Pedestrian violations crossing behavior at signal intersections: A case study in Anning District of Lanzhou

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Abstract. Pedestrian violations crossing behavior at intersections can easily lead to traffic disorder, accidents, injuries and deaths. This paper conducts a case study in Anning District of Lanzhou City to investigate the pedestrian violations by field observation, questionnaires and video recording. Out of 2852 identified valid pedestrian crossing samples at signalized intersections are randomly selected, of which 617 are involved as illegal violation samples. The factors affecting the violations are extracted and divided into internal and external factors. The internal ones are according to age and gender factors, while the external factors contain the crosswalk length, crossing time, headway, red light duration and number of partners. The results show that the rate of violation crossing among the elderly pedestrian is higher than that of other age categories and the rate of male is slightly higher than that of female. In the external factors, the crosswalk length, the crossing time and the headway of motor vehicle are positive correlation with the violation rate. For the signal light part, the longer red light duration means longer waiting time and the pedestrian violation rate will significantly increase. Furthermore the countdown signals are conducive to reducing the violation rate compared with no countdown display. Interestingly, the violation rate do not increase with the number of companions, however it’s more prone to violation for the individual pedestrians. Based on the above analysis, the corresponding solving strategies are proposed.

1. Introduction
Pedestrians as the vulnerable groups in travel are easy to get injured in traffic accident. In addition, pedestrian movement is more flexible and less constrained by laws and regulations. This caused the relatively high violations rate and management difficulties. About 36% of pedestrians’ injuries in the United States and 60% in Tokyo happened at signalized intersections, of which one third happened during red light period[1]. In Chinese urban road traffic system, pedestrian crossing behavior has a greater impact on traffic order and efficiency and become an important factor to induce traffic disorder and accidents. Pedestrian traffic deaths account for about 25% of total deaths, of which 10% in Beijing and 19% in Chengdu occurred at intersections[2]. Pedestrian violation crossing become one of the important causes for pedestrian traffic accident. This study aims to characterize pedestrian violation crossing behavior. Several variables that potentially affect the violation rate are extracted from video data and field record. Based on the measured data, this paper analyzes the impact factors on violation rate and proposes targeted improvement to reduce accident rate.
2. Literature review

Scholars have relatively little research on pedestrian violations crossing behavior, mainly from the impact of pedestrian internal and external factors. Moyano have determined that men have a tendency to commit more violations than women and young adults tend to violate a traffic light more often than other age groups[3], which conclusion can also be confirmed by Rosenbloom[4]. In the study of external factors, Marilyn analyzed the impact of pedestrian maximum waiting time on pedestrian crossing violation rate and classified the severity of different violations[5]. Koh studied pedestrian violations and a relationship is established with dependent variables such as waiting time, the number of conflicting traffic lanes, conflicting vehicular traffic volume and personal characteristics of the pedestrian[6]. Owen et al. studied the effects of red countdown lights on pedestrian behavior, which indicated that the countdown lights help improve pedestrian compliance[7]. Wang et al. found the probability of compliance decreases with longer waiting duration and half of the pedestrians would not wait longer than 40s[8]. Martin analyzed the researches in Europe and North America and found that when the wait time is more than 40s at the crosswalk, pedestrians’ violations will increase dramatically[9]. Qian observed the signalized intersection in Shanghai and stated that the increasing length of the sidewalk diminished the violation rates of pedestrian[10]. Zhang applied the Logistic model to analyze risk factors influencing traffic signal violations for car drivers, cyclists and pedestrians groups and the results indicate that road types and lighting conditions have different effects on traffic signal violations for the three groups. In addition, different ages have different effects on traffic signal violations for car drivers and pedestrians. Finally, occupations have different effects on cyclists and pedestrians[11]. Wang compared the the violation rate and waiting position at different intersecting lights. The influence of traffic signal type on pedestrian crossing behavior is evaluated. The results show that the violation rate of the intersection of the static pedestrian lights is significantly higher than that of the countdown signal lights. There are significant differences in the waiting position of the intersection of different signal lights[12]. Rosenbloom compare the behavior of individual pedestrian to the groups where is located at an intersection with a traffic signal. Logistic regression predicting red-light crossing for pedestrians arriving during a red-light phase indicated that, apart from gender, the tendency to cross on red was greater when there were fewer people waiting at the curb, either when a pedestrian arrived or joining after arrival[13]. Furthermore, Xing predicted the violations rate of pedestrian crossing the street by establishing a model with the influencing factors. The results show that the type of crossing facilities has a greater impact on the violation rate. Among them, the violation rate with channelized safety island is low[14]. Li studied the safety on twice crossing and the pedestrian compliance rate, the results showed that inclement weather and refuge island design adversely influenced pedestrian behavior at a signal controlled twice crossing[15]. Guo used automated video analysis to collect pedestrian data at a signalized intersection in Nanjing by gait parameters. The results show high accuracy in automatically detecting pedestrian violations with an 85.2% correct detection rate. The walking speed and gait parameters for spatial violators are found to be significantly higher compared to non-violators. It is also found that pedestrians who enter the crosswalk during the late stage of the green pedestrian phase often adopt higher walking speed[16]. Ren et al. studied crossing behaviors at signalized intersections in three cities and found the largest violated proportion of surveyed individuals is 30.25%, which indicated the main reasons for violations are saving time and for convenience[17].

In summary, the scholars focus on the research of pedestrian violation for safety and design problem, however, there is still lack of related research in China. In this article, eight typical signal intersections in Anning District of Lanzhou City are selected as the survey site to investigate the pedestrian violation. The data of pedestrian crossing is collected by video camera and artificial record. Comprehensive field investigations and literature materials, the influence factors, which affect pedestrian crossing behavior, are selected and analyzed. Finally, targeted improvement measures are proposed to reduce pedestrian violations and improve pedestrian crossing environment.
3. Analysis of Pedestrian Violations

3.1. Basic information of survey sites
Anning District of Lanzhou City, where converges many universities and colleges with 288,500 population, is a state-level Economic and Technological Development Zone. In this study, 8 typical signalized intersections in the Anning District were selected. Six of them are on major arterials and two are on minor arterials. Five are crossroads and three are T-intersections. Data were collected through field manual investigation, video recording and questionnaires. The parameters of road traffic facilities are mainly measured by manual method, while the pedestrian characteristics and traffic conditions are collected by video recording. The time period of data collection was selected on April 24(Monday), 25 and 26, 2017, and divided into three periods: 8:00-9:00 (morning rush hour); 12:30-13:30 (noon peak); 17:30-18:30 (evening rush hour). The weather on the days selected for data collection was sunny. The pedestrian characteristics of the selected intersection are shown in Table 1.

The following points should be paid attention to when collecting data:
- The erection of the camera should be selected in an open field of view, to capture the characteristics of all pedestrians within 20 meters of the sidewalk of the observation point.
- The information collected includes: age, gender, group size, countdown display, pedestrian waiting times, pedestrian green time, crossing length, conflict vehicle flow, right turn vehicle flow, number of pedestrians waiting at the corner at the beginning of the crossing.

Table 1. Characteristics of selected intersections

| No. | Intersection | Pedestrian signal | Land use      | Pedestrian waiting time (s) | Pedestrian green time (s) | Crossing length (m) | Conflict Vehicle Flow (pcu/h) | Right Turn Vehicle Flow |
|-----|--------------|-------------------|---------------|-----------------------------|--------------------------|-----------------------|------------------------------|------------------------|
| 1   | Anning West Road/ Xuefu Road | E-W: Yes N-S: Yes, countdown | Urban/mixed | E-W:62 N-S:75 | E-W:45 N-S:32 | E-W:40.6 N-S:32 | 1700 | 920 |
| 2   | Xing’an Road/ Wanxin North Road | Yes, countdown | Urban/mixed | E-W:45 N-S:45 | E-W:45 N-S:45 | E-W:14 N-S:12.6 | 880 | 400 |
| 3   | Baoshihua Road/ Jianning Road | Yes, countdown | Urban/Commercial | E-W:40 N-S:48 | E-W:48 N-S:40 | E-W:13.2 N-S:16.3 | 2001 | 1129 |
| 4   | Nanbinhe Road/ Yintan Road (T) | Yes | Urban/residential | E-W:25 | E-W:80 | E-W:15.8 | 1724 | 1032 |
| 5   | Jianning West Road/ Yintan Road | Yes, countdown | Urban/mixed | E-W:40 N-S:40 | E-W:40 N-S:40 | E-W:35 N-S:25 | 1524 | 788 |
| 6   | Baoshihua Road/ Anning West Road (T) | Yes, countdown | Urban/mixed | E-W:33 N-S:61 | E-W:61 N-S:33 | E-W:13.2 N-S:19.6 | 1220 | 800 |
| 7   | Anning West Road/ Yintan Road (T) | Yes, countdown | Urban/mixed | E-W:44 N-S:74 | E-W:47 N-S:17 | E-W:12 N-S:20 | 1096 | 536 |
| 8   | Anning West Road/ Wanxin North Road | Yes, countdown | Urban/mixed | E-W:40 N-S:54 | E-W:54 N-S:40 | E-W:24.8 N-S:16.2 | 876 | 634 |

3.2. Analysis of Pedestrian Violations in Anning District

3.2.1. Definition of Pedestrian Violation
This paper defines pedestrian violations crossing behavior as time and space violations. Time violations refer to pedestrians cross the street on a red light. There are two types of situations: (1) Pedestrians break into the crosswalk during a red-light phase; (2) Pedestrians begin to cross the street
during the green light, but they do not complete the cross-street behavior during the green light period and occupy the red light time. The first kind of violation belongs to intentional violation, which causes by subjective reasons or too long waiting time. The second is forced violation, which refers to rushing through under the condition of less pedestrian green light time or the green time cannot reach the minimum time for pedestrians to cross the street. This article only selects the first violation as time violations. Space violations, referring to pedestrian crossing without using crosswalks within 20 meters on both sides of the crosswalk, is not considered in this paper. The ratio between the number of pedestrians using the crosswalk during red phase and total number of pedestrians arrived at signalized intersection is defined as pedestrian's violation rates.

3.2.2. Analysis of pedestrian violation factors

This video recording investigated 25 crosswalks in Anning District, using continuous acquisition methods for observation. Each observation point are collected twice, each video contained 10 continuous signal cycles, guaranteeing that each video lasts more than 15 minutes and the data are sampled randomly from the videos. 2852 valid pedestrian crossing samples at signalized intersections are randomly selected, of which 617 are illegal violation samples. The pedestrian violation rate reaching 21.6%. Compared with other city, the violation rate is higher than that in Beijing China (10%) and lower than that in Izmir Turkey (40%)[18]. By comparison with other western second-tier Chinese cities such as Chengdu, the violation rate in Anning District is also higher 2.6%[19]. In general, the violation rate in Anning District of Lanzhou is still relatively high.

Considering pedestrian characteristics and traffic environment, combined with the convenience and accuracy of data observation, the influencing factors can be divided into internal and external factors. The internal ones are according to age and gender factors, while the external factors contain the crosswalk length, crossing time, headway, red light duration, countdown display and number of partners.

1) Age and gender

Age and gender are the most basic attributes of a person. Different age and gender mean the variation of physiological and psychological characteristics and social conditions factors, the differences of which result in the various behavioral patterns.

According to the survey data of Fig.1, the violation rate are obvious differences among different age groups. While elderly pedestrians have higher violation rate (reached 24.7%) than other age categories, they are closely followed by the young and middle-aged group, the children and the juveniles.

One explanation could be that the elderly have a decline in physical function, weak resolution and slow response that causes them to be unable to accurately assess the crossing time. Together with they believe more in their own experience, which make them have higher violation rate. Young and middle-aged pedestrians, which are anxious, impatient and high time value, know the traffic law but not regulated. They incline to rush across the street when they see fewer cars. Children’s cross-street behavior depends on the behavior of accompanying adults. Most of the juveniles are in the period of earnestly accepting and implementing educational achievements. They are more and impressed by traffic safety education in schools and homes, while most of them are willing to follow the signal to cross street using crosswalk, so the violation rate is the lowest among all age groups.

Mental and physical conditions of male and female are different, while there are differences in their crossing behavior. As shown in Fig.2, a violation rate of males is 19%, which is about 3 percentage points higher than female. This is because male is impulsive, competitive and impatient.
2) Crosswalk length and crossing time

According to the survey data (see Fig.3 and Fig.4), pedestrian crosswalk length and crossing time show synchronous changes with the violation rate. When the crossing time is less than 20s, the violation rate decreases slowly with the crossing time. However, when crossing time is longer than 20s, the violation rate increases sharply with the crossing time.

The crosswalk length is positive correlation with the violation rate. When the crosswalk length is 24.8m, pedestrian violations rate is the lowest reaching 6.8%, however, when the length of the crosswalk is longer than 24.8m, pedestrian violations are on the rise dramatically.

3) Headway

Pedestrian violation rate caused by right-turn vehicle and pedestrian conflict accounts for 56% of the total pedestrian violation rate. Pedestrian crossing behavior is based on the premise of ensuring their own safety. The greater the headway means the higher gap for pedestrian. They tend to wait for the intervals that they think safe enough to cross street, rather than follow the instructions of traffic signal. Consequently, the headway of motor vehicle are positive correlation with the violation rate. A clear trend can be observed in Fig.5, few people dare to try to cross the fast traffic within 0～2s of the headway and the violation rate is 5.1%. While when the headway up to 4～5s, which is considered as a safety gap for passing through the right-turn vehicle, the violation rate increased rapidly. Then it is growing slowly and the violation rate reaches to 31.6%.
4) Red light duration

The pedestrian waiting time is directly related to the pedestrian phase red light time. The longer red light duration means longer waiting time and the pedestrian violation rate will significantly increase. That is related to pedestrians' tolerance of waiting. According to Fig. 6, the longest red light time of intersection in Anning District is 75s, while the pedestrian violation rate reached 55.8%. The overall trend is positively correlated in the range of 25~75s.

5) Countdown

In the intersections with countdown pedestrian signals, the pedestrian crossing behavior presents different characteristics. The countdown devices in Anning District are all digital countdown, which display the precise remaining time of signal phase in digital form. Under the control of countdown display, pedestrians tend to cross according to the time remaining to adjust the crossing behavior. For example, at the end of the red light pedestrians will determine the crossing behavior depending on the conflict vehicles flow and other pedestrians’ behavior. If the conflict flow is low, the pedestrian incline to early entry into the crosswalk as they know there will be no more conflict vehicles. While at the period of transition from the green light to red light, pedestrians choose to risk running through or determine by the number of pedestrians on the crosswalk.

According to Fig. 7, pedestrian violation rate without countdown display is 20.4%. According to the survey data, it’s observed that pedestrian violations without the countdown light are mostly concentrated in the early stage of red light, while the violations mainly focus on the late red light with countdown display.

6) Number of companions

Different from previous studies, the conformity seems not affect pedestrian violation behavior in Anning District. As shown in Fig. 8, the violation rate did not increase with the number of companions. When the pedestrian cross the street alone, it’s more easily to cross illegally and the violation rate will peak somewhere near 24.6%. In this case, the pedestrian could flexibly adjust the pace in time according to the gap. As the number of companions increase, it’s difficult to unify the pace to find the enough clearance for safety passing. Therefore, when the number of companions is six or more, the violation rate is only 4.8%. 
4. Suggestions for improvement

In view of the causes of pedestrian violations, some measures have been proposed to prevent pedestrian violations by improving crossing traffic facilities, enhancing traffic safety knowledge education, strengthening the management. The system offers an effective mechanism to ensure that pedestrians and vehicles at the intersection can operate safely and orderly.

(1) It’s suggested that intelligent control should be introduced to traffic lights, the time-sharing management and refined management should be implemented according to the actual situation.

(2) It should refine the traffic regulations and be strictly enforced. The suggestion is that Lanzhou promulgate punishment measures suitable for the economic level of Anning District. It’s also recommended to establish a panel to enforce the regulations at utmost. The identify methods of obtaining information on illegal pedestrians also should be improved through marketing operations. Photographs of illegal pedestrians are collected through high-tech facilities (pictures, video, etc.) to compare with the credit archives information in the public security network to carry out the credit management.

(3) Propaganda and education of traffic safety must be further strengthened among ordinary people. Traffic regulations should be thoroughly understood and meticulously implemented by setting up compulsory courses of citizen safety knowledge.

5. Conclusion

This paper conducts a case study in Anning District of Lanzhou City to investigate the pedestrian violations. 2852 valid pedestrian crossing samples are randomly selected at 8 signalized intersections, of which 617 are illegal violation samples. The violation rate is 21.6% and this figure is higher than 14% at each intersection.

Seven factors affecting the violations are extracted: age, gender, crosswalk length, crossing time, headway, red light duration, countdown display and companions. For the pedestrian characteristics, the rate of violation crossing among the elderly pedestrian is higher than other age categories and the male is slightly higher than female. In addition, the crosswalk length, the crossing time and the headway of motor vehicle are positive correlation with the violation rate. For the signal light part, the longer red light duration means longer waiting time and the pedestrian violation rate will significantly increase. The countdown signals are conducive to reducing the violation rate compared with no countdown display. Furthermore the violation rate do not increase with the number of companions, however it’s more prone to violation for the individual pedestrians. Therefore, it’s recommended to refer to the influence of various factors on the violation rate and set up crossing facilities at intersection according to local conditions to reduce the accident rate and ensure pedestrian safety.
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