but fatal accident rate still remains higher than that of other occupational sectors (Amiri et al., 2017; Beavers et al., 2009; Kang et al., 2017; Suarez-Cebador et al., 2015). Therefore, there's an urgent need to carry out the research on the prevention of fatal accidents in building construction activities.

Accident prevention can be originated from the period of the industrial revolution when industrial accidents occurred frequently (Heinrich, 1927, 1930). To prevent accidents and reduce their consequences, the academia had made considerable efforts to put forward and develop accident causation theories (Smillie and Ayoub, 1976), such as pure chance theory (Greenwood and Woods, 1919), accident proneness theory (Farmer and Chambers, 1929), accident causation sequence theory (Heinrich, 1931), epidemiological theory (Gordon, 1949), trace intersecting theory (Sui, 1982), Swiss Cheese Model (Reason, 1997), HFACS Model (Wiegmann and Shappell, 2001) and 24 Model (Fu et al., 2017). Most of these theories insisted that accidents maybe occur if a sequence of contributing factors are interacted on each other, and lots of accidents can be prevented by identifying and eliminating contributing factors of accidents in theory (Hu et al., 2011). Therefore, figuring out contributing factors of accidents is strongly necessary for accident prevention (Mistikoglu et al., 2015).

The high-risk contributing factors in the building industry are closely related to inherently hazardous nature of construction activities, which is one of the biggest challenges in the building industry (Choudhry et al., 2009; Sang and Carlson, 2014). First of all, building construction sites are crowded with various worker types (e.g., supervisors, foremen, steelworkers, scaffold workers and machinery operators) due to employing labor-intensive method, so carrying out closely construction activities within limited operation space is prone to fatal accidents such as struck by (Mohammadfam et al., 2014). Subsequently, building construction activities are always outdoor and on-site workers are either directly or indirectly exposed to uncertain hazards such as abnormal climate change, falling object, falling person and running machinery (Fung et al., 2010; Liao and Perng, 2008). Furthermore, the temporary and transitory nature of construction workplaces and projects usually contributes to dynamic workforce, so that construction enterprises have to frequently hire new workers who may lack experience and training, which made them prone to construction accidents (Hinze and Gambatese, 2003; Kang et al., 2017; Liao and Perng, 2008). Last but not the least, the multistory or high-rise buildings remain predominant in building construction projects and there exist numerous hazards related to working at height, vertical transportation and heavy machinery equipment (Fung et al., 2010). Based on accident causation theories above, many contributing factors of construction accidents have been explored and identified over the past decades, and they're further categorized into five main aspects: Man, Material, Machine, Management and Environment ('4ME') (Abdelhamid and Everett, 2000; Choudhry and Fang, 2008; HSE, 2009; Hu et al., 2011; Kang et al., 2017; Mohammadfam et al., 2014; Zheng et al., 2018).

Construction accidents are always caused by the combination of these contributing factors, but the factors don't appear with uniform frequency (Kourniotis et al., 2000). To clarify this issue, some scholars started to explore accident patterns. Accident pattern discussed here is different from that defined by the combination of types of cause that leads to the accident (Carrillo-Castrillo et al., 2017), but it tends to mean what circumstances are prone to accidents (Mason, 1979). Mason (1979) explored injury patterns by time-of-day and day-of-week and concluded that more injuries happened on Mondays and in the mid-morning and mid-afternoon. Chi et al. (2005) conducted statistical analysis of fall patterns by gender and found that male workers were prone to outdoor fall and female workers were prone to fall when performing plasterwork of building interiors, cleaning and housekeeping tasks. Liao (2012) analyzed accident patterns of the seasonal variation and mainly observed that the heat often influenced workers' concentration in summer, causing accidents more likely, and wetness from rain was prone to fall and electric shock in winter. Amiri et al. (2016) extracted the patterns of high-risk accidents in the construction industry and argued that more accidents occurred (1) in summer, (2) inside the workshop and (3) during 7:00–11:00 and 14:00–16:30. It was also found that married workers and workers with over 56 years old were prone to accidents. Notably, discernable accident patterns could provide targeted direction for preventing fatal accidents in the construction activities. Compared to contributing factors of accidents, accident patterns could be more useful for accident prevention due to their advantages such as easy implementation and immediately effective safety performance.

Most of the accident patterns mentioned above were based on the entire construction industry, but the types of construction projects had a significant influence on accident patterns (Cheng et al., 2012). For instance, the fact that fall is the most common exists in the construction projects (Kang et al., 2017; Ling et al., 2009), but not in subway construction projects (Zhou et al., 2014). Generally, accidents with different project types (e.g., bridge projects, tunnel projects, building projects and municipal projects) have different patterns. Therefore, only relying on accident patterns from the entire construction industry to prevent building construction accidents is not sufficient. It's essential that the characteristics of building construction activities must be adequately considered to prevent building construction accidents. Meanwhile, most of the mentioned patterns were excavated from non-fatal accidents, which may lead to unreliable accident data. For example, some injury accidents occurring at weekends could be reported on Monday for obtaining more compensation paid from insurance companies (Campolieti and Hyatt, 2006; Lopez Arquillos et al., 2012). Conversely, fatal accidents can, to a large extent, make accident data more objective due to particularly bad consequences, which can avoid numerous omission reporting, false reporting and concealed reporting of accidents. It's rather a proof that fatal accidents are mandatorily published by using "short report (SR)" style on the MHURD website (MHURD, 2017).

Accidents are regarded as discrete events without uniform frequency and their occurrences are difficultly predicted due to uncertain contributing factors (Fung et al., 2010). Probability theory is considered to be the rational way available for coping with these uncertainties (Kourniotis et al., 2000). Statistical analysis of aggregated accident data can cover predominant information of accidents and provide scientific estimates and predictions of accident trends by using various statistical methods such as descriptive statistics, correlation coefficient analysis, variance analysis and regression analysis (Aneziris et al., 2012; Kvaloy and Aven, 2005). Therefore, statistical analysis has been widely carried out to detect, interpret and predict accident patterns through generating new information and knowledge, from which accident patterns can be learned to prevent similar accidents and reduce bad consequences in the future (Li et al., 2014; Ohtani and Kobayashi, 2005; Zarikas et al., 2013). Nowadays, statistical analysis has been extensively applied in the field of accident patterns, especially the high-risk field such as chemical accidents (Kourniotis et al., 2000; Li et al., 2014), mining accidents (Wang et al., 2014; Zheng et al., 2009), construction accidents (Amiri et al., 2016; Kang et al., 2017), which can provide powerful reference for this study.

Considering building construction characteristics, this paper presents a statistical analysis of fatal accidents reported in China's building construction activities and makes an attempt to explore fatal accident patterns to put forward recommendations of accident prevention. The rest of this paper is organized as follows. The collection and arrangement of accident data and their analysis process are firstly given in the next section. The exploration and discussion of fatal accident patterns are introduced in Section 3, followed by the conclusions and recommendations in Section 4 and research limitations in Section 5.

## 2. Materials and methods

### 2.1. Data collection

The data came from the MHURD, which is mainly responsible for reporting fatal accidents in China's building construction projects by using SR. The accidents with at least one fatality were daily mandatorily reported to the MHURD under strict procedures, and they were timely published online. Although poor audit system of reporting and processing accident information may make officially issued statistical data less reliable (Fang et al., 2004), mandatory audit system had been greatly improved through a set of strong reform in recent years (MHURD, 2015). Moreover, accident data from the MHURD were always cited by authoritative national institutions such as the National Bureau of Statistics, National Development and Reform Commission. Therefore, there was every reason to believe that collected accident data were reliable and valid.

The accident data covered the time interval from January 1, 2012 to December 31, 2016, including 2355 fatal accidents from 31 provinces in China except Hong Kong, Macao, Taiwan. Additionally, accident data from Tibet were ruled out for lack of issued data in 2012 and 2016. Eventually, 2348 fatal accidents from 30 provinces, leading to 2859 fatalities, were cited in the study. Meanwhile, accident information in each SR contained key factors, such as 'date', 'time of day', 'accident location', 'type of accident', 'number of casualty' and 'project participants' (MHURD, 2017).

### 2.2. Data arrangement

There're normalized formats for SRs, but the contents of raw reports are perhaps heterogeneous due to the description of accident information varying from individual to individual (Ohtani and Kobayashi, 2005; Salguero-Caparros et al., 2015). To obtain homogeneous data which are well suited for accident analysis, key accident information was extracted from raw data, for instance, 'day of the week' from 'date', 'province' from 'accident location', 'severity of accident' from 'number of casualty'. With respect to the 'type of accident', it was reported to the MHURD based on the Classification Standard of Occupational Casualty Accidents. Considering that the identification of accident types is helpful in preventing accidents (Amiri et al., 2016; Chi et al., 2005), fatal accidents in this study were categorized into 7 construction-related types, including fall, struck by object, collapse, mechanical damage, hoisting damage, electrocution and other (Standardization Administration of China, 1986). Although fatal accidents caused lots of negative consequences, only the 'number of casualty' was collected to describe the severity of accidents in SRs. According to regulations on the reporting, investigation and disposition of production safety accidents issued by State Council of China (2007), the severity of accidents was only determined based on the number of fatalities because the number of major injuries caused by each fatal accident was less than 10. The severity was thus classified into following 4 categories: *Ordinary accident* refers to the accident with 1–2 fatalities, *serious accident* with 3–9 fatalities, *major accident* with 10–29 fatalities and *particularly major accident* with at least 30 fatalities.

Therefore, relevant factors applied in statistical analysis and their possible states were arranged in Table 1, and each fatal accident can be briefly described by the key accident information.

### 2.3. Data analysis methods

Statistical analysis is always conducted to explore accident patterns, and a good understand of certain accident patterns is useful for accident prevention (Zheng et al., 2009). In this study, frequency analysis technique was firstly carried out to extract useful information by the frequency of fatal accidents for relevant factors presented in Table 1. The statistical characteristics of fatal accidents were shown by various statistical charts, according to which some accident patterns were explored. Subsequently, correlation coefficient analysis was employed to further explore the relationship between relevant factors. In the contingency tables, the *p*-value was calculated to test a significant difference between two factors, and the Cramer's V coefficient and Phi coefficient were used to examine the correlations between such factors. Finally, the factors with significant correlation were further investigated by ANOVA analysis, which aimed to explore the relationship between different categories levels of such factors. Besides, the Excel-format database of fatal accidents arranged in Section 2.2 was imported into the SPSS19.0, by which statistical analyses mentioned above were performed.

**Table 1**
Definition of useful information and their possible states.

| Relevant factors | Possible states (Code) |
|---|---|
| *Year* | 2012, 2013, 2014, 2015, or 2016 (Y1–Y5) |
| *Month* | A month from January to December (M1-M12) |
| *Day of week (DW)* | Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, or Sunday (DW1–DW7) |
| Time interval of day (*TD*) | 8:01–12:00, 12:01–18:00, 18:01–22:00, or 22:01–8:00 (TD1–TD4) |
| *Province* | A province from 30 provinces (P1–P30) |
| *Type of accident (TA)* | Fall, struck by object, collapse, mechanical damage, hoisting damage, electrocution, or other (TA1–TA7) |
| *Severity of accident (SA)* | Ordinary accident, serious accident, major accident, or particularly major accident (SA1–SA4) |

## 3. Results and discussions

### 3.1. Frequency analysis

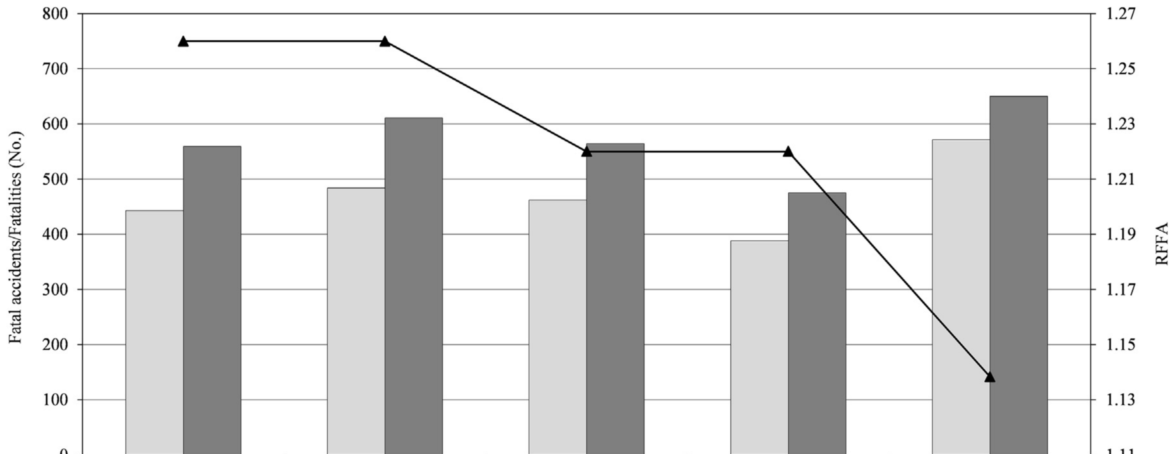
The frequency analysis is mainly focused on the statistical description of fatal accidents by *year*, *month*, *DW*, *TD*, *province*, *TA,* and *SA*, respectively.

#### 3.1.1. Year

As shown in Fig. 1, the number of fatal accidents has a slight decline during 2013–2015, but a sharp increase in 2016. The number in 2016 is 28.7% more than the average value during other four years and dramatically increases by 47.2% compared to that in 2015. Considering the nature of outdoor operations in building construction activities, the accident rate is usually proportional to climatic working conditions (Amiri et al., 2014). Although the finding could be attributed to the fact that the GDP of building industry in 2016 has a growth of 6.8% compared to that in 2015 (National Bureau of Statistics of China, 2017a), it may be explained by another fact that building construction activities in 2016 have been largely affected by super El Niño Phenomenon, which led to extreme climate in China (Bi et al., 2017; MHURD, 2016). Because of abnormal climate change, construction workers could be more prone to expose themselves to uncertain work hazards. On the other hand, it's rather a proof of a radical change in personnel mentality to report fatal accidents under strict audit procedures. Meanwhile, the figure also presents a slight decline in the RFFA, which refers to the Ratio of the number of Fatalities to the number of Fatal Accidents. It can reflect the average severity per accident during a certain period of time. The on-site emergency plans have been gradually developed by construction enterprises in recent years, and appropriate first-aid measures on site could be the main reason for this trend (Zhou et al., 2015). In addition, there're daily 1.3 fatal accidents causing 1.6 fatalities, as in the US the number is about 2 (Macario et al., 2015). However, it's equally notable that some fatal accidents could be unreported, which has happened similarly in other countries (Amiri et al., 2014).

#### 3.1.2. Month

Fig. 2 shows that 71.4% of total accidents occurred during the

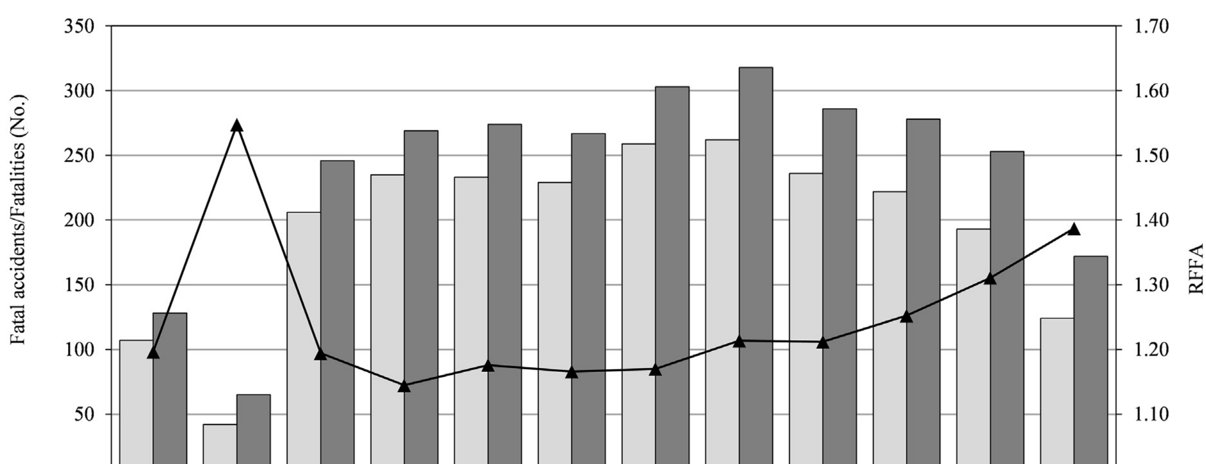



| | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Fatal accidents(No.) | 443 | 484 | 462 | 388 | 571 |
| Fatalities(No.) | 559 | 611 | 564 | 475 | 650 |
| RFFA | 1.26 | 1.26 | 1.22 | 1.22 | 1.14 |

**Fig. 1.** Distribution of fatal accidents by *year*.

months from April to October and there're over 220 fatal accidents per month. The monthly number of accidents is quite similar over the seven months except July and August. The number of fatal accidents and fatalities in such two months ranks the top in all months, accounting for 22.2% and 21.7% overall, respectively. July and August are covered by the summer in China and more accidents in summer similarly existed in the US (Hinze and Gambatese, 2003) and Iran (Amiri et al., 2016). The heat in summer, even above 40 °C, usually goes beyond what human beings can bear, and construction workers could be assigned to work long hours to meet construction schedule requirements because the daytime gets longer in summer. Both the heat and excessive laboring are prone to make workers fatigue, which is the reason why fatal accidents frequently happen in July and August (Liao, 2012; Wang et al., 2014).

Conversely, the number of fatal accidents and fatalities in February (winter month) ranks the last, partly because the coldness is not helpful for certain construction activities (e.g., reinforced concrete pouring), which avoids intensive construction activities during a typical working day. Similarly, the reason above could be applied to the interpretation of the situation in December and January (winter months). Moreover, the relatively lower accident rate in February could be mainly explained by the Chinese Spring Festival, which is the most important traditional festival in China. As to construction workers, they have about two-week leave around the Spring Festival. There're fewer construction activities to construct for fewer working days in February, because the Spring Festival happened in February for three times (February 10, 2013; February 19, 2015; February 8, 2016) and next to February 1 for one time (January 31, 2014), together with only 28 or 29 days in February. Furthermore, this situation is also verified by the fact that the number of fatal accidents in January ranks the last in 2012, mainly because the Spring Festival happened on January 23, 2012. The low accident rate during the month with important festivals is also found in other countries such as Iran (Amiri et al., 2014). However, there's the highest RFFA in February, because safety management personnel could be still immersed in the Spring Festival and couldn't sufficiently focus on on-site construction activities and accident emergency rescue. Additionally, it's difficult to give a plausible reason for gradually increasing RFFA from June to December.




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fatal accidents(No.) | 107 | 42 | 206 | 235 | 233 | 229 | 259 | 262 | 236 | 222 | 193 | 124 |
| Fatalities(No.) | 128 | 65 | 246 | 269 | 274 | 267 | 303 | 318 | 286 | 278 | 253 | 172 |
| RFFA | 1.20 | 1.55 | 1.19 | 1.14 | 1.18 | 1.17 | 1.17 | 1.21 | 1.21 | 1.25 | 1.31 | 1.39 |

**Fig. 2.** Distribution of fatal accidents by *month*.

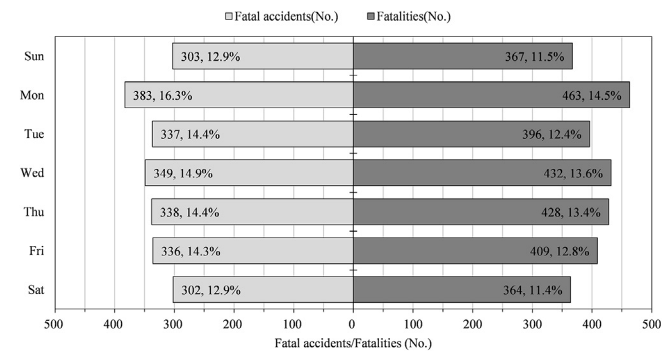



**Fig. 3.** Distribution of fatal accidents by *DW*.

#### 3.1.3. Day of week (DW)

Fig. 3 shows that the number of fatal accidents and fatalities at weekends is obviously less than those on weekdays, respectively. Amiri et al. (2014) observed that the least number of fatal accidents existed on Fridays (weekends in Iran), which is in line with our study. The lower accident rate at weekends could be related to the leave, which helps avoid much more construction activities. It's also seen that the number of fatal accidents on Mondays is averagely 12.6% more than that on other weekdays. The higher accident rate on Mondays, called the "Monday Effect", has been studied by Lopez Arquillos et al. (2012) and Campolieti and Hyatt (2006), and they held that some accidents occurring at weekends were reported on Mondays for obtaining more compensation paid from the insurance company. However, this idea is suitable for work-related injuries, but not fatalities. There could be two other main reasons for more fatal accidents on Mondays. One reason is that it's difficult to quickly focus on work and safety hazards on Mondays for workers with leisure weekends (Barlas, 2012). The other is that new construction activities are usually scheduled to start on Mondays (the first working day of the week) in China, and workers have to spend more time on the familiarity of new activities and the identification of new safety hazards (Tam et al., 2004). Under these circumstances, some workers could be prone to fatal accidents on Mondays.

#### 3.1.4. Time interval of day (TD)

During a typical working day in the building industry, construction activities are usually carried out from 8:00 to 18:00, with a lunch break from 12:00 to 14:00. Considering that there existed 115 accidents (accounting for 4.9% overall) with unknown occurrence time, a frequency analysis of 2233 accidents (95.1%) was conducted. Fig. 4 shows that more fatal accidents occurred during TD1 and TD2 (covered by the daytime), with the hourly number of fatal accidents ranking the top two, while TD3 and TD4 (covered by the nighttime) have much less fatal accidents. Because sufficient light is difficultly provided for construction activities related to numerous working at height in the nighttime (Amiri et al., 2016), the majority of construction activities intensively happened in the daytime, which causes fatal accidents more likely.

Fig. 4 also presents that the distribution curve of fatal accidents by an hour of the day is approximately axial symmetry about the noon, with two peaks during 10:00–11:00 and during 15:00–16:00, respectively. The finding is similar to that in previous studies (Amiri et al., 2014; Huang and Hinze, 2003; Mason, 1979). The first peak could be attributed to the fact that construction workers were distracted by hunger and fatigue after working for about four hours; excessive laboring could be the reason why the second peak appears. Conversely, the number of fatal accidents that occurred during 12:00–13:00 is the smallest during the typical working time. The result could be explained by the fact that the majority of construction workers have a lunch break during the period when they're not involved in much more construction activities.

Although eight hours are scheduled for each working day, actually more than ten hours' work is conducted according to Fig. 4, with over 100 fatalities per hour from 7:00 to 19:00. Therefore, excessive laboring hours could be one of the main reasons for high accident rate in building construction activities. Additionally, Fig. 4 indicates that the RFFA during 18:00–3:00 is higher than that in the daytime except 13:00–14:00, mainly because first-aid measures are difficultly taken when one accident occurs in the nighttime. Notably, higher RFFA exists during 13:00–14:00 in the daytime. During this period, workers tend to return to construction activities, but the period is, to the large extent, still regarded as lunch break by some rescue-related persons (e.g., onsite managers and medical staff), which makes them insufficiently focus on safety hazards and accident emergency rescue. The highest RFFA during 2:00–3:00 cannot be ignored, but the actual reason is unknown.

#### 3.1.5. Province

Fig. 5 shows that the geographical distribution of fatal accidents is presented in various colors. The darker the color of one region is, the more accidents occurred in the region. Generally, the southern provinces (e.g., Guangdong, Guangxi and Yunnan) have more fatal accidents than the northern provinces (e.g., Shaanxi, Shanxi and Hebei) and the coastal provinces (e.g., Jiangsu, Zhejiang and Guangdong) have more fatal accidents than the northwestern provinces (e.g., Qinghai, Gansu and Ningxia). Both the Yangtze River and the Yellow River are regarded as the mother river of China, but the provinces along the Yangtze River basin (e.g., Chongqing, Hubei and Anhui) generally have more fatal accidents than that along the Yellow River basin (e.g., Shandong, Henan and Nei Monggol). According to the yearly GDP of building industry in each province published by the National Bureau of

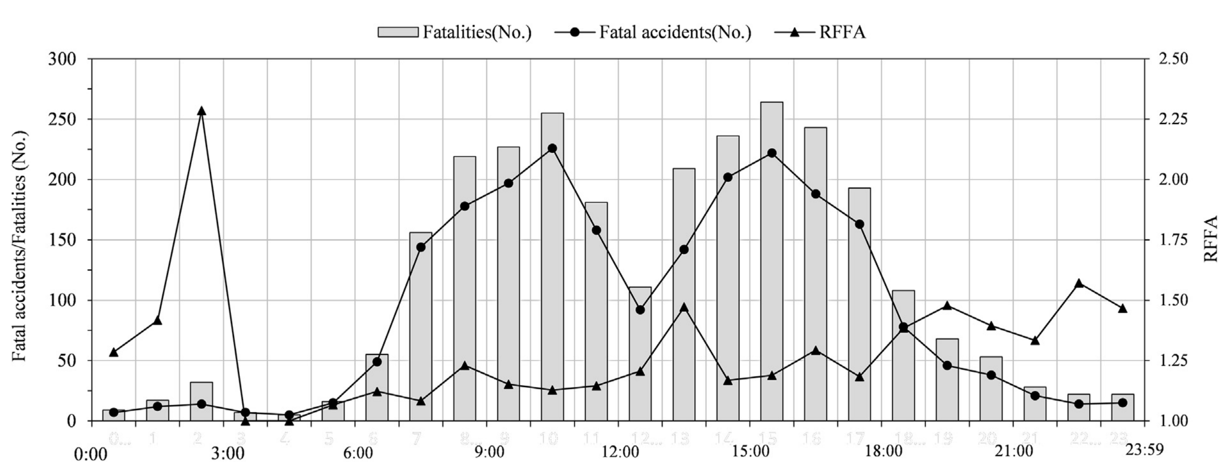



**Fig. 4.** Distribution of fatal accidents by *TD*.

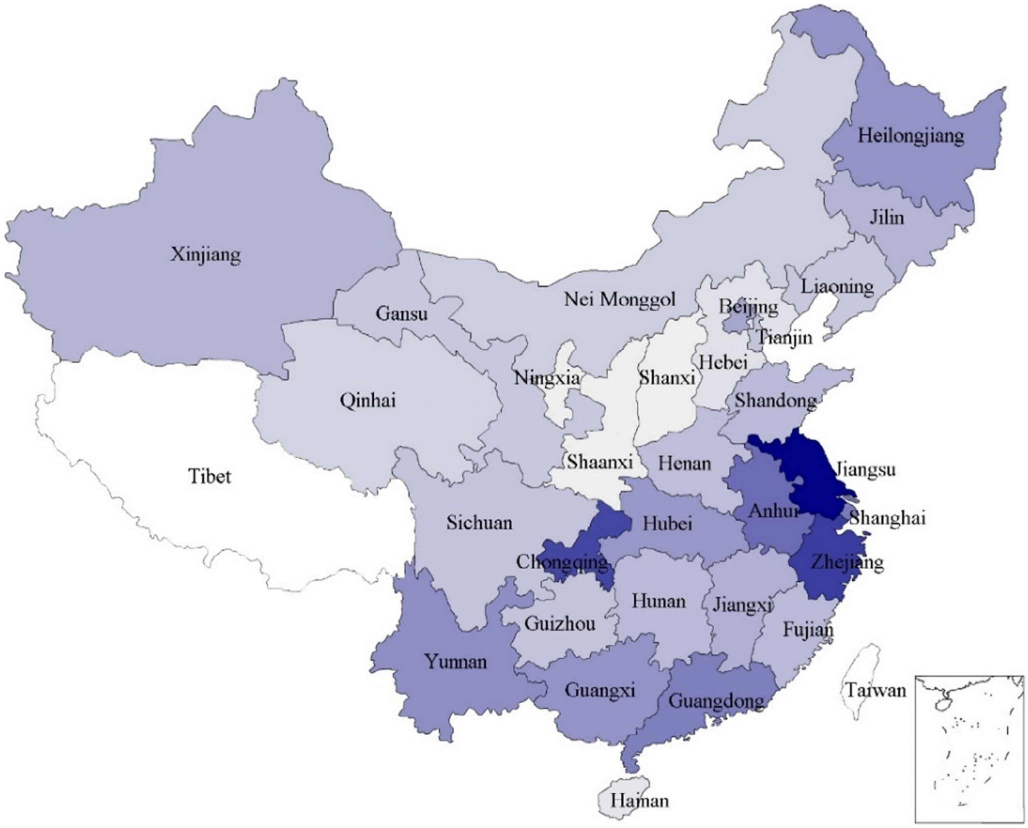



**Fig. 5.** Geographical distribution of fatal accidents (No.) by *province*.

Statistics of China (2017a), the findings could be closely related to economic development level in these provinces. For instance, Jiangsu, one of the most developed provinces, has the maximum GDP of building industry during 2012–2016, totally about 8.5 trillion yuan, but it has the worst record, with 286 fatal accidents accounting for 12.2% overall. Moreover, the number in Jiangsu is 71.3% more than that in Zhejiang (167), which ranks the second. Conversely, Qinghai, one of the underdeveloped provinces, has the minimum GDP of building industry during the five years, and it correspondingly experienced much less fatal accidents (43). To the large extent, economic development level is proportional to the occurrence of fatal accidents, and it has long been considered as a determinant factor of changing patterns of mortality rate (Moniruzzaman and Andersson, 2008).

Mortality rate per Hundred Million yuan GDP (MHMGDP) is regarded as an important control indicator to measure the sustainability level of economic and social development (State Council of China, 2011). Therefore, the MHMGDP is selected to analyze further fatal accident patterns. In many developed countries, the MHMGDP in all industries mainly ranges from 0.02 to 0.06, such as 0.02 in the UK (Liu and Wu, 2011). According to statistical data issued by National Bureau of Statistics of China (2017b), the MHMGDP of construction industry in China is 0.142, 0.124, 0.107, 0.098 and 0.058 from 2012 to 2016, respectively. The decreasing trend means that the MHMGDP in China gradually drops to the range in other developed countries, and the safety situation in China has been improved steadily in recent years (Zhou et al., 2015).

The MHMGDP of building industry in each province is depicted in Fig. 6. Notably, the MHMGDP is less than 0.02 in all provinces except Qinghai (0.092), Hainan (0.025) and Heilongjiang (0.022), which reveals that building industry has a relatively lower MHMGDP among all industries. Moreover, the fact that the MHMGDP in Qinghai, Hainan and Heilongjiang rank the top three shows that bad safety management performance exists in the three provinces. It's also presented that the lower MHMGDP generally exists in developed provinces such as Beijing (0.005), Jiangsu (0.004), Zhejiang (0.002) and Guangdong (0.006), although they have more fatal accidents.

### 3.1.6. Type of accident (TA)

As shown in Fig. 7, fall, struck by object, collapse and hoisting damage are the main types of fatal accidents due to ranking the top four by the number of accidents. Above all, fall is the most common type of fatal accidents, accounting for more than 55% overall. The high proportion is in line with the previous researches in many countries (Kang et al., 2017; Ling et al., 2009; Mohammadfam et al., 2014). It's mainly because the majority of building construction activities occur in the multistory or high-rise buildings, where more fall-related hazards exist. By comparison, fall accounted for 10% of all accidents in subway construction activities because subway construction projects have much less fall-related hazards (Zhou et al., 2014). It's also widely recognized that construction sites are always crowded with many workers, machinery, equipment and other construction-related objects. Therefore, the fact that numerous crossed operations and close-range operations exist on construction sites can explain why the struck by object ranks the second. Meanwhile, more collapses could be attributed to the fact that the supporting systems used in various construction activities are prone to accidents due to temporary and transitory nature (Rubio-Romero et al., 2013). Besides, many machinery and equipment are necessarily applied in construction activities, especially hoisting machinery are essential for vertical transportation. Both hoisting damage and mechanical damage happen frequently because of improper operation and maintenance. Notably, each collapse and hoisting damage can cause more fatalities than other types, which is suggested by Fig. 8.

### 3.1.7. Severity of accident (SA)

As shown in Table 2, the number of ordinary accidents dominates in the four categories, which reveals that accidents with one or two deaths

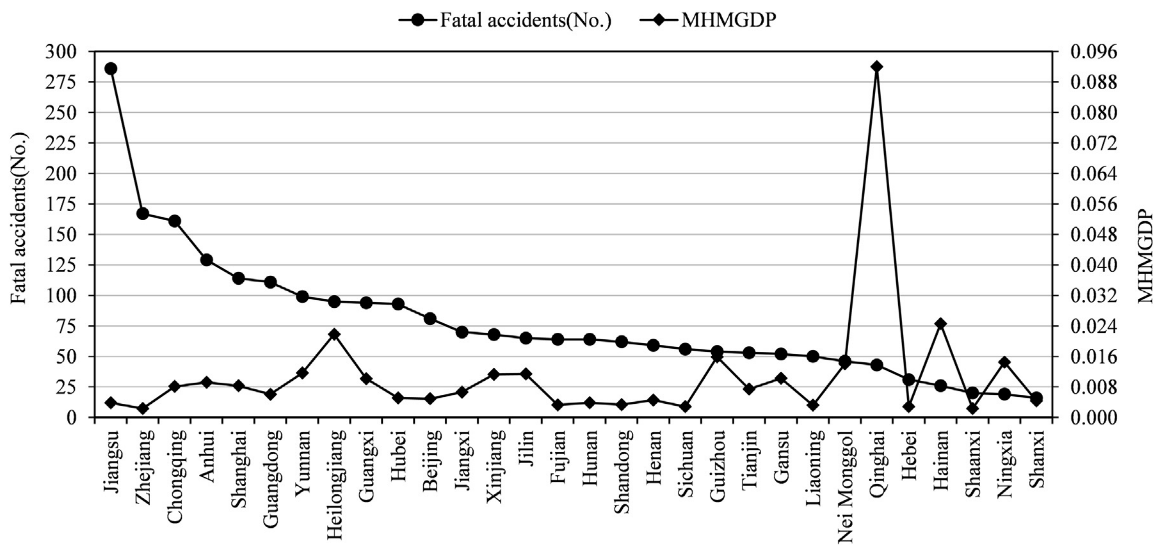



**Fig. 6.** Distribution of the MHMGDP of building industry by *province*.

are the most common among fatal accidents in China's building construction activities. Fortunately, particularly major accidents have never happened during 2012–2016, and only 2 major accidents are there during the five years. However, there're about yearly 20 serious accidents, which is closely related to high-risk nature of the building industry.

### 3.2. Correlation coefficient analysis

To explore further fatal accident patterns in building construction activities, the possible correlation between factors except the *year* is investigated. First of all, *SA* was selected as a dependent factor while the rest were selected as independent factors. Afterwards, *TA* was selected as a dependent factor while *month*, *DW*, *TD* and *province* were selected as independent factors. For the consistency of data analysis, the 2233 accidents were applied in correlation coefficient analysis. The contingency table was employed in this study and correlation coefficients between factors were calculated in Table 3, with 95% confidence intervals. The Cramer's V coefficient was selected to examine the correlation because of the R × C (R > 2 and C > 2) table. When the

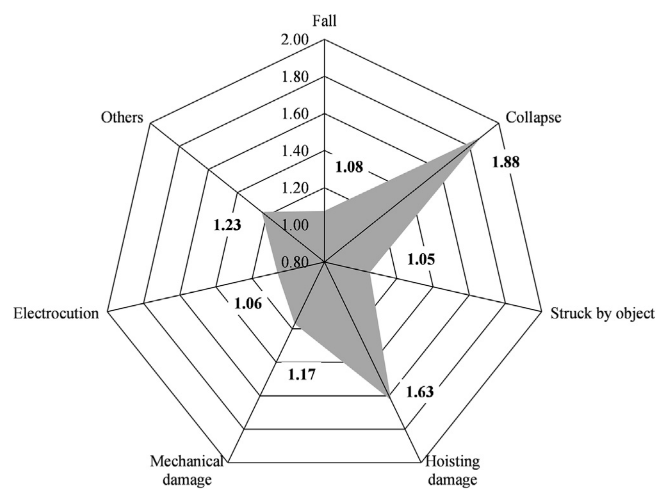



**Fig. 8.** RFFA of various accident types.

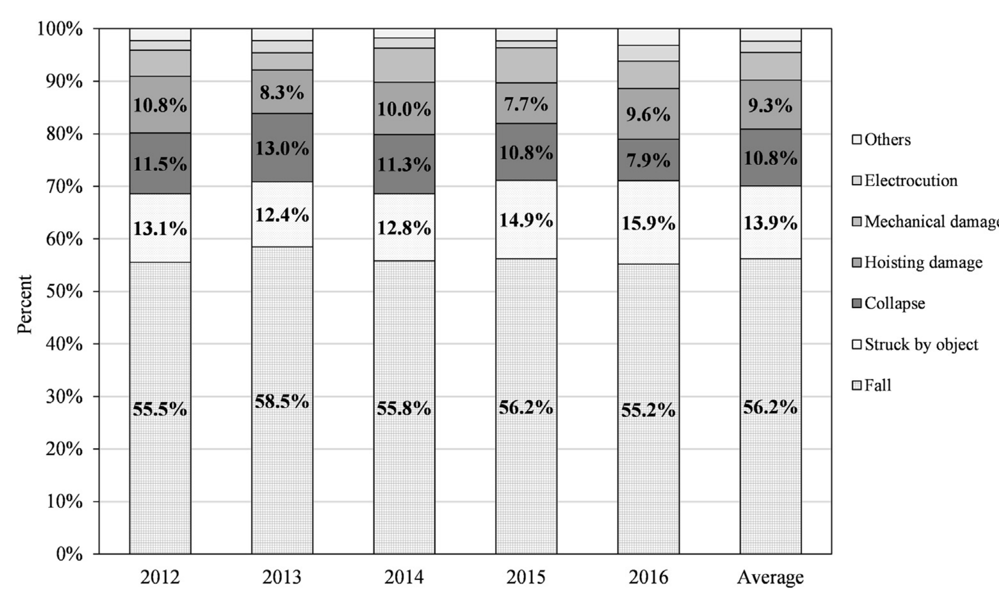



**Fig. 7.** Cumulative percent of fatal accidents from 2012 to 2016 by *TA*.

**Table 2**
Distribution of fatal accidents by *SA*.

| Severity of accident | Fatal accidents | | | Fatalities | | |
|---|---|---|---|---|---|---|
| | Number | Percent | Cumulative percent | Number | Percent | Cumulative percent |
| SA1 | 2244 | 95.6% | 95.6% | 2451 | 85.7% | 85.7% |
| SA2 | 102 | 4.3% | 99.9% | 379 | 13.3% | 99.0% |
| SA3 | 2 | 0.1% | 100.0% | 29 | 1.0% | 100.0% |
| SA4 | 0 | 0.0% | 100.0% | 0 | 0.0% | 100.0% |

**Table 3**
Contingency table for correlation coefficients between factors.

| Dependent factor | Independent factor | Chi-square | df. | Sig. | Phi | Cramer's V |
|---|---|---|---|---|---|---|
| *SA* | *Month* | 38.715 | 22 | 0.015* | 0.132 | 0.093 |
| | *DW* | 9.154 | 12 | 0.690 | 0.064 | 0.045 |
| | *TD* | 27.817 | 6 | 0.000** | 0.112 | 0.079 |
| | *Province* | 19.544 | 12 | 0.076 | 0.094 | 0.066 |
| | *TA* | 273.885 | 12 | 0.000** | 0.350 | 0.248 |
| *TA* | *Month* | 73.425 | 66 | 0.248 | 0.181 | 0.074 |
| | *DW* | 26.748 | 36 | 0.869 | 0.109 | 0.045 |
| | *TD* | 94.542 | 18 | 0.000** | 0.206 | 0.119 |
| | *Province* | 54.434 | 36 | 0.025* | 0.156 | 0.064 |

* $p < 0.05$.
** $p < 0.01$.

Cramer's V coefficient between two factors ($p < 0.05$) is more than 0.1, it indicates that significant correlation between such factors exists. The significant correlation between *SA* and *TA* (V = 0.248, $p < 0.01$) is listed in Table 3, as well as *TA* and *TD* (V = 0.119, $p < 0.01$).

Table 3 also shows that the *p*-values between *SA* and the factors including *DW* and *province* are more than 0.05, without significant difference, and the Cramer's V coefficients between *SA* and time factors including *month* and *TD* are 0.093 and 0.079, respectively, without significant correlation. The results indicate that the severity of one fatal accident is a random event, which is not related to both time and space. Similarly, the type of one fatal accident is not related to *month, DW* and *province*.

### 3.3. ANOVA analysis

To further excavate useful information from the significant correlation between factors found in Section 3.2, one-way ANOVA is selected to investigate the internal relation between *SA* and *TA*, as well as *TA* and *TD*.

Table 4 shows that both collapse and hoisting damage have a significant influence on *SA*. Based on the findings, Fig. 9 further reveals that collapse and hoisting damage are prone to cause serious accidents or major accidents. Im et al. (2009) and Amiri et al. (2014) advocated that collapse and electrocution tended to cause more deaths, but severe

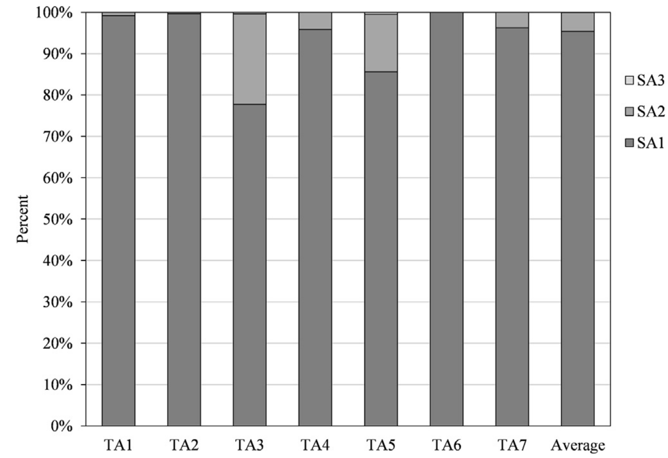



**Fig. 9.** Cumulative percent of *SA* vs. *TA*.

accidents caused by electrocution are not found in this study. Hoisting machinery are tall and vertical machines used for moving heavy objects or persons, thus hoisting damage not only threatens workers related to hoisting operations, but also other working personnel, even pedestrians (Tam and Fung, 2011), which could be the reason why hoisting damage is prone to more deaths.

Since serious accidents and major accidents always had bad influences on the society and economy in the regions where accidents occurred, full reports of accidents had to be timely published online. Therefore, more information of serious accidents and major accidents in SRs can be obtained from the news websites such as China Production Safety Net (China Production Safety Net, 2018). Meanwhile, five aspects of contributing factors of construction accidents, namely '4ME', can be assigned to two main categories: human error and unsafe states of objects (Zheng et al., 2018; Zhou and Tong, 2015). To further explore internal relation between *SA* and *TA*, only unsafe states of objects are considered into the contributing factors discussed in this study.

Fig. 10 shows that serious accidents and major accidents related to tower cranes, formwork-supporting systems and construction elevators rank the top three, accounting for about two-thirds of 104 fatal accidents. Furthermore, the contributing factors including tower cranes, construction elevators, construction platforms, scaffoldings and aerial baskets are related to working at height, accounting for 48.1% overall. The contributing factors including formwork-supporting systems, steel structure systems and construction floorslabs are related to numerous reinforced concrete construction activities in building projects, accounting for 35.6% overall. The contributing factors including earthworks and construction pits are related to the deep foundation of the multistory or high-rise buildings, accounting for 8.7% overall. Notably, tower cranes and construction elevators, called hoisting machinery, always caused hoisting damage, while formwork-supporting systems, construction floorslabs, working platform, scaffolding, construction pits and earthworks always caused collapse. Therefore, the fact that collapse

**Table 4**
One-way ANOVA analysis of *TA* affecting *SA*.

| Type of accident | Code | Code | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | TA1 | TA2 | TA3 | TA4 | TA5 | TA6 | TA7 |
| Fall | TA1 | | 0.621 | 0.000** | 0.099 | 0.000** | 0.750 | 0.324 |
| Struck by object | TA2 | 0.621 | | 0.000** | 0.078 | 0.000** | 0.919 | 0.253 |
| Collapse | TA3 | 0.000** | 0.000** | | 0.000** | 0.000** | 0.000** | 0.000** |
| Mechanical damage | TA4 | 0.099 | 0.078 | 0.000** | | 0.000** | 0.233 | 0.907 |
| Hoisting damage | TA5 | 0.000** | 0.000** | 0.000** | 0.000** | | 0.000** | 0.001** |
| Electrocution | TA6 | 0.750 | 0.919 | 0.000** | 0.233 | 0.000** | | 0.354 |
| Others | TA7 | 0.324 | 0.253 | 0.000** | 0.907 | 0.001** | 0.354 | |

** $p < 0.01$.

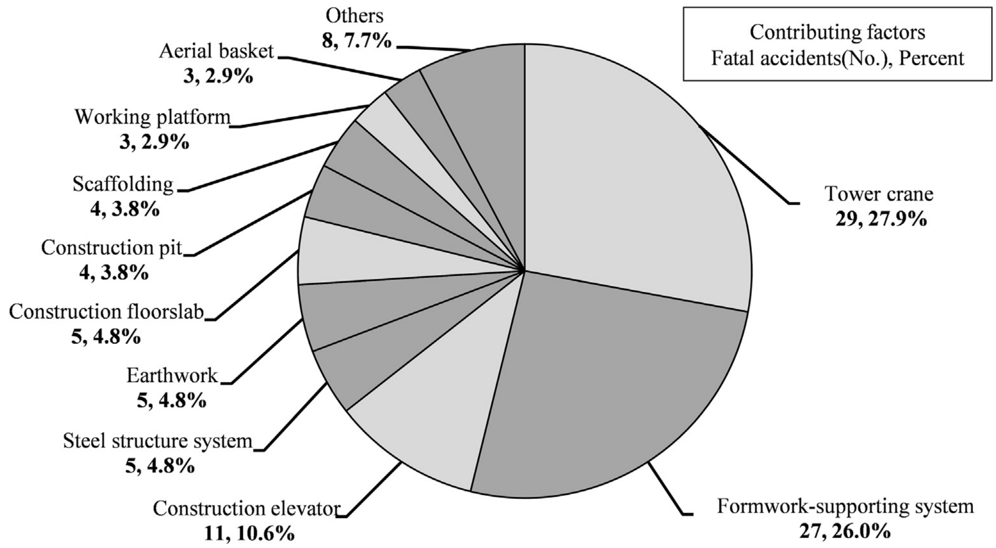



**Fig. 10.** Distribution of fatal accidents by contributing factors.

and hoisting damage cause more serious accidents or major accidents could depend on inherently hazardous nature of building construction activities such as temporary supporting systems, limited operation space, deep foundation, labor-intensive nature, numerous vertical transportation and reinforced concrete construction.

Table 5 suggests that 18:01–22:00 and 22:01–8:00 have significant influence on *TA*. Furthermore, Fig. 11 reveals that more collapses occurred during 18:01–22:00 and more mechanical damage and hoisting damage occurred during 22:01–8:00. More collapses during 18:01–22:00 may be mainly because early collapse-related omens are difficultly discovered in the nighttime. It's well known that labor-intensive construction activities (e.g., Scaffolding works and formwork-supporting system erection) don't exist during 22:01–8:00 due to the period for break (Amiri et al., 2014). Therefore, relatively more machinery-related construction activities are still carried out during 22:01–8:00. Moreover, mechanical damage and hoisting damage are usually caused by improper operation under the circumstance of insufficient light (Amiri et al., 2016).

## 4. Conclusions and recommendations

Building construction activities experience high fatal accident rate due to inherently hazardous nature. The purpose of this study is to investigate fatal accidents reported in China's building construction activities and explore fatal accident patterns. The results show that there do exist discernable patterns related to fatal accidents. Based on these findings, corresponding recommendations are put forward to prevent fatal accidents in building construction activities. Therefore, the patterns found in this paper can provide a valuable reference for both policymakers and building enterprises to improve safety condition in the building industry.

**Table 5**
One-way ANOVA analysis of *TD* affecting *TA*.

| Time interval of day | Code | Code | | | |
|---|---|---|---|---|---|
| | | TD1 | TD2 | TD3 | TD4 |
| 8:01–12:00 | TD1 | | 0.088 | 0.001* | 0.000** |
| 12:01–18:00 | TD2 | 0.088 | | 0.017* | 0.000** |
| 18:01–22:00 | TD3 | 0.001* | 0.017* | | 0.010* |
| 22:01–8:00 | TD4 | 0.000** | 0.000** | 0.010* | |

* $p < 0.05$.
** $p < 0.01$.

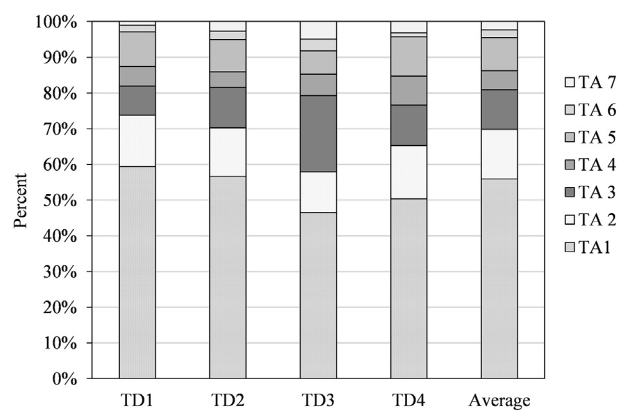



**Fig. 11.** Cumulative percent of *TA* vs. *TD*.

The number of fatal accidents in 2016 saw a dramatic increase. There's an urgent need to formulate more effective prevention strategies to reduce the fatal accident rate.

More fatal accidents exist in summer, particularly in July and August. It's thus necessary to keep appropriate working time and provide workers with essential personal protective equipment. Also, when the heat is beyond the favorable working temperature of human beings, workers shouldn't be assigned to excessive daily construction activities.

Fewer construction activities occur around important festivals, especially the Spring Festival, but close attention should be drawn to higher RFFA during the period. The construction enterprises should bear in mind the importance of construction safety. Moreover, the on-site safety management personnel ought to sufficiently focus on construction activities and accident emergency rescue, rather than being immersed in the festivals.

Mondays see more fatal accidents. Therefore, it's necessary to pay special attention to the "Monday effect" and take targeted measures. For example, construction activities may start with a short safety meeting on Mondays.

During a typical working day, there exist more fatal accidents during the time intervals 10:00–11:00 and 15:00–16:00. Safety awareness should be specially emphasized during the two periods for workers, particularly workers lacking personal protective equipment and safety training. Toolbox talks can be selected to educate workers about creating and maintaining safer work conditions, and encourage them to recognize, avoid, report and correct work hazards. What else, workers who have survived, witnessed, or those who have been informed about specific accident information can be invited to share their experiences and knowledge to avoid potential accidents. To lower the RFFA during 13:00–14:00, safety managers should shorten lunch break and return to construction activities with workers around 13:00, or frontline workers extend lunch break and continue their work with safety managers after 14:00. To follow construction schedule, it's advisable to improve construction management level, instead of pursuing excessive laboring hours, which is at the cost of more fatal accidents.

Relatively underdeveloped provinces have fewer fatal accidents, but they experience higher MHMGDP of building industry. Therefore, while pursuing the growth of GDP, provinces like Qinghai, Hainan and Heilongjiang should also attach great importance to high-risk building construction activities for sustainable economic development.

Attention should also be highly focused on the fact that over half of fatal accidents are caused by fall in building construction activities. It's necessary to widely utilize fall protection equipment in fall-prone location, such as roofs, scaffoldings, aerial baskets, platform catwalk and temporary openings. Meanwhile, The severity of both collapse and hoisting damage is much more significant compared to that of other types. Therefore, construction activities related to tower cranes, construction elevators and formwork-supporting systems should be carried out after developing more detailed safety operation plans.

More collapses occur during 18:01–22:00; more machinery-related construction activities still exist during 22:01–8:00. Greater efforts are thus needed to guarantee good lighting for construction activities in the nighttime, as well as better operation and more meticulous maintenance for machinery equipment.

## 5. Limitations

This study analyzed fatal accidents reported in China's building construction activities and discernable fatal accident patterns were discussed. The MHURD is mainly responsible for reporting fatal accidents by using SR, but only some essential factors including 'date', 'time of day', 'accident location', 'type of accident', 'number of casualty' and 'project participants' are published online. This is the reason why statistical analyses in the study only focused on factors in Table 1. Therefore, discernable fatal accident patterns are restricted to the present findings. Future research will be performed in China's building construction activities for collecting more accident information, which is the inevitable requirement of accident prevention.

Although mandatory audit system has been greatly improved in recent years, omission reporting, false reporting and concealed reporting of accidents maybe still exist. To some extent, the results could not reach more precise.

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