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A Study of Pedestrians Crossing Speed at Signalized Intersections Considering Weather

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Abstract:

Walking speed is an essential parameter for traffic engineering applications. Signalized intersections are the most essential joints connecting transportation hub and destinations in urban area. A thorough understanding of pedestrian crossing speed shall be a precondition for a proper pedestrian signal timing design at signalized intersections. This study aims to determine the pedestrian crossing speed under various weather conditions, taking into account pedestrian's basic information and the crosswalk length. The research found that pedestrians increase their crossing speed compared with the control group's walking speed, regardless of age, gender, weather or the length of crosswalks. The results, however, shows on rainy days, the 15th percentile speed is 0.95 m/s, which is slower than all the other type of weather. The research also found that in age group, elder always crossing at the slowest speed, regardless of 15th percentile or mean percentile crossing speed. In gender group, female always walk slower than male group, regardless of 15th percentile or mean crossing speed. For various sorted pedestrian groups, speed in rainy weather is slowest, which is even slower than elder group that many researchers and agencies interested. Besides, pedestrians using shorter crosswalk walk slower than those walk in longer crosswalks. Finally, the pedestrian cross crossing speed from this investigation is compared with other areas and countries.

Keywords*: Pedestrian crossing speed, Statistical analysis, Cumulative frequency*

I. INTRODUCTION

Governments and research institutions have been attached great importance to the pedestrian walking speed at signalized intersections for decades. In the US, Manual on Uniform Traffic Control Devices (MUTCD) assume the design speed for pedestrian was 1.22m/s in the 1960s, and it was continuous adjusted. The Manual on Uniform Traffic Control Devices for Canada (MUTCDC) assume 1.2m/s as the pedestrian walking speed for signalized timing facilities (2002). The previous study reports that elder waking speeds are slower than other age group of people [1-3] therefor, the design speed would be adjusted and modified when elder pedestrians are considered.

The study and practice on pedestrian crossing speed have been implicated crossing safety, as well as

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vehicular delay. On one hand, as the aging of population increase worldwide, design of pedestrian walking speed should take extra consideration for elder pedestrians. China's population aged 60 and above accounted for more than 18 percent of domestic population, according to the National Census (2021). The United States, population of 65-year and above occupied 20.56% and in Japan, aging population achieved 27% in the most recent census. Therefore, conducting walking speed should take into consideration of "elderly group". Pedestrian walking speed of elder group provides the design reference of modification and adjustment for pedestrian design purpose in local area. On the other hand, overestimation of pedestrian crossing time at signalized intersections is inevitably delay the vehicles' travel time. Hence, a thorough understanding of pedestrians crossing speed and at intersections are essentials for both pedestrian safety and traffic efficiency.

KnobLauch et al (1996) conducted a research on the pedestrian walking speed [4]. They reported that 15th percentile speed for people at age below 65 is 1.51m/s, but for the age of 65-year-old and above, walking speed is 1.25m/s. Their research also reveals the different characteristics of pedestrian at the signalized intersections. Duim et al (2017) had some interesting finding including majority elder pedestrians walk at speed of 1.2m/s [2]. Woman and poor educated people walks slower than traffic signal required pace. Based on the walking speed observed, their research also analyzed the reasons of difficulties that pedestrian passing the crosswalk. Mohamed (2001) [5] recommended the design speed of 1.11m/s in Jordan area. Richard et al (1996) reported the mean pedestrian walking speed for teenager was 1.51m/s, and 1.25 for elderly people. The 15th percentile speed for teenager is 1.25m/s and 0.97m/s for elder individuals. Mohamad Ali et al (2010) [6] compared the pedestrian walking speed between the bus terminal area and crosswalk. Webb et al (2017) found older pedestrians walk slower than the UK and US required speed of 1.2m/s [7].

Even though pedestrian crossing speed analysis has been done by many researchers in past decades, the influencing of weather is seldom to discussed if it has effect on pedestrian's crossing speed. the rest of this paper include: materials and methods are described in section II. The results is addressed later. Section III is the conclusion of this study.

II. MATERIALS AND METHODS

2.1 Study Site Selection

Five typical signalized intersection for different land use are selected as the study site. All the selected signalized intersections consist of extra pedestrian signal controllers. First type is the intersection nearby the hospital area. In this area, some people are not quite familiar with the surrounding environment. Pedestrians tend to more vigilant than walking in other areas. In addition, elder people apparently show up more frequently in the area than any other study sites. Second type of signalized crosswalk located in front of a plaza where opened grocery stores, hair salons, bakeries and restaurants. Intersections in these commercial areas often have characteristic of joyful and noisy. The third type of intersections are near the

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schools and Lanzhou Jiaotong University. A large part of users in this area are college students, middle school and high school students. All data are collected in weekdays either 11:30am-12:30pm, or 5:30pm-6:30pm. A few notes need to mention: children pedestrian is often accompanied with their parents, and since we only consider individual's crossing speed, so these children pedestrians that walking together with their parents are not counted in sample data. However, middle school and high school students whom age 13-18 years old usually walk independently. In addition, the school require students dress the uniform on weekdays and our data collectors are easy to identify from teens and adults. The people who not walk within the crosswalks, and bicycle rides using the crosswalks are not counted either.

The length of each crosswalk is measured three times with a survey meter and the average value is used for walking speed calculation. The crosswalk length is range from 12.7m to 36.8m long. In this study, the crosswalk that is smaller than 20 meters are categorized to short crosswalk, and 20 meters and above is divided into long crosswalks. The below Figure 1 shows the study location which distributed in Lanzhou, China.

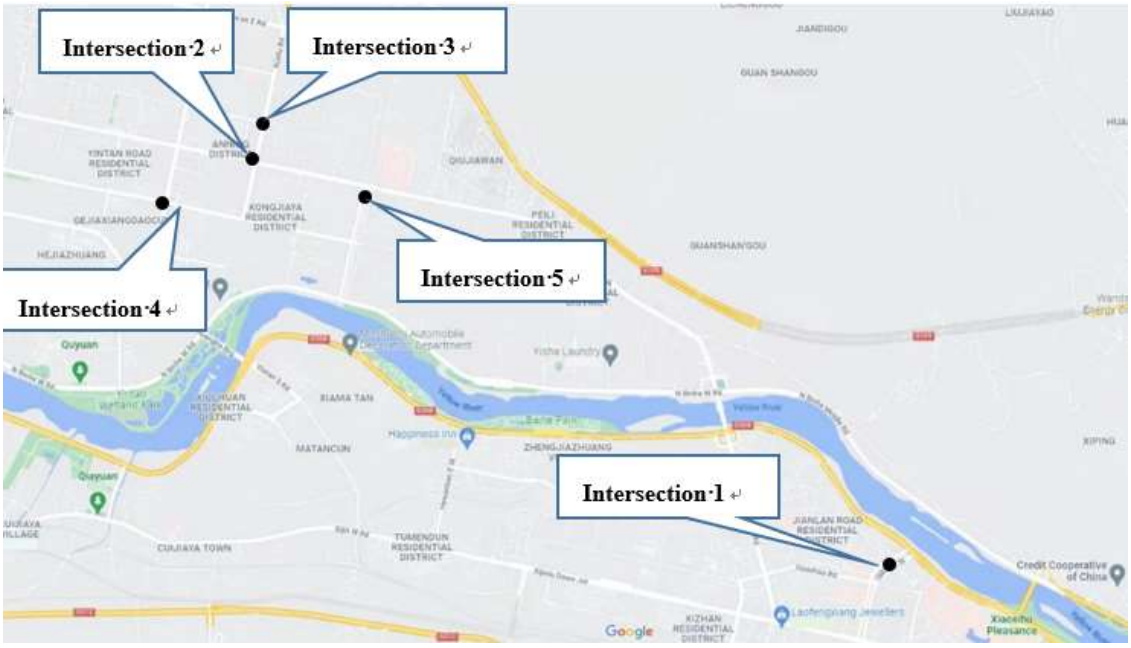

Fig 1: The study site of pedestrian walking speeds

2.2 Weather

This study experienced 9 months to collect the data. Beside the clear weather in autumn, clear means no smog, rainfall, sand and dust to bedim pedestrian's sight; the temperature is moderate. We scheme to capture the crossing speed from other weather conditions including media rain, sand and dust, as well as winter cold day (17.6 ℉) separately.

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This result shows pedestrians' speed and exterior environment potentially exist interaction. Even though the weather preference might vary from individual to individual, an average crossing speed based on the weather is reported in this study. Cold weather's speed data is collected in January 8th; Sand and dust speed data is collected in March 16th; clear day's speed data is collected in August and September; Rainy day speed data is collected in September. Figure 2 shows the pictures of walking scenarios under four weather conditions.

(a) (b)

Fig 2: Pedestrians crossing scenarios under different weather conditions. (a) Rainy day at Baoshihua Road and West Anning Road. (b) Sand and dust weather at Xingan Road and Xuefu Road.

2.3 Age and Gender

Age and gender are two variables that discussed intensely in the previous references on pedestrian walking study. 60-year-old and above grope of pedestrians are often viewed as the elderly pedestrians and they are often specific studied since design speed ought to adjust or modified based on elderly pedestrians.

2.4 Data Preparation and Analysis

More than 15 hours' video are taken at 5 signalized intersections. The total number of 4630 pedestrians walking speeds are extracted and prepared for statistical analysis. In the first stage, Data collectors were distributed at the study sites from 11:30am to 12:30pm in noon day, and 5:30pm to 6:30pm in the evening time. The data is collected from August 2020 to March 2021 in the first stage. Intersections with high pedestrian density are intentionally avoided when study sites are schemed in this study.

In the second stage, all the videos are brought back to the lab and count manually. Each pedestrian' speed is calculated by the following equation.

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$$s = \frac{\mathrm{L}}{\mathrm{T1}-\mathrm{T2}} \quad (1)$$

Where:

s= individual's crossing speed, m/s
L= length of crosswalk, meters
T_1=exit time, in hh:mm:ss
T_2=enter time, in hh:mm:ss

Each pedestrian's gender, age, enter time and exit time from the curbside, and weather condition is well read and recorded from the videos. The detailed information for each category is reported in Table I.

TABLE I. Sample size based on different classification

Data Classification	Variables	Sample size(collected)	P value	Total number
Overall		4630	/	4630
Age	Teen	594	0.000	4630
	Adult	3836		
	Elder	200		
Gender	Male	2415	0.012	4630
	Female	2215		
Weather	Clear	3387	0.000	4630
	Rain	642		
	Sand and dust	354		
	Winter cold	247		
Crosswalk length	Short	2589	0.000	4630
	Long	2041		

P value is used to explain the influence of potential variables including age, gender, weather, as well as crosswalk length on the pedestrian walking speeds. P value often defined as the probability under the assumption of hypothesis H_0, which assumes the obtaining result is equal or more extreme than what was actually observed. The smaller P-value represents larger significance for it tells investigators hypothesis H_0 is such a small probability event that the hypothesis cannot adequately explain the observation. The hypothesis H_0 can be rejected if any of these probabilities is less than or equal to a small, fixed but arbitrarily pre-defined threshold value α, which is referred to as the level of significance. In this study we have preset α value of 0.05. If P-value is less than 0.05, H_0 is rejected. Based on result on this study, p-value is less than 0.05 for all variables, which represents the interested variables are all statistically significant to the average pedestrian walking speeds.

Table II summarized 15th percentile speed, mean speed and 85th percentile speed. 15th percentile speed represents that 85 percent of pedestrian walks faster than this speed. 15th percentile speed is often

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used for the design purpose which accommodate 85% of pedestrians' walking speeds. 85th percentile speed means only 15th percentile pedestrian walks faster than that speed. Mean speed is also reported for each category and it represents the average walking speed of that group.

TABLE II. Statistical results based on area types

Data Classification	Variables	15th percentile speed	Average speed	85th percentile speed
Overall		1.10	1.38	1.61
Age	Teen	1.19	1.43	1.65
	Adult	1.10	1.38	1.61
	Elder	0.95	1.15	1.37
Gender	Male	1.10	1.38	1.61
	Female	1.08	1.33	1.59
Weather	Rain	0.91	1.21	1.6
	Sand and dust	1.31	1.58	1.8
	Winter cold	1.31	1.66	1.92
	Autumn Clear	1.15	1.37	1.61
Crosswalk length	Short	1.03	1.31	1.58
	Long	1.20	1.49	1.71

For overall pedestrians, 15th percentile speed is 1.10m/s in Lanzhou. The average speed for overall is 1.38m/s and 85th percentile speed is 1.61 m/s. When the data is divided into age group, teens (age 13-19) have the average crossing speed of 1.43 m/s. The average crossing speed of adult (age 20-60) followed teens which shows 1.38 m/s. Crossing speed of elder group of people has the lowest mean speed which is 1.15m/s, and with 15th percentile speed of 0.95m/s. In gender's category, male's 15th percentile and mean crossing speed is 1.8% and 3.6% faster than female. Crosswalk in this study is divided from 20 meters. The research found that the crosswalk group more than 20 meters has higher 15th percentile, average and 85th percentile speeds than the corresponding speeds of short crosswalk group. The results show long crosswalk have 1.20m/s 15th percentile walking speed whereas short ones have the 15th percentile speed value of 1.03m/s.

In order to compare pedestrian walking speed at signalized intersections with the normal walking speed. A control group is prepared (464 pedestrians). The location of control group is between sidewalk walk with very low traffic (less than 50veh/h). We realize in that site, most people walking through the crosswalk with the speed that close to the sidewalk walking speed, where they do not fell much uncertainties and dangerous. This crosswalk is only 9.2 m long. This pedestrian crosswalk neither has traffic signal lights nor pedestrian signal lights. The 15th percentile speed for this control group is 0.96 m/s, the average speed is 1.16 m/s and 85th percentile speed is 1.281 m/s for control group.

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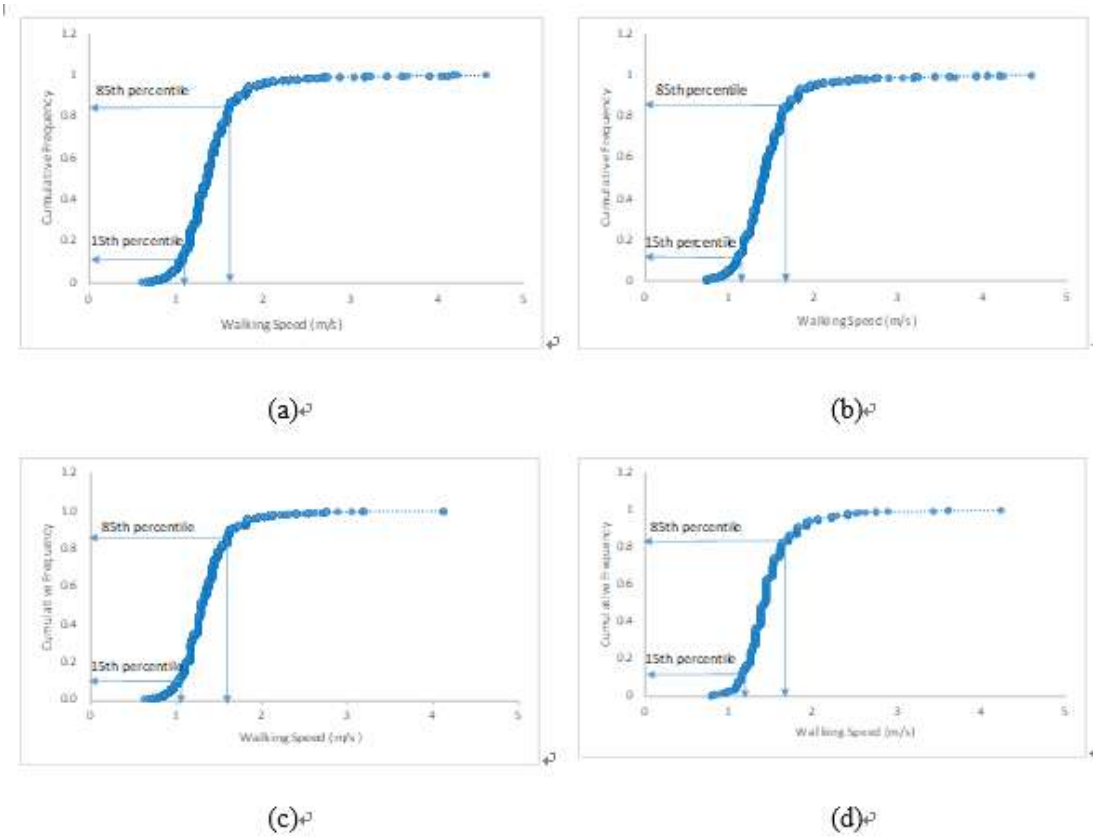
The cumulative frequency distribution curves presented in Figs. 3, which illustrate the speed distribution in every circumstance and category. Figs. 3 (a) shows the overall pedestrian crossing distribution. Figs. 3 (b), (c) and (d) represents the age group distribution of crossing speeds. Figs. 3 (e), (f), (g) and (h) shows how weather affects the crossing speed distribution group. Figs. 3 (i) and (j) curve reflect the how length of crosswalk influences the crossing speed distribution. For age group, elder always crossing at the slowest speed, regardless of 15th percentile or average crossing speed. In gender group, female always walk slower than male group, regardless of 15th percentile or average crossing speed. If taking weather as the influencing factor, from the slowest to the fastest ordered as rainy, clear, sand and dust, and winter cold crossing speed. The latter two weather conditions own the same 15th percentile speed though. Taking into consideration of the crosswalk length as the influencing factor, pedestrians walk slower in short facilities than the long crosswalk set, regardless of the 15th percentile or mean crossing speed.



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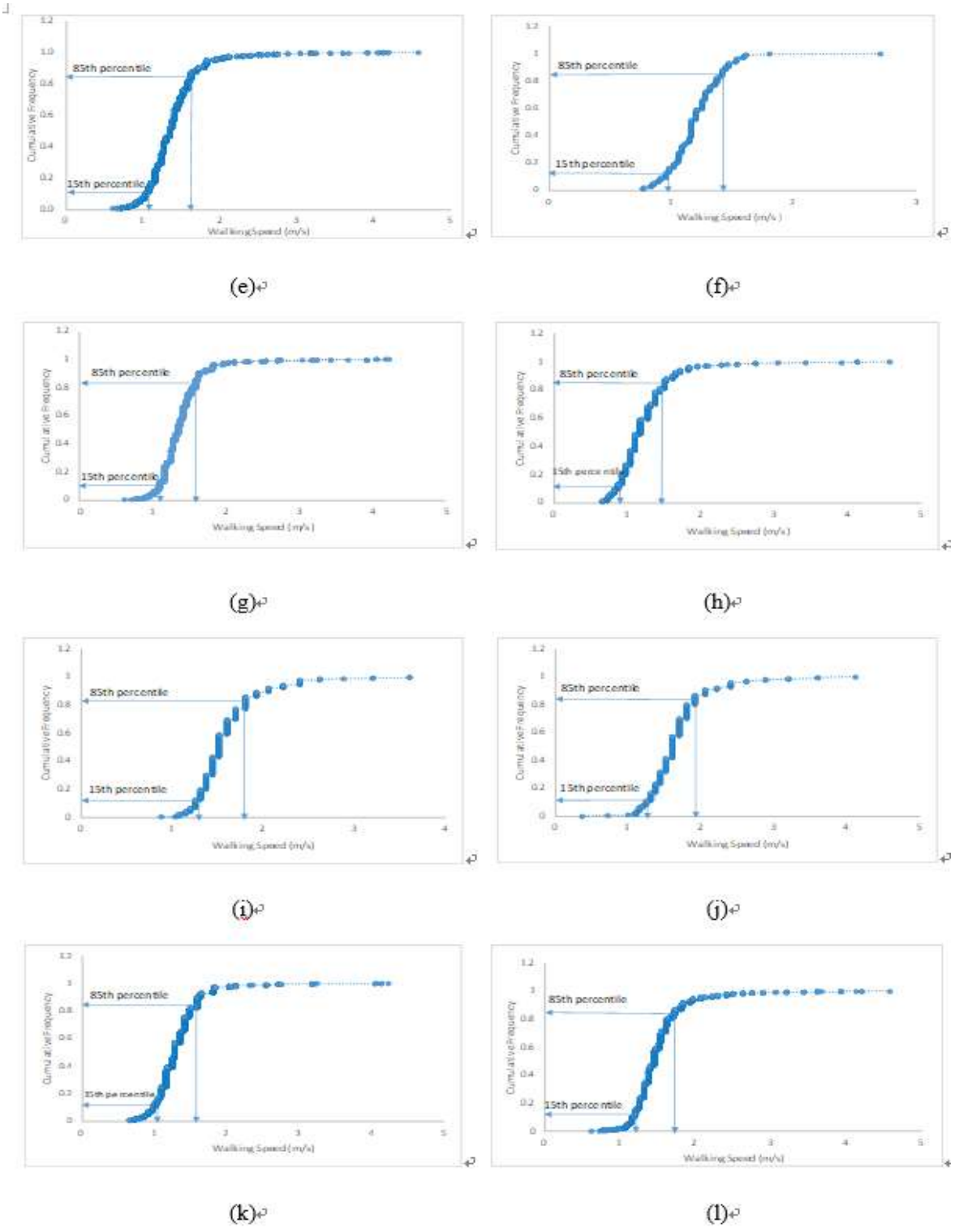

Fig 3: Cumulative frequency distribution for speeds under various circumstances. (a) Overall pedestrian crossing speed. (b)Male group. (c) Female group. (d) Teen age group. (e) Adult group. (f) Elder group. (g)Clear day group. (h)Rain day group. (i) Sand and dust weather group. (j) Winter cold group. (k) Short crosswalk group. (l) Long crosswalk group.

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III. CONCLUSION

Walking speed is an essential parameter for traffic engineering applications. This study explores pedestrians walking speed at signalized intersections with extra pedestrian signal lights. The study examined how different weather condition, crosswalk length, and pedestrian's age and gender, could have influenced on the crossing speed. Data of this investigation are collected from various signalized intersections in Lanzhou, in order to involve as diverse pedestrians as possible, pedestrians' crossing purpose and characteristics. At the same time, a group of speed measured close to sidewalk speed data are prepared for control group. The research found the following facts:

Compared with the control group, the pedestrian's crossing speed at signalized intersections is faster than the crosswalk that between two segments of sidewalk walk (control group). Pedestrian crossing at the signalized intersections with extra pedestrian signal lights all increase their speed, regardless of gender, age, weather conditions, right turn flow and crosswalk length.

This study investigates the effect that weather and other significant factors on pedestrian crossing speeds at signalized intersections. The result shows weather condition including clear, rainy, sand and dust, and winter cold are statistical significant to the crossing speed. The sequence of 15th percentile speed from slow to fast is rainy day, clear day, cold winter day and sand and dust day's crossing speed tied for the third place. The percentage of their difference is 26.4%, 13.9%, and 0% separately. This is reasonably explained that pedestrian in rainy weather are affected by slippery road surface. Water hazard on crosswalk surfaces also reduced the previous available space. Holding umbrellas also increased pedestrian's individual's spacing that required to crossing. Compared with elder group, the crossing speed of rainy day is 9.9% slower. The 15th percentile speed of sand and dust, and winter cold (17F) is equally to 1.31m/s. The increased speed in these two weather condition could be understood that pedestrians want to escape from the villainous external environment as soon as possible.

Pedestrians' speeds at the crosswalk length longer than 20 meters are faster than short facilities. Longer crosswalk often has more complicated exterior circumstances. Pedestrians tend to walk faster in order to leave from all the dangerous. On the other hand, when the crosswalk is short, the apprehension and uncertainty is less.

The study result of speed at signalized intersections in this research is compared with the crossing speed at other area and countries. The average crossing speed at signalized intersections is 1.38 m/s in Lanzhou. The average crossing speed is higher than the mean speed in Turkey [8], 1.22 m/s crossing speed in Malyaysia (Jabatan Kerja 1987), 1.23 m/s crossing speed in Canada [1] and 1.32 m/s in Qatar by Khaled Shaaban (2019) [9]. The speed however, is slower than 1.39 m/s in Malyaysia [10], 1.42m/s in Austria by Akcelik (2001) [11], 1.48m/s in Canada by Montufar et al. (2007) [11], 1.63 m/s in Austria [10], as well as 2.01m/s and 2.07 m/s in the U.S [4.,13].

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The recommendation based on this study include: (1) In rainy days, the pedestrian clear time should be adjusted. In Highway Capacity Manual (HCM 2010) [14], in the section of calculation of pedestrian effective walk time, the manual suggested that "the additional time can vary from 0.0 s to an amount equal to the pedestrian clear interval". The manual pointed that this additional time can be from many factors, but weather condition has not been considered. Hence, the additional crossing and clear time considered in this study can be applied in such manual. (2) Elder pedestrians' walking speed is slowest among other age groups. Communities with intense elderly people dwelling should adjust the pedestrian signal timing and clear time. (3) Even though in the sand and dust weather pedestrian walk faster than clear days, the vision of pedestrians and drivers become blurred, to ensure pedestrians' crossing safety at signalized intersection in such weather condition, the related study should be further conducted in the future. The design of pedestrian signal timing is a matter of both pedestrian's physical qualifications and the exterior circumstances. This investigation on pedestrians walking speeds at signalized intersection not only provide reference to traffic engineers design pedestrian crossing signal timing comprehensively.

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