Pedestrian Crossing Environments in an Emerging Chinese City: Vehicle Encountering, Seamless Walking, and Sensory Perception Perspectives

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Abstract: While pedestrian crossings play a vital role in providing seamless mobility for pedestrians, they have also continually been spaces of negotiation, contestation, and conflicts between and among different users. Several evidences have shown that such conflict has always been costly, risky, and even fatal to pedestrians. This research aims to assess the pedestrian crossing from an operational perspective in one emerging Chinese city, Suzhou. To evaluate, this research has developed three indices associated with vehicle encountering (VE index), crossing time (CT index) and H-index which refers to audio-sensory perception or a count on the number of horns. This research used video and audio recordings on sample pedestrian crossings. Pedestrians encountered 1.16 vehicles on average when crossing at the sample roads. The average CT index was 1.19 signifying that pedestrians waited for 19% more than their seamless walking when there was no pedestrian crossing. The H index was 5.8 on average at peak time, meaning that there were 5.8 horns (Hs) from vehicles every one minute or approximately one H per every 10 s at a pedestrian crossing. The analysis of these three indices was strengthened by multilevel regression and multi-variable regression analyses. The paper concludes with insights on how the level of safety of inferior walking environments associated with ambiguous traffic rules, vehicle-prioritised traffic behaviours and passive roles of traffic police officers can be improved.

Keywords: walkability; pedestrian crossing; safety; sensory perception; crossing time; Suzhou

1. Introduction

While walking is an almost universal activity that is most affordable, inclusive and easy to do, it has also continued to be one of the most dangerous activities participated in by everyone on a regular basis. Pedestrians accounted for 22 percent of the 1.25 million road traffic deaths in 2013 [1]. Road traffic injury (RTI)-related pedestrian deaths, however, varied depending on a country’s development level. Forty-five percent of RTI-related pedestrian deaths occurred in low-income countries and 29 percent in middle-income countries, while only 17 percent of pedestrian deaths were found in high-income countries [2].

One of the most common type of crashes resulting in pedestrian deaths generally involves pedestrians who are crossing the road. Pedestrian crossings are not only crucial to ensuring seamless mobility but they are also locations that can support safer pedestrian networks. However, because pedestrian crossings are shared spaces among vehicles, pedestrians, cyclists, and other users, they can also be spaces of conflicts where safety, ease and security of pedestrians are compromised. Moreover, while conflicts between pedestrians and vehicles have generally been
costly, risky, and fatal, these occurrences have often been blamed on the more vulnerable road user, the pedestrian. For instance, a study has found that approximately 40 percent of pedestrian-vehicle conflicts happening at intersections had been blamed on pedestrians [3]. This assertion is further supported by the fact that a high proportion of pedestrians participate in illegal crossing behaviours. Illegal crossing has been reported as the main cause of pedestrian crashes [3–5], hence the need to examine the operational condition of pedestrian crossings becomes imperative.

This research aims to assess the operational condition of pedestrian crossings by using three key measurements: Vehicle Encountering (VE), Crossing Time (CT) and Horn (H) indices by video/audio recordings, to appraise the pedestrian crossings, so as to better understand the extent to which such factors are inter-related. These three indices help measure the quality of pedestrian crossings that the pedestrians perceive, but little attention has been paid in the literature. Despite many efforts to promote pedestrianisation (to separate pedestrians from traffic), crossing roads is still an inevitable activity within cities. This can be more challenging in developing countries because of the lack of clear traffic rules, weak enforcement of traffic rules, poor technical and infrastructural supports for traffic flows, and vehicle congestion [6].

This research pays attention to an emerging Chinese city, Suzhou, as this paper’s case study, not because this city is unique, but because it shows a typical vehicle-oriented traffic condition at road crossings, a common condition found in other cities in many developing countries. Suzhou has created liveable built environments by virtue of collaborative planning efforts with the government of Singapore, yet its roads prioritise vehicles, hence the case study of this research [7–10]. Suzhou has grown rapidly in recent years, both in terms of population size and also road traffic volumes. Suzhou population was pegged at 5.3 million in 1982 on a land area of 8488 km$^2$. The population almost doubled in 2010 (Suzhou Statistical Yearly Book, 2010). Along with population growth, the number of motorised vehicles also increased from 1.13 million in 2003 to 2.39 million in 2012 (Suzhou Statistic Bureau) and car ownership rose from 4.8% (the ratio of the number of cars to the registered population) in 2003 to 32% in 2013 (Suzhou Statistical Bureau, 2013). With increased motorisation, road transport fatalities have become a major problem. The Suzhou Public Security Bureau reported 608 deaths in 2012 and 522 in 2013 due to traffic accidents. Suzhou therefore presents an appropriate setting to examine the aim of this study.

2. Walkability and the Evaluation of Pedestrian Crossings: A review

Walkability is broadly defined as “the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network” ([11]: p.247–248). However, there is no common understanding nor a definition of walkability, hence contentious [12]. The presence of vehicles on the roads is a major contributor to street hazard, degrading the walkability of the streets. In fact, a US national level survey reported that 62 percent of survey respondents identified “danger from motorists” as the leading reason pedestrians feel unsafe when walking [13]. The lack of a safe and secure environment, which can be both perceived or actual, strongly deters walking, significantly influencing a pedestrian’s decision to walk, including when and where to walk [14].

Pedestrian safety is an important goal in designing built environments [15]. Safety means both being safe and feeling safe [16]. Several studies show that pedestrian-oriented street design, such as separated and elevated pavements and pedestrian-only lanes, provides safer environments [17] while a chaotic mix of vehicles and pedestrians creates unsafe walking environments [18]. When accidents happen, however, pedestrians are the most vulnerable among all road users [1]. The provision of pedestrian crossings and the installation of traffic signals at road intersections are ways to mitigate conflict at points where road users must join or cross another stream of traffic, therefore, resulting in safer environments [19,20].
Relative to other parts of the pedestrian network, higher incidence of pedestrian-vehicle conflicts happens at street intersections. This has been the major focus of a number of pedestrian studies. For example, studies dealing with pedestrian safety, in both signalised and un-signalised intersections, have been carried out by Muraleetharan et al. [21], King et al. [3] and Guo et al. [22]; pedestrian risk-taking behaviour [4,23,24], such as drunk pedestrians [25], distracted walking [26], illegal pedestrian crossing behaviour [3,26], across different age groups, such as child pedestrians [27] and college students [26]; modelling pedestrian behaviour [28]; and pedestrian safety factors [5]. However, traffic signals are effective only when traffic rules are enforced as intended. Dysfunctional pedestrian crossings cannot guarantee its effectiveness, which will be shown in this research.

Despite well-designed physical elements, the quality of operation becomes inevitably important. Many developing countries underwent motorisation alongside urbanisation and industrialisation, a trend which was experienced by several western countries from the late 19th century to the mid-20th century [29,30]. Although majority of less-developed cities have poorer physical facilities [31,32], some emerging cities have already constructed better quality road networks for both vehicles and pedestrians. However, despite the newly established ‘hardware’ infrastructure, ‘software’ or operational quality has not kept pace, as analysed in this research. This operational concern in developing contexts is most evident in pedestrian crossings.

Path continuity is an important attribute in improving walkability. Crossing a road in a seamless manner is a crucial element that contributes to path continuity. However, certain operational-level design such as the long waiting time (red traffic signal phase) encourages risk-taking and illegal behaviour among pedestrians at crossings [4]. A survey conducted along Brisbane’s street intersections confirmed that a high percentage of pedestrians exhibited illegal behaviour, such as ‘crossing against the lights’ and ‘close to the lights’ [3]. While pedestrians seem to be unaware of the increased risk associated with non-compliance, King et al. (2009) found that it, in fact, increased their risk eight times. Illegal pedestrian behaviour has been shown to be the main cause of pedestrian crashes, but still non-compliance rate has continued to increase [3,5]. Harrel’s study [33] also concluded that pedestrians’ level of cautiousness is significantly influenced by the volume of traffic, which he attributed to the diffusion of responsibility. When crossing, pedestrians tend to be less cautious in large groups than alone in the assumption that either someone in the group will check oncoming vehicles or they feel more ‘secure’ because of the visibility offered by the large group size. Muraleetharan et al. [21] identified the following factors: space at corner, crossing facilities, turning vehicles, delay at signals, and pedestrian-bicycle interaction as primary factors affecting pedestrian level of service at intersections.

There are at least three important aspects to this research. First, designated pedestrian crossings (or a crosswalk), designed to provide safe crossing for all, continue to be subject to high risk traffic accidents. They are locations where vehicles and pedestrians intersect, hence while they affect all traffic, the impact is more critical on children and the disabled. Second, crossing roads can distort walking behaviour. Pedestrians can react to this barrier by seeking out geographic and/or temporal shortcuts, as they want to minimise their walking distance and, therefore, walking time. Third, pedestrian crossings affect vehicle flows as well as pedestrian movements, often via the use of traffic rules and traffic signals. Inefficient traffic controls cause congestion and long queues of cars which, in turn, can be an unpleasant experience for both drivers and pedestrians.

High standard designs, therefore, have been developed [34]. Traffic lights have been a focus in transport engineering in an attempt to make efficient traffic flows and prevent traffic rule violators [35]. Traffic management through speed limits, restrictions on turning movements, traffic lights, and other measures has been a typical approach in transport engineering [36]. However, there are a range of non-physical, operational dimensions that shape the role that pedestrian crossings play in city’s walkability. This research explores three of these dimensions: speed, safety, and audio-sensory perception using quantitative measurements. One Chinese city, Suzhou, is used as a case study for these measurements. Now, the focus of this discussion turns to the local context.
3. Contextual Background: Suzhou

Despite unprecedented motorisation in Chinese cities, traffic rules have not been clearly established. While the reform of the Road Traffic Safety Act imposed higher fines and a point system for penalties, road priorities were still given to vehicles. For instance, vehicle drivers are prioritised at road intersections wherein they can turn right at any time. This acts as a barrier in creating safer walking environments for pedestrians. Traffic signals give green lights to both pedestrians and vehicles turning left concurrently, which results in high chances for pedestrians to encounter vehicles at pedestrian crossings. The ambiguity of traffic control leads to unsafe, uncomfortable walking environments. Without prioritising pedestrians, collisions will more likely occur, causing increased levels of hazard at crossings.

In Suzhou there has been massive development around two national-level industrial parks, namely the Suzhou Industrial Park (SIP) and the Suzhou New District (SND) [37–39]. In particular, the SIP plays a crucial role in urban transformation in the Suzhou region [10]. It was an outcome of the collaboration between the Singaporean government and the Chinese government. So, the SIP has been planned and developed to provide high quality of life [7]. In this sense, pedestrians' road crossing is expected to perform better than other developing areas in China due to well-designed street networks primarily transplanted from the Singaporean experience [40]. In Suzhou, in particular, the SIP, appears to have well-constructed physical street design. Along the main road, there are footpaths and separated bicycle lanes on both sides. Along the streets, plants provide comfortable environments. However, Suzhou has shown problematic traffic management at an operational level that is manifested in this research.

4. Three Indices

This research has developed three indices to evaluate pedestrian crossings from a safe system and operational perspective, with a focus on the evaluation of non-physical elements. These are the VE index, CT index and H index.

Ensuring safety at a pedestrian crossing is an important way to eliminate fatal and serious injuries. Most traffic management guides measure road intersection safe system performance based on likelihood/exposure (e.g., minimizing conflict points through the separation of road users) and severity (e.g., encouraging lower speed and enforcement of traffic rules that prioritise pedestrians over vehicles). The safety index can be measured by the chance of traffic accidents at the pedestrian crossing [36]. As the data regarding the number of traffic accidents in each pedestrian crossing is limited, this research has employed the number of vehicles that each pedestrian encounter while crossing the road, which represents the likelihood of conflict, is labelled as the Vehicle Encountering (VE) index. The VE index was measured by counting the number of vehicles that pedestrians come across as they cross the zebra crossing. Vehicles behind the pedestrian were excluded. Higher numbers of vehicles may signify the higher likelihood of conflict and/or exposure to traffic accidents and, therefore, result in inferior walking environments.

Second, pauses at pedestrian crossings are often inevitable. A perfect situation here would involve crossing roads without any interruption by walking at the same pace as walking along a sidewalk. A more realistic situation involves waiting for a safe crossing opportunity in the traffic. No matter how efficient traffic lights are functioning, pedestrians are generally expected to spend longer time waiting when crossing at intersection, unless they rush or run. A Crossing Time (CT) index measures actual crossing time relative to the time that would be taken without any waiting and interruption at an average walking speed (the seamless crossing time) as Equation (1). The seamless crossing time is proportional to the width of the road.

\[
\text{CT Index} = \frac{(\text{Pedestrians’ effective crossing time})}{(\text{Seamless crossing time})}
\] (1)
When the CT index is equal to one, the speed at the crossing is the same to normal sidewalks. If the CT index is higher than one, for instance 1.2, pedestrians spend 20% more time relative to seamless walking time. When crossing is delayed, the CT index becomes high.

Third, sensory perception is an important non-physical element to walkability. This research employed a noise level at pedestrian crossings by counting the number of car horns as a source of unpleasant noise for pedestrians. When both drivers and pedestrians attempt to pass the crossing concurrently, the drivers may stop for crossing pedestrians, or sound the car horn to secure their way. This can also occur when pedestrians continue crossing even when the traffic signal gives the green light for vehicles. In both cases the use of horns may indicate an inferior crossing environment. So, this research created the Horn (H) index that counts the number of horns per unit time at pedestrian crossings.

5. Data Collection

The three indices were measured at six pedestrian crossing locations in Suzhou, China, in June 2014. Five pedestrian crossing locations were in the SIP and one was in the SND. Both areas have been newly developed since the 1990s, and so have relatively high quality physical walking environments. These sample of pedestrian crossings were located in typical urban areas servicing different land use types, including residential areas, a university town, office areas, and a school zone (Appendix A). It was important that roads with different widths and different shapes of intersections were chosen for this research to discover differences between them. Two pedestrian crossing were located within un-signalised intersections, meaning there were no traffic signals present at these road intersections (Type A and Type F in Appendix A), while the rest were located in signalised intersections. Detailed descriptions for each study location are presented in Appendix A.

All six pedestrian crossings were zebra crossings. Zebra crossing refers to a crossing with parallel line markings within a rectangular area near the intersection, for the use of crossing pedestrians from one side of the road to the other.

Data was collected by observing and counting the number of crossing pedestrians at the six pedestrian crossing locations. The study was limited to counting pedestrians who crossed within the marked zebra crossing. Those crossing outside of the zebra crossing (jaywalking) were excluded in the total count. Measuring was completed including one-whole day observation from 6:00 a.m. to 9:00 p.m. in one pedestrian crossing (Renai Road or Type A), and peak time observation in all six pedestrian crossings. Identified peak time was from 4:30 p.m. to 8:30 p.m. The VE index, the CT index and the H index were generated at each pedestrian crossing. In total, there were 7400 pedestrians and 43,000 vehicles recorded in videos in peak time. Peak time observation is significant because there were high pedestrian and vehicle volumes that affect the quality of road crossings. At times pedestrians crossed in a tight group; in this case, the number of pedestrians in that group was counted, to be included in the analysis. Watching the recorded videos, 2–3 observers counted the number of pedestrians and the number of vehicles at one pedestrian crossing. For the VE index, the observers qualitatively judged the number of vehicles that the pedestrians have encountered. The vehicles passing behind the pedestrians were not counted. Crossing a road was timed by the observers from the moment when a pedestrian appeared on the verge of the pedestrian crossing to the moment when he/she reached the opposite end of the pedestrian crossing. This research used the average walking speed of 1.5 m/s, drawn from the Highway Capacity Manual [41]. For the H index, another observer counted the number of Hs blown within every 10-min period. The H data were compiled with the VE index and the CT index.

Samples (2188) were used for the VE index and the CT index in peak time. Besides, information about gender, children, and pedestrians with special needs (identified by sticks, a wheel chair, a pram and other supplementary tools) were included. The measurements were captured in video and audio recordings. These recordings were effective in measuring these three indices precisely.

As identified in a wide range of literature, and in this research, the analysis on the VE index and the CT index drew upon different age groups, with a special focus on children and aged pedestrians,
people with special needs [42], gender [43], the presence of traffic signals [35,44], traffic conditions such as traffic volumes and widths [45,46], and a group effect [43]. These factors have been used as explanatory variables in analysing the two indices. However, some critical factors for safety such as the speed of vehicles [42] were not included due to unavailability from the methods employed in this research. Multilevel regression analysis was used because pedestrian crossings have two hierarchical factors. The first level is about individual characteristics such as pedestrians’ profile, whether they are crossing while light is green or red, and traffic volumes that pedestrians face when crossing the road. The second level is about facility circumstances at the pedestrian crossings such as the widths and the presence of traffic signals. To reflect this hierarchical structure, this research has employed a multilevel regression model for the VE and CT indices, estimated by restricted maximum likelihood.

6. Results

6.1. Overall Performance

The observed road (Type A: Renai Road) was located in between universities and a retail centre. Renai Road had a simple street form, with four car lanes and two bicycle lanes in total. There was no traffic signal installed along the road. Figure 1 shows the pedestrian volume observed over one day. As expected, there was a single peak in the morning between 8 and 9 a.m.; a very sharp rise during midday; a slight peak around 2:30 p.m.; and there were two peaks for pedestrian volume observed around 5:30 p.m. and then around 7:30 p.m. Peak time was in the morning, during lunch time, and in the evening. The highest number of pedestrians counted within a relatively short period of time was during lunch time.

![Figure 1. The number of pedestrians in one day at Place A: Renai Road.](image)

The peak time observation at all sample pedestrian crossings showed that pedestrians encountered 1.16 vehicles when crossing at the sample roads. This VE index critically showed safety and comfort issues. Although the pedestrian crossing was designed to give priority to pedestrians, they had to wait for crossing or dodge vehicles. The CT index was 1.19 on average, meaning that pedestrians spent 19% longer walking time when there was a pedestrian crossing, compared to an average seamless walking. The H index was 5.8. At the sample pedestrian crossings, there were 5.8 Hs per minute or approximately one H every 10 s on average in peak time. Each index will be analysed in detail.

6.2. VE Index

Encountering vehicles while crossing was the most critical problem in terms of comfort and safety, in particular the feeling of safety. The result shows poor performance at the sample pedestrian crossings, to the extent that pedestrians encountered a maximum of 26 vehicles. The multilevel
regression analysis was carried out to explain the factors that affect the VE index. This analysis included all the six pedestrian crossings with two levels.

Level-1 Model:

\[ \text{VE}_{ij} = \beta_{0j} + \beta_{1j} \times \text{Traffic Volume}_{ij} + \beta_{2j} \times (\text{Children}_{ij}) + \beta_{3j} \times (\text{Special Needs}_{ij}) + \beta_{4j} \times (\text{Group Size}_{ij}) + \beta_{5j} \times (\text{Female}_{ij}) + \beta_{6j} \times (\text{Red Light}_{ij}) + \epsilon_{ij} \]

Level-2 Model:

\[ \beta_{0j} = \gamma_{00} + \gamma_{01} \times (\text{Presence of Traffic Signal}_j) + \gamma_{02} \times (\text{Width}_j) + u_{0j} \]

Descriptive statistics of the variables are in Appendix B. The result from the multilevel regression analysis showed that traffic volumes, measured by the number of vehicles for each time unit (10 min), and jaywalking increased the chances to encounter vehicles (Table 1). As high numbers of vehicles contributed to traffic congestion, vehicles tended to be intolerable at pedestrian crossings. From the perspective of the pedestrian, crossing at a red light aggravated their safety. When a pedestrian was crossing at a red light, the person encountered 0.374 vehicles more than other lights as can be seen in the coefficient of the dummy variable (\( \beta_6 \)). Crossing in a group was expected to provide safer environments for pedestrians. However, the result was statistically insignificant (Group size, \( \beta_4 \)). This might be attributable to possible time delays when crossing with other group members that could cause the intermixed traffic environment with vehicles. Given a crowded condition in a high traffic volume intersection, increasing pedestrian volumes may create even more crowded crossing environments when the drivers are aggressive and intolerable. From this result, a positive group effect on pedestrians’ crossing was not observed. One more interesting result was that single female pedestrians tended to encounter a higher number of vehicles than males and pedestrians in a group. Although the reason was uncertain from the data, this result might be related to their walking habits, walking speed, or drivers’ intolerable reaction to females [47]. At Level 2, the result showed that the presence of traffic lights at the pedestrian crossing was effective to protect pedestrians (\( \gamma_{01} \)).

As the regression analysis only included pedestrians in peak-time periods, Figure 2 shows differences in each time zone a day. Afternoon and evening was more vulnerable to vehicle encountering. Although there were other peak-time zones such as morning- and lunch-time, vulnerability was manifest in the afternoon and the evening (Figure 2).
were the same to the previous analysis except for the inclusion of this VE index. Thus, these variables were included in the regression analysis (VE, \( \beta_7 \)) at Level 1. The variables used in the multilevel regression model for the CT index were the same to the previous analysis except for the inclusion of this VE index.

Level-1 Model:

\[
CT_{ij} = \beta_{0ij} + \beta_{1j} \times (\text{Traffic Volume}_{ij}) + \beta_{2j} \times (\text{Children}_{ij}) + \beta_{3j} \times (\text{Special Needs}_{ij}) + \beta_{4j} \times (\text{Group Size}_{ij}) + \beta_{5j} \times (\text{Female}_{ij}) + \beta_{6j} \times (\text{Red Light}_{ij}) + \beta_{7j} \times (\text{VE}_{ij}) + r_{ij}
\]

Level-2 Model:

\[
\beta_{0ij} = \gamma_{00} + \gamma_{01} \times (\text{Presence of Traffic Signal}_{j}) + \gamma_{02} \times (\text{Width}_{j}) + u_{0j}
\]

The result showed that the crossing level factors (Level-2) had less relevance to the CT index than individual level factors (Level-1) (Table 2). Descriptive statistics of the variables are in Appendix B. The overall vehicle volumes were statistically insignificant for crossing time. Also, there was no statistically significant difference between children and adults in terms of crossing time. However, pedestrians with special needs spent longer time to cross the intersection. The coefficient showed that these people spent more than three times longer for crossing than normal pedestrians. The pedestrians violating the traffic signal could save crossing time significantly (\( \beta_6 \)). The traffic signal effect will be further analysed in the next section. It was observed that females spent more time to cross, but the coefficient was not statistically significant. It was found that interruption, measured by the chances of vehicle encountering (VE, \( \beta_7 \)), was a strong deterrent to crossing time. When pedestrians encountered more vehicles, they spent significantly longer time in crossing the road. In many cases, pedestrians paused in the middle of the road to wait until all vehicles have passed them. As seen in the Group size variable (Group size, \( \beta_4 \)), pedestrians spent longer time when they were in a group.
Table 2. The result of multi-level regression analysis for CT index, fixed effects.

| Fixed Effect                  | Coefficient | Standard Error | t-Ratio | p-Value |
|------------------------------|-------------|----------------|---------|---------|
| Intercept, $\gamma_{00}$     | 29.730      | 29.846         | 0.996   | 0.393   |
| Presence of Traffic Signal *, $\gamma_{01}$ | 6.904      | 17.539         | 0.394   | 0.720   |
| Width, $\gamma_{02}$         | -0.321      | 17.539         | 0.394   | 0.720   |
| Traffic volume, $\beta_1$    | -0.003      | 0.004          | -0.870  | 0.385   |
| Children *, $\beta_2$        | 1.171       | 0.910          | 1.288   | 0.198   |
| Pedestrians with special needs *, $\beta_3$ | 3.030      | 1.173          | 2.584   | 0.010   |
| Group size, $\beta_4$        | 0.585       | 0.143          | 4.093   | <0.001  |
| Female *, $\beta_5$          | 0.129       | 0.370          | 0.349   | 0.727   |
| In red light *, $\beta_6$    | -2.569      | 0.569          | -4.513  | <0.001  |
| VE, $\beta_7$                | 2.224       | 0.078          | 28.579  | <0.001  |

* Dummy variables. Children are one, otherwise zero. Pedestrians with special needs are one, otherwise zero. Presence of traffic signal is one, otherwise zero. Females are one, otherwise zero. Pedestrians in red light are one, otherwise zero. Note: The dependent variable is the CT index; and the total sample size is 2188 for this analysis.

Traffic volume, Group size and VE are centred around the group mean.

6.4. H Index

The frequent honking behaviour of vehicle drivers which is associated with traffic congestion is a major source of noise pollution in cities [48]. Noise from horns is the sonic expression of the presence of traffic congestion. To better understand the H index, a multi regression model was specified with the sample pedestrian crossings. The H index analysis here employed the ordinary least square method for estimation. The dependent variable was the number of Hs per unit time, 10 min ($10 \times H$ index), while independent variables were the traffic volume, i.e., the number of vehicles per unit time, and the pedestrian volume, i.e., the number of pedestrians crossing the road per unit time. Although this multi regression model included only three variables including one dummy variable, the R-squared value reached at 58.8%. The result showed that an increase in traffic volumes by one vehicle led to 0.1 more Hs (Table 3). In a similar way, an increase in the number of pedestrians led to increases in the number of Hs by 0.14. The operation of traffic signals helped reducing a noisy level as can be seen in the difference, 12.8 Hs. The observed number of Hs suggested vehicle-dominant behaviour in the city.

Table 3. The result of regression analysis for H index.

| Model                  | Coefficients | SE    | Standardised Coefficients | T     | Significance |
|------------------------|--------------|-------|--------------------------|-------|--------------|
| (Constant)             | 33.981       | 5.660 | 6.004                    | 0.000 |              |
| Num. of vehicles       | 0.099        | 0.011 | 0.588                    | 8.789 | 0.000        |
| Num. of pedestrians     | 0.136        | 0.041 | 0.172                    | 3.327 | 0.001        |
| Presence of Traffic Signal *, $\beta_7$ | -12.753     | 3.994 | -0.216                   | -3.193 | 0.002       |

* Dummy variable. If there is a traffic signal, this dummy variable is one; otherwise, zero. Note R-square: 58.8%; The dependent variable is the $10 \times$ (the H index); and the total sample size was 168 for this analysis.

6.5. Traffic Signal Effects

As discussed, traffic signals affect crossing behaviour of both drivers and pedestrians. Traffic signals are designed to provide clear flows of traffic, to prevent traffic accidents and, accordingly, to protect pedestrians. However, only 54.5% of pedestrians crossed the road when light was completely green. The statistics seemed to be high compared to other developing countries, but this figure did not include jaywalking outside the pedestrian crossing. About 12.6% of pedestrians crossed the road at the partial-green/partial-red light. Their crossing could be partially green by chance; could be attributable to too short green light duration; or could be attributed to their impatient behaviour. Approximately 33% of crossing pedestrians crossed while traffic light was completely red. These pedestrians neglected the traffic signal, demonstrating impatient crossing behaviour.
The results of the analysis showed the advantages and disadvantages in the operation of the traffic lights in Suzhou. As can be seen in Table 4, the crossing the roads at green lights decreased the chances of facing vehicles. When pedestrians crossed the roads at a red light, they encountered higher numbers of vehicles, 0.83. Partial green lights were in the middle in terms of the VE index. Crossing the road when light was red could save crossing pedestrians a significant amount of time, as seen in the CT index. The CT index of pedestrians at the red light was 1.03, which was acceptable, as their extra walking time was a merely 3% longer than seamless walking. The CT index of pedestrians at the green light was 1.11. When pedestrians were patient enough to wait for the green light, they needed to spend 8% longer time duration when crossing. The result represents that green lights offered safer crossing environments for patient pedestrians who waited. In return of waiting for the green light, the pedestrians could reduce the chances of encountering vehicles. However, although green lights for pedestrians should guarantee absolutely safe walking environments as a clear rule, the VE index in a green light at 0.37, showed poor performance in the sample pedestrian crossings. Although pedestrians patiently waited for the green light, some vehicles passed ahead of them. The dysfunctional traffic signals could be attributed to multiple factors. First, despite rapid motorisation and increase in car ownership, pedestrian-friendly driving practices is not fully enforced. Vehicle drivers continue to be prioritised. Second, there is an ambiguous traffic signal in China. There is a coincidence of green lights for pedestrians and vehicles. While pedestrians cross the road at the green light, the traffic signal is also green (left-turn signal) for vehicles attempting turn-left at an intersection. Both the pedestrians and the vehicles are legally allowed to have priority to cross or turn left, which generates higher chances that pedestrians encounter vehicles in the middle of the pedestrian crossing. Vehicle drivers may think they will lose the opportunity to turn left and therefore will wait longer, if they give way to pedestrians. In their perception, pedestrians might be able to cross the roads anyway. Crossing the roads may be more difficult for certain groups of pedestrians such as visitors, foreign nationals, and children. Third, vehicles attempting right-turn tend to neglect pedestrians at the crossing. The Road Traffic Act in China does allow drivers to turn right any time. Due to the priority given to drivers, the green light is unable to provide completely safe walking environments. Fourth, two wheel-driven vehicles including auto-bikes, e-bikes, and bicycles were likely to neglect traffic signals. These vehicles seemed to be less threatening than cars, but they contribute to uncomfortable, unsafe crossing environments for pedestrians. Finally, there was instance of dysfunctional traffic signal as can be seen in Place D. The green light for pedestrians was too short to complete their crossing (22 s for green light), relative to the width of the road (19.5 m). As a result, almost 90% of pedestrians were crossing while light was in partial green. In fact, if pedestrians walked at a normal speed, they would likely be walking while the light was red.

Table 4. Traffic light effects.

|                | VE Index | CT Index |
|----------------|----------|----------|
| Green light    | 0.37     | 1.11     |
| Partial green light | 0.62     | 1.23     |
| Red light      | 0.83     | 1.03     |

7. Conclusions

In a more liveable city scenario, we expect individuals to be satisfied, at ease and contented in manoeuvring their urban environments. Yet the current approach to street intersection design which prioritises vehicles over other road users, including pedestrians, assumes that we design for efficient mobility. This places a strong disincentive to more walking. This research examines the pedestrian crossing as the case in point with the assumption that such urban space takes on a vital role in ensuring seamless movement as well as providing a safer environment for all. This research proposed three indices to measure the performance of pedestrian crossing environments with respect
to non-physical elements and operational factors, namely: Vehicle Encountering (VE), Crossing Time (CT) and Horn (H) indices. Results show that the VE index was 1.16 on average and the average CT index was 1.19. The H index was 5.8 on average at peak time signifying that there were 5.8 Hs from vehicles every one minute or approximately one H per every 10 s at a pedestrian crossing in Suzhou.

Under pedestrian-friendly environments, these measurements may not be necessary. However, the reality is that in many developing countries, including China, there is a lack of understanding on what is appropriate behaviour at pedestrian crossings. Even pedestrians in a tight group reported higher VE index than individual pedestrians. The proposed measurements also reveal operational limitations. This research confirms that walkability can be improved not only by improving the physical factors, but also by ensuring that operational efforts are addressed and maintained.

There is therefore a need to shift our understanding on how we design our cities, particularly for whom we are designing it for. There is an urgent call for a policy framework that would help in better understanding the ‘pedestrian’ not just as an entity of mobility but an entity who must be healthy, happy, and contented, therefore, a satisfied member of society [49].

The next step for this research is to examine ways on how to better manage and create pedestrian-friendly crossing environments. At present, pedestrian-oriented transport rules and regulations are not the norm in China. For instance, police officers do not offer to help pedestrians when crossing the road. This paper suggests three recommended actions as a way forward. First, from an institutional perspective, the government, in particular the police department, may need to take action in firmly establishing transport rules to ensure pedestrian safety and engaging police officers to take on a more proactive role in enforcing these rules to ensure more secure and safer environments. Second, drivers need to be aware that they become pedestrians after they get off from their vehicles. This awareness, particularly of the importance of adhering to the green transport hierarchy, where the most vulnerable should be the top priority in designing streets, contributes to stronger ‘social capital’ [50]. The society-wide benefits of pedestrian-prioritised behaviour needs to be shared among active ‘street fighters’ [51]. Third, in the short term, complete protection should be provided to pedestrians when crossing the street. The simple, reasonable rule agreed by both drivers and pedestrians will significantly reap major benefits. This is critical, particularly for children who are less aware of unexpected street hazards.

There are limitations in this research. This research focused on a sample city. Comparisons with multiple cities within the same country and international comparisons will enrich understanding of different stages of traffic conditions for pedestrians. Also, the threshold to what extent these proposed indices are acceptable has not been analysed, and would therefore require further rigorous research.

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## Appendix A  Summary of the Sample Pedestrian Crossings and the Location Map

| Place A: Renai | Place B: Linquan | Place C: Time Square |
|---------------|-----------------|---------------------|
| Shape         |                 |                     |
| Image         |                 |                     |
| Width (m)     | 19.5            | 22.5                | 36       |
| VE index      | 2.47            | 0.46                | 0.61     |
| CT index      | 1.25            | 1.05                | 1.14     |
| H index       | 7.1             | 3.9                 | 4.2      |
| Max. H index  | 11.3            | 6.3                 | 9.6      |
| Pedestrian volumes (per min) | 5.9 | 9.5 | 4.5 |
| Vehicle volumes (per min) | 19.3 | 10.2 | 14.5 |
| Green light (%) | 67.1% | 41.4% | 41.4% |
| Half Green light (%) | No traffic signal | 19.8% | 47.3% |
| Red (%)       | 13.1%           | 13.1%               | 11.3%    |
| N (sample pedestrians) | 405 | 879 | 522 |
| Note          | Between universities and retail shops | Surrounded by residential buildings | An urban sub-centre surrounded by office buildings and retail shops |
### Table 1: Critical Infrastructure Performance Data

| Place | Shape | Image | Width (m) | VE index | CT index | H index | Max. H index | Pedestrian volumes (per min) | Vehicle volumes (per min) | Green light (%) | Half Green light (%) | Red (%) | N (sample pedestrians) | Note |
|-------|-------|-------|-----------|----------|----------|---------|--------------|-----------------------------|------------------------|------------------|---------------------|---------|----------------------|------|
| D     | ![Shape](image1.png) | ![Image](image1.png) | 19.5      | 0.86     | 1.88     | 4.9     | 7.5          | 0.6                         | 30.1                   | 2.5%             | 88.9%               | 8.6%    | 81                   | Interchange with irregular shape surrounded by residential buildings |
| E     | ![Shape](image2.png) | ![Image](image2.png) | 19.5      | 0.32     | 1.22     | 4.1     | 7.8          | 1.1                         | 9.9                    | 55.1%            | 29.6%               | 6.6%    | 176                  | A residential area near a primary school |
| F     | ![Shape](image3.png) | ![Image](image3.png) | 19.5      | 0.0       | 1.5      | 5.6     | 12.2         | 3.9                         | 40.2                   | No traffic signal | No traffic signal | 4.3%    | 125                  | An arterial road surrounded by office and residential buildings |
|      |       |       | 19.5      | 0        | 1.5      | 5.6     | 12.2         | 3.9                         | 40.2                   | 5.8%             | 32.9%              | 12.6%   | 2241                 |

**Note:**
- Shapes: Place D: Dadiyuezhang, Place E: Primary school, Place F: Shishan road (SND)
- Image Description: Place D: Dadiyuezhang, Place E: Primary school, Place F: Shishan road (SND)
- Width (m): 19.5, 19.5, 19.5, 19.5
- VE index: 0.86, 0.32, 5.60, 1.16
- CT index: 1.88, 1.22, 4.1, 1.71
- H index: 4.9, 7.8, 6.6, 5.8
- Max. H index: 7.5, 7.8, 12.2, 12.2
- Pedestrian volumes (per min): 0.6, 1.1, 2.5%, 88.9%
- Vehicle volumes (per min): 30.1, 1.1, 3.9, 40.2
- Green light (%): 55.1%, 2.5%, No traffic signal, 54.5%
- Half Green light (%): 29.6%, 88.9%
- Red (%): 15.3%, 6.6%
Appendix B  Descriptive Statistics of Level 1 Variables

|                  | N     | Minimum | Maximum | Mean   | S.D.    |
|------------------|-------|---------|---------|--------|---------|
| VE               | 2188  | 0       | 26      | 1.16   | 2.500   |
| CI               | 2188  | 0.2000  | 5.1724  | 1.1924 | 0.5150749 |
| Traffic Volume   | 2188  | 35      | 570     | 158.24 | 91.224  |
| Children         | 2188  | 0       | 1       | 0.03   | 0.172   |
| Pedestrians with special needs | 2188 | 0 | 1 | 0.02 | 0.140 |
| In red light     | 2188  | 0       | 1       | 0.10   | 0.293   |
| Female           | 2188  | 0       | 1       | 0.21   | 0.407   |
| Group size       | 2188  | 1       | 28      | 1.79   | 1.220   |

* Dummy variables. Children are one, otherwise zero. Pedestrians with special needs are one, otherwise zero. Presence of traffic signal is one, otherwise zero. Females are one, otherwise zero. Pedestrians in red light are one, otherwise zero.

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