Study on the Influencing Factors of Falling Object Accidents in Urban Buildings

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Abstract. With the rapid increase in the density of urban high-rise buildings and the gradual aging of the constructed buildings, pedestrian injuries and casualties due to falling objects have become a common occurrence, falling objects have become an unavoidable problem in terms of building safety. To clarify the root causes of falling objects accidents is the first task to eradicate the occurrence of accidents, and this study aims to explore the factors that lead to urban falling object accidents.In this study, the crawler technology was used to collect 260 cases of falling objects accidents on news websites. Based on the case data, the logit model was used to analyze the relationship between the influencing factors of accidents and whether injuries were caused.The results of the study found that the type of falling objects, fall time, weather, and road conditions have a significant effect on the injury of falling objects accidents, of which glass (windows), external walls, and billboards are the most important types of falling objects. The results of the study reveal the triggering mechanism of falling object injury accidents and provide important theoretical support for the effective management of urban falling objects.

Keywords : Falling objects; Influencing factors; Binary logistic regression; Urban buildings

1 Introduction

With the progress of urbanization in China, the number of urban high-rise buildings has been increasing, and in recent years, the incidents of falling and throwing objects from height causing human damage have been reported repeatedly, especially with the increasing aging of urban high-rise buildings, the shedding of facades and other hanging objects has become a major hazard threatening the lives and properties of the residents of the district and the people passing by. The average impact force generated by an apple falling from the 24th floor is between 103N~105N, which will jeopardize the life of pedestrians and seriously endanger public safety if it falls on them.

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There are fewer existing studies on falling objects accidents and vary in direction. Early studies on falling objects focused on facade inspection and objects falling from construction sites. Aneziris[1] pointed out that in the Netherlands, occupational injuries and fatalities caused by falling objects are a serious public problem. Between 1998 and 2004, falling object accidents accounted for 12% of the 12,500 accidents that occurred in the Netherlands. Grivna et al.[2] analyzed data from hospitals in the UAE regarding patients admitted due to falling objects from heights, suggesting that most falling object injuries occur on construction sites. Liu Liping[3] calculated the scattered radius of falling objects at construction sites based on the characteristics of falling objects at construction sites and the theoretical model of the falling point of falling objects, providing the ground safety protection level width at construction sites. Kiyoung[4] categorized safety accidents caused by falling objects in accidents occurring at construction sites into fatal and non-fatal accidents and derived association rules between influencing factors and safety accidents caused by falling objects. Regulations on facade inspections can be traced back to 1980 when New York City laws required owners of buildings taller than 6 stories to provide a facade inspection report every 5 years, and eight years later, the law was amended to require inspections of all facades[5]. In addition, Chicago, Singapore, Quebec, Canada, and other places have also introduced facade inspection policies[6]. Lup Wai Chew[7] also pointed out that the root causes of facade defects in Singaporean buildings should be considered in conjunction with climate change. In the legal field, there have been many relevant studies in recent years, mostly focusing on exploring issues of tort liability and judicial adaptation. Due to the many legal disputes arising from falling objects from heights, Li Chen[8] conducted a series of studies on falling object accidents, first researching the reasons for architectural design, analyzing specific accident cases, proposing five specific architectural design defects, and proposing specific spatial anti-falling strategies and design schemes.

Overall, there are certain differences in research directions on high-altitude falling objects in different regions, mainly due to significant variations in urban building density and population density. Despite differences in urban building conditions, safety issues arising from falling objects due to facade damage still exist in various countries. It is evident that falling object problems from heights are a common concern worldwide. Currently, there is relatively limited research on systematically analyzing the influencing factors of falling objects from heights. Therefore, this paper aims to collect and analyze the latest data on urban falling object accidents, using statistical modeling to accurately identify key factors influencing the severity of accidents. This will provide theoretical support for preventing urban falling object accidents and formulating relevant regulatory policies.

2 Data and Methodology

2.1 Data Sources

The case sources of this study are "Judgment documents network" and news websites. In terms of network news platform, this study chooses "Tencent News" platform, which has more complete accident collection and more related news, as the news collection source. This study uses web crawler technology to automatically capture related news and pictures. "Web crawler" is a tool that automatically identifies and crawls the qualified information on the web page according to established rules. Scrapy is an application framework based on python programming language to crawl website data and extract structural data, which is suitable for data mining and information processing programs. In this study, scrapy library was used to compile relevant crawler code, and news pictures and content with the keyword "falling objects" published from January 2022 to October 2023 were crawled from the website of "Teng News". After screening to remove duplicate stories, a total of 60 cases were selected.

Research on the influencing factors of falling object accidents has been limited in the past. This study uses expert interviews to preliminarily identify potential influencing factors. Twelve experts and scholars in the field of engineering construction and management were invited, they were interviewed by telephone, and the information obtained from the interviews was summarized and analyzed. Seven main risk factors for urban falling objects were identified, including the type of falling object, the time of the fall, weather conditions, the location of the fall, the date of the fall, the subject of injury, and road conditions. By combining information from case documents and news reports, it was possible to clearly identify five risk factors, the other two factors were not considered due to difficulties in extracting information.

2.2 Research Methodology

The logistic regression model is an effective statistical method for analyzing the causal relationship between binary or multinomial variables. The dependent variable can be either a binary variable or a multinomial variable. This study mainly investigates the causal relationship between injury accidents and multiple influencing factors, making the logistic model suitable for the research objectives. In addition, IBM SPSS 25 software is used for model calculation and analysis. The larger the absolute value of the standardized regression coefficient, the greater its impact on the dependent variable. The standardization method refers to the method in Menard S[9].

By extracting and datamining the collected elements related to falling objects cases, the characteristics of falling objects accidents with injuries were analyzed based on a binary logistic regression analysis model. The degree of injury in cases of falling objects from heights was divided into 2 types of cases, injured and non-injured, and the binary logistic regression analysis model was used to analyze the 2 corresponding case categories. The model can be expressed as equation (1).

$$\ln\left(\frac{p(Y=1)}{1-p(Y=1)}\right)=\alpha+\sum_{i=1}^{k}\beta_i x_i \tag{1}$$

In the equation, P represents the probability of injury from falling objects, and 1-P represents the probability of no injury from falling objects. xi represents the ith explanatory variable that influences whether the falling object causes injury, k is the number of explanatory variables, βi represents the partial regression coefficient of explanatory variable xi, which is the correlation with whether the case causes injury, and α is the intercept term. Injury (P=1) and non-injury (P=0) were the dependent variables, and the type of falling object (X1), time of falling object (X2), weather conditions (X3), date of falling object (X4), and road accessibility (X5) were the independent variables. Binary logistic regression analysis was used to determine whether the above independent variable factors were independent influencing factors of falling objects.

To accurately identify the effects of each variable on falling object accidents, the data is first processed. Data with unclear information is removed, and data with imbalanced distribution is merged. Regarding the type of falling object, it is classified into glass (windows), exterior wall materials, metal frames, billboards, pipes, and shelving objects. For falling time, it is divided into daytime (6:00-19:00) and nighttime (19:00-6:00). Weather conditions are categorized as severe weather (rain, snow, strong wind) and good weather (clear, cloudy). Dates are classified as weekdays and holidays. The falling location on the street is divided into passable roads (with walkable streets under the falling object) and prohibited roads. Finally, 260 accident records are retained for quantitative analysis, accounting for 95.6% of the original data. The majority of the cases are located in urban areas with dense buildings, with 92 cases classified as injury events. Although the number of high-altitude falling object accidents causing injuries is not large nationwide, the consequences are severe. To further explore the characteristics of accidents, variables that can be identified in documents and news reports are selected for study, as can be seen from Table 1,including falling object type, falling time, weather, date, and road accessibility.

Table 1. Description of independent variables

Independent Variable	Variable description	Valuation
Falling Object type（X_1）	glass (windows)/exterior wall material/billboard/metal frame/pipe/shelving object	1/2/3/4/5/6
Falling Time（X_2）	daytime/nighttime	0/1
Weather condition（X_3）	good/severe	0/1
Date（X_4）	weekday/holiday	0/1
Road conditions（X_5）	passable/prohibit	0/1

3 Incident Characterization and Data Analysis

3.1 Descriptive Analysis of Fall Incidents

The types of falling objects mainly include glass (windows), external wall bricks (boards), external wall insulation materials, cement blocks, air-conditioning racks, guardrails, various types of billboards, pipelines, window sill shelves, roof shelves, etc., of which the glass (windows) and external wall materials accounted for 41.2% and 18.5%, respectively, and are the main falling object categories. It can be seen that the falling of external walls and glass (windows) poses a serious threat to the safety of pedestrians traveling.

Among the 260 cases of falling object accidents, there were a total of 169 cases involving only property damage, including 160 cases where vehicles were hit and 9 cases where buildings below or nearby were hit. 180 accidents occurred on working days, while 80 occurred on holidays. 193 accidents occurred in good weather, while 67 occurred in rainy, snowy, or windy conditions. The majority of accidents (86.5%) happened during the day on streets (80.4%) accessible to pedestrians. It can be seen that there are multiple factors affecting object falls, and it is not possible to identify key factors through basic statistical data alone, so further analysis of the data is needed.

3.2 Logistic Model Analysis

The total sample size selected for this study was 260, with 5 independent variables. The sample size was more than 50 times the number of independent variables, and the positive case rate of the outcome variable was 35.4%, which is not less than 15% of the total sample size, meeting the criteria for sample size in binary logistic regression analysis.

In order to ensure the accuracy of the results of binary logistic regression analysis, it is necessary to analyze the independent variables for multicollinearity. In this study, the variance decomposition of regression coefficients was used to test the existence of multicollinearity between variables. The test results are shown in Table 2， there is no significant covariance coefficient (VIF < 10) between the independent variables, which can be used as independent variables for the next step of logit regression analysis， and P for significance.

Table 2. Results of multicollinearity analysis

	P	Covariance statistic	
		Tolerances	VIF
X_1	0.001	0.875	1.143
X_2	0.015	0.967	1.034
X_3	0.028	0.904	1.106
X_4	0.193	0.968	1.033
X_5	0.000	0.960	1.042

Five variables were selected as independent variables to construct a binary Logit model for the degree of accidental. The chi-square value was 43.176 with 9 degrees of freedom, and the significance(P) was 0.000, which is less than 0.05, indicating that the model is statistically significant. The goodness of fit of the model was evaluated using the Hosmer-Lemeshow test, with a significance value of 0.624, indicating a good fit. The results of the binary logistic regression analysis using IBM SPSS 25 are shown in Table 3. In the table SD stands for standard error, OR stands for logarithmic ratio.

Table 3. Results from the binary logistic regression analysis.

Variable	SD	Wald	P	OR	95%CI	
					Lower	Upper

Falling Object type	—	19.296	0.002	—	—	—
Type1-External wall materials	0.495	10.425	0.001	0.202	0.077	0.533
Type2-Billboard	0.376	7.697	0.006	0.353	0.169	0.736
Type3-/Metal frame	0.494	0.684	0.408	1.505	0.571	2.963
Type4-Pipe	1.117	0.000	0.990	0.986	0.110	8.804
Type5-Man-made object	0.755	1.285	0.257	0.425	0.097	1.865
Falling Time	0.407	4.194	0.041	0.434	0.196	0.965
Weather condition	0.347	4.513	0.034	2.088	1.059	4.118
Date	0.321	2.304	0.129	0.615	0.328	1.152
Road condition	0.475	8.346	0.004	3.942	1.554	9.997
Constant	0.808	0.160	0.689	0.724	—	—

4 Results

4.1 Analysis of the Causes of Injuries Caused by Glass (Window), External Wall Materials and Billboards

The proportion of cases of glass (window) falling is 18.5%, exterior wall materials falling is 41.2%, and billboard falling is 10.2%. Among them, incidents of people being injured by falling glass (windows) and exterior walls have become increasingly prominent.

The falling of glass (windows) may be influenced by various factors, including but not limited to material aging, design defects, and insufficient maintenance. Glass windows undergo long-term exposure to wind, rain, and sunlight, leading to the aging of the glass material, making it more fragile and increasing the risk of breakage and falling. The detachment of exterior wall materials is the most common cause of high-altitude falling objects in recent years, accounting for nearly 50%. Although China's external wall insulation policies have undergone several major changes, quality supervision is still inadequate. Currently, billboards between urban buildings are usually made of large metal, wood, or other heavy materials, with a certain weight, and are mostly located at high positions, especially on buildings, elevated roads, or columns. Design non-compliance, improper installation, excessive height, excessive size, and lack of maintenance are the main causes of safety hazards for outdoor billboards [10]. China currently has an approval process for billboards, but there is little consideration given to the daily management and maintenance of billboards.

4.2 Analysis of Increased Risk of Pedestrian Injury in Bad Weather

There were 67 cases of falling objects during rainy, snowy, or windy weather, with an odds ratio (OR) of 2.088 (95% CI), indicating that the probability of injury in adverse weather conditions is 2.088 times higher than in good weather. Excessive wind force may affect the stability of buildings, especially tall buildings, where under strong wind, the structure of the building may be subjected to lateral forces, increasing the probability of falling objects. The harm caused by heavy rain or prolonged rainfall should not be underestimated. Lup Wai Chew[11] believes that the wet environment after rain will accelerate the corrosion of materials, and a higher frequency of rainfall will directly increase the risk of objects falling due to corrosion, which is consistent with the results of this study.

Northern icy and snowy weather is also a dangerous source. Icicles often appear on the eaves of houses and buildings. When pedestrians walk under the eaves, as the weather warms up, the ice and snow melt, causing frequent accidents of icicles falling and injuring people. It can be seen that weather changes will indirectly or directly affect falling objects to a certain extent, accelerating the fall of objects or the creation of falling object sources.

4.3 Analysis of Increased Risk of Pedestrian Injury on Prohibited Roads

The passability of roads has a significant impact on the degree of injury caused by falling objects, with an odds ratio (OR) of 3.942 (95% CI), indicating that the probability of falling objects causing injury on roads prohibited for passage is 3.942 times higher than on streets where passage is allowed, showing that roads prohibited for passage are more risky. Fallen objects have a certain range of falling. When the road is too close to the building, falling objects may hit pedestrians, which is not conducive to pedestrian safety. The lack of overhead shielding on the road directly facing the falling object hazard from the building also increases the possibility of objects falling and causing injury. In this study, the prohibited roads are mostly set up with barriers by the property management or relevant departments and are assessed as roads with a certain degree of danger, strictly prohibited for pedestrian passage.

4.4 Analysis of Increased Risk of Pedestrian Injury During Daytime

The time of falling objects significantly affects the degree of injury, with an odds ratio (OR) of 0.434 (95% CI), indicating that the probability of injury at night is 0.434 times that during the day. The analysis believes that the reason may be that there are more pedestrians during the day and they are easy to be in the area of falling objects. And people in high-rise buildings are more active[12]. Although falling objects are accidental events, the influence of human activities on them cannot be ignored.

5 Conclusion

With the continuous increase in urban high-rise buildings and the growing number of old residential areas, the related falling object accidents are becoming more and more frequent, and safety issues are becoming increasingly prominent.

The study found that in urban high-altitude falling object accidents, four variables including falling object type, falling object time, road passability, and weather have a significant impact on the severity of injuries after falling, while whether it is a working day does not significantly affect the severity of falling object injuries. Based on theoretical analysis and empirical conclusions, several governance strategies can be formulated to reduce urban falling object accidents:

Firstly, focus on checking whether there are safety hazards in the external walls, glass (windows) and billboards. Aging of material components is an unavoidable natural process, especially for high-rise buildings that have been built for a certain number of years and whose spatial design is not reasonable enough, it is necessary to establish a system of regular inspections, special inspections, and self-inspection by users.

Secondly, increase publicity, supervision, and prevention of falling objects, including risk prevention and control, supervision and inspection, publicity and education, involving administrative agencies, developers, construction units, property management companies, grassroots organizations, and other responsible entities. At the same time, optimize the legislation and administrative enforcement processes.

Thirdly, construct a new practical high-altitude falling object monitoring system and achieve major breakthroughs in monitoring technology innovation. This study still has some shortcomings. Due to objective conditions and data collection conditions, the sample size of the data used in this study is small, and the information provided by accident cases reported in the news is very limited. In the future, with the continuous accumulation of falling object accident data, it is hoped that more detailed data can be obtained to carry out more refined research.

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