BICYCLE SPEED ANALYSIS FOR ASSESSMENT OF BICYCLIST PRE-COLLISION SYSTEM

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ABSTRACT

Research Question/Objective: Many bicyclists were killed or injured when they were riding on the street because of the traffic crashes. To avoid or mitigate accidents, Pre-Collision System (PCS) is introduced to give drivers warning or make the car brake automatically. Analysis of the bicycle speed for assessment of bicyclist Pre-Collision System is critical in developing realistic test scenarios, which can also help design PCS evaluation system and improve PCS itself. In this study, bicycle speeds were analyzed in two scenarios including "along the road" and "across the road". Furthermore, one special case we called "ride out" in crossing the road was analyzed separately because of the inconstant speed during the whole crossing period. All analysis results provide reference for developing bicyclist Pre-Collision System evaluation and are used by real testing scenarios in Transportation Active Safety Institute(TASI) lab at IUPUI.

Methods and Data Sources: Bicyclist information was taken from TASI 110-car naturalistic driving video database which was collected in the metropolitan area of Indianapolis. We obtained GPS locations and corresponding time stamps of the bicyclists through an image-processing-based semi-automatic process for a subset of the overall database. For traveling along the road cases, bicyclist speed was calculated based on the changes in GPS locations and the corresponding traveling time. For crossing cases, three to five velocity values were achieved during the whole period. These values are proved to be consistent for "ride-through" crossing scenario. To best fit speed situation for "ride-out" scenarios, we built a speed model including two consecutive stages, accelerating stage and constant-speed traveling stage. Then the optimized traveling trajectory was achieved using cost function method in MATLAB after a two-way search when dividing the ride-out crossing process in eight different ways.

Results: Per three main scenarios of the bicycle motion, 895 bicyclist cases were obtained randomly from the database. Statistics analysis results suggest 25 percentiles, mean value, and 75 percentiles of bicyclist traveling speeds in different scenarios. Especially for the ride-out scenario, the speed model we build quantitatively explain and predict the bicyclists speed.

Discussion and Limitations: Comparing to other constant speed or mean speed scenarios, our model is more comprehensive considering the speed variation during the whole motion period. We could more accurately estimate bicyclists speed in different scenarios. However, due to the limit amount of cases, we cannot break down more detail scenarios such as the street conditions or weather conditions. In future research, we may enlarge our sample database to improve our model close to realistic situation more deeply.

Conclusion: Studying information from TASI-110 car naturalistic database, we calculated bicyclist speeds in different situations. We specially focused on the "ride out" situation and analyzed the curve trend of its whole process. These data results were used to develop for bicyclist Pre-Collision System evaluation scenarios. These speed data give a great contribution to Pre-Collision System development and may help other researchers for further research.

INTRODUCTION

According to the crash data of National Highway Traffic Safety Administration (NHTSA), 726 pedal-cyclists were killed and an estimated 49,000 were injured in the vehicle traffic accidents in 2012[1]. Bicyclist-PCS is in developing process and will play a significant role in traffic safety. Different from the traditional passive safety method such as seatbelt, airbag and so on, PCS is dedicated to detect accident before it happens. It is also referred as Collision Imminent Breaking system (CIB) or Automatic Emergency Braking system (AEB) [2-6]. It can give drivers warning or brake automatically. There are several similar systems that are already on the market and will increase over the next several years [5]. However, there is no common criteria to evaluate and compare the performances of different PCSs. TASI lab in IUPUI is conducting research on developing evaluation system for both pedestrian- and bicyclist- PCS [4] [7-8].

Analysis of the bicycle speed for assessment of bicyclist Pre-Collision System is critical in developing realistic test scenarios, which can also help design PCS evaluation system and improve PCS itself. This paper introduces several bicycle speed analyses in different scenarios. All analysis results provide reference for developing bicyclist Pre-Collision System evaluation and are used by real testing scenarios in Transportation Active Safety Institute(TASI) lab at IUPUI.

METHODOLOGY

Bicyclist movement information was taken from TASI 110-car naturalistic driving video database which is collected in metropolitan area of Indianapolis from 2011 to 2012 [9-10]. In these 110 cars, every car was installed with facing forward camera which could capture forward scenario and with GPS tracking unit embedded to capture vehicle location and movement data. From the big data set, a total of 1000 bicyclist cases were obtained using bicyclist image recognition technology. Figure 1 shows the flowchart of the entire data processing. The input data, including the video, GPS and G-sensor information, were first categorized based on its location, time, vehicle speed and weather. Based on the categorization, the automatic bicyclist detection was performed on all the raw naturalistic driving video. The detected results are next verified by the human operators to remove false detections. Videos of interest containing bicyclists were then generated from the verified results and further used for bicyclist behavior analysis.
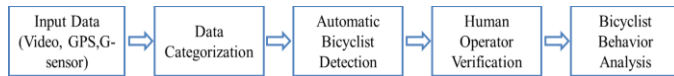

Figure 1. **Data preparation process for bicyclist videos.**

Bicyclist traveling speeds were measured in these videos manually towards different scenarios that are categorized depending on different moving angels of the bicyclists. These scenarios were mainly divided into riding along the road and riding across the road. While the speed changes are small for most driving along the road cases, bicyclists are not always crossing the road with constant speeds. For example, when a bicyclist notices a red light or forecasts an accident will happen, he will slow down to avoid risk before entering the road. When the risk is eliminated, he will start to go across the street. In this situation, bicyclist should be considered as three states which are (1) deceleration or stop, (2) acceleration and (3) uniform motion. Therefore, a best fit curve was drawn to describe the motion process more correctly. We define this situation as "ride out". Correspondingly, the situation of riding across the street without stop or deceleration is defined as "ride through". In this study, the main research focus is to calculate bicyclist speeds in all these different scenarios.

Averaged bicyclist moving speed estimation
Figure 2 shows the GUI (Graphical User Interface) used for calculating the averaged bicyclist speed. In the GUI, all the bicyclist video clips interested will be loaded and listed in the box. Then the video can be played in the player with the corresponding Google Earth map and Google Street View map shown in the GUI too. The maps are clickable with GPS coordinates of the selected locations automatically being recorded in the log file. The markers will be shown at the clicked locations on the map that can be dragged around on the map to the most appropriate locations. The GUI can support 45 seconds of videos in five continuous clips to show the complete encountering process between the vehicle and the bicyclist. The trained video reductionists will then:

Figure 2. **GUI for bicyclist speed calculation.**

1. Pick the appearance frame in the videos;
2. Click the vehicle location on the map for the appearance frame;
3. Click the bicyclist location on the map for the appearance frame;
4. Pick the end frame in the videos;
5. Click the vehicle location on the map for the end frame;
6. Click the bicyclist location on the map for the end frame.

For each case, we obtained two GPS locations and two different video times to calculate traveling distance and traveling duration. For the bicyclist speed calculation, the appearance frame is not necessarily to be the first frame that the bicyclist is seen in the video, and the end frame may not always be the last frame that the bicyclist is seen in the video. The appearance frame and end frame are selected so that it is convenient to find the locations of the bicyclist and the vehicle on the maps.

The appearance frame and the end frame will be used to calculate the time between the two moments, and the GPS coordinates of the two bicyclist locations corresponding to these two time-frames will be used to calculate the bicyclist moving distance based on the "Haversine" formula shown below as Equation (1).

$$d = 2r sin^{-1} \cdot$$
$$\sqrt{sin^2\left(\frac{\varphi_1 + \varphi_2}{2}\right) + cos(\varphi_1)\,cos(\varphi_2)\,sin^2\left(\frac{\omega_1 + \omega_2}{2}\right)} \quad (1)$$

d is the distance between the two red marks in figure 1
r is the radius of the sphere (r = 6371000)
φ_1, φ_2: latitude of mark 1 and latitude of mark 2
ω_1, ω_2: longitude of mark 1 and longitude of mark 2

The averaged bicyclist traveling speed can be calculated as traveling distance divided by traveling time.

Ride-out bicyclist crossing speed calculation
As defined in the previous section, the ride-out bicyclist speed estimation is not accurate when only average speed over a period can be calculated, considering the big speed changes during the three crossing phases. Thus, additional efforts are needed to improve the estimation of ride-out bicyclist speeds. To better estimate the bicyclist ride-out speed, we have defined six points on the road for these cases:
1. Point 1: Bicyclist starts to ride from waiting at the roadside;
2. Point 2: Bicyclist enters the road;
3. Point 3: 25% of the whole crossing distance;
4. Point 4: 50% of the whole crossing distance;
5. Point 5: 75% of the whole crossing distance;
6. Point 6: Bicyclist leaves the road.

Using a similar GUI as described in Figure 2, we have focused on ride-out cases and clicked the map positions of these six points with associated time frame captured. Based on these

data, we have calculated the bicyclist speeds at different points in each of the ride-out crossing cases.

We can estimate averaged bicycle speed excluding "ride out" situation from GUI program directly. For ride out, a new algorithm was designed for calculating "ride out" speed. We simplified "ride out" process to two phases: constant acceleration phase and constant speed phase. These two consecutive phases should be connected smoothly. It means there is no inflection point when state changes. So "ride out" model is written as follows:

$$y_a = ax_a^2 + bx_a + c \quad (2)$$

$$y_l = hx_l + k \quad (3)$$

$$\frac{\partial y_a}{\partial x_a} = y_l = hx_l + k \quad (4)$$

The first acceleration process is Equation (2) that is depicted as a parabola curve. Equation (3) describes the constant speed process. In order to satisfy no inflection point, Equation (4) was deduced by combining the equation (3) and derivative of equation (2). Using least square error method, 1 parabola curve and 1 straight line best fit the whole "ride out" process. Based on these six points, nine different ways were designed to estimate the least square error. For instance, if we use three points to plot parabola to best fit constant acceleration firstly, we use equation (4) and other three points to plot a line to best fit constant speed motion. Then we best fit the whole riding process. Other eight best fitting curves can be used the similar methodology. In 118 "ride out "cases, we find the least square error for every case.

RESULTS

Bicyclist speed when moving in parallel
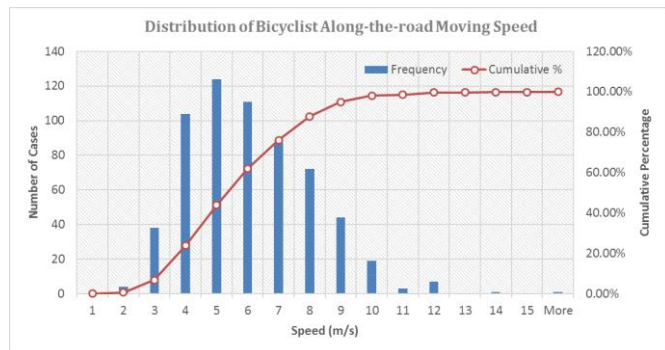Table 1 shows the adult bicyclist moving speeds (m/s) when

- Vehicle moving straight, changing lane, or stopped
- Bicyclist moving away from the vehicle, towards the vehicle, and combined (in parallel)

Table 1.
Bicycle speed when moving in parallel (m/s)

	Away from the vehicle	Towards the vehicle	In Parallel
Mean	5.59	5.57	5.59
Max	18.26	13.41	18.26
Min	1.33	1.82	1.33
Median	5.41	5.1	5.32
25% Percentile	4.04	4.11	4.06
75% Percentile	6.9	6.96	6.94
Sample Size	457	158	615

Based on *t*-test results (p_{613}=0.91), there is no significant difference of bicyclist moving speeds between the "away from the vehicle" and the "towards the vehicle" cases. The results

cover all the road locations, and both when the bicyclist moving at left and right side of the road. Fig. 3. shows the speed distribution of bicyclist moving along the road. There are two kinds of motion along the road, away from the vehicle and towards the vehicle. Because *t*-test shows no difference in the bicycle moving speed between the "away from the vehicle" and "towards the vehicle" cases, they are combined as "along the road". The average speed of all along the road cases is 5.6m/s. The 25th percentile and 75th percentile speed distribution are 4.6m/s and 6.9m/s, respectively.

Figure 3. **Histogram for the bicyclist along-the-road moving speed (n=615).**

Bicyclist speed when crossing
The following table 2 shows the adult bicyclist moving speeds (m/s) when

- The bicyclist is crossing the street
- Vehicle moving straight or stopped

The overall cases include all the crossing cases satisfying the above conditions. Within the overall cases, the "ride out" cases and the "ride through" cases are separately calculated, and *t*-test ($p_{278} < 0.001$) shows that the bicyclist speeds for these two types of cases are significantly different.
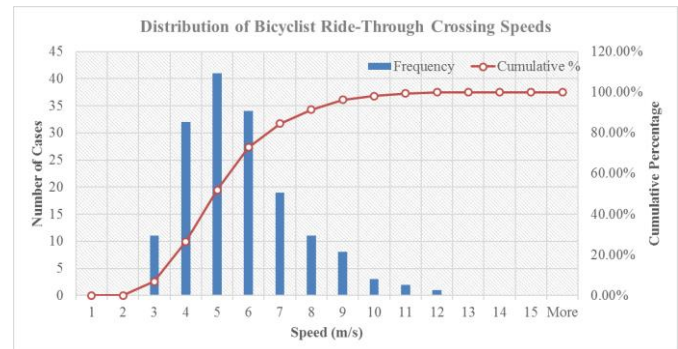
The ride-out and ride-through crossing speeds for the cases are averaged across the whole measuring periods. For the ride-out cases, the bicyclist speed may keep increasing during the crossing period, but only the averaged bicyclist speeds are calculated here. Please keep in mind that assuming (1) zero initial speed, (2) constant acceleration, and (3) measuring distance covered from curb to curb, the averaged bicyclist speed for the ride out cases will happen before the bicyclist reaches the middle of the road. With these assumptions, we

can calculate the estimated constant bicyclist speed (after the acceleration phase) for each ride-out case using the following equation (5):

$$V_{Adjusted} = \sqrt[2]{2} \times V_{Mean} \qquad (5)$$

With applying equation (5), we calculated adjusted-ride-out speeds for all ride-out cases, also shown in table 2. We can find out that the adjusted-ride-out bicyclist speeds are not significantly different from ride-through speeds ($P_{278} = 0.16$). This proves that after the acceleration phase, ride-out and ride through bicyclists move similarly fast.

Figure 4 shows the speed distribution of "ride through" cases. The 25th percentile, 50th percentile and 75th percentile of speed distributions are 4.0m/s, 5.2m/s and 6.3m/s, respectively. We can tell that the distribution of ride through speed is very similar to the distribution of along-the-road speed.

Figure 4. **Histogram for the bicyclist ride-through crossing speed (n=162).**

Ride-out bicyclist speed when Crossing
Although the averaged crossing speeds have been calculated for the ride-out and ride-through cases, it is important to note that the averaged speeds are not good measures for ride-out cases considering the existing of acceleration phase. In order to better fit "ride out" situation, we preliminarily built and simplify ride out model as 2 consecutive phases, as described in the methodology section, equations (2) – (4). With applying this model, 118 ride-out cases were analyzed. Figures 5 to 7 show fitted results for traveling distances and time for all the ride-out cases, corresponding the number of points measurable. Not all six defined points are available for all ride-out cases. One reason is that the data analysis was based on the in-car facing-forward camera videos, which have limited view ranges preventing from seeing some road

Table 2.
Bicycle speed when crossing

	Average	Median	Maximum	Minimum	25% Percentile	75% Percentile	Sample Size
Overall	4.48	4.11	11.82	1.01	3.30	5.29	300
Ride-Out	3.50	3.35	7.29	1.01	2.82	3.99	118
Adjusted-Ride-Out	4.95	4.73	10.31	1.43	3.98	5.64	118
Ride-Through	5.23	4.97	11.82	2.38	3.94	6.26	162

locations. Another reason would be case-related. For example, if bicyclist is staying beside the street, point 1 and point 2 should be the same point. In this case, we delete point 1 and just achieve five points.
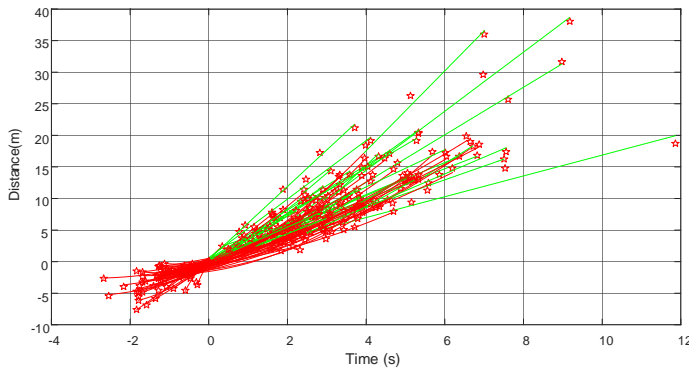

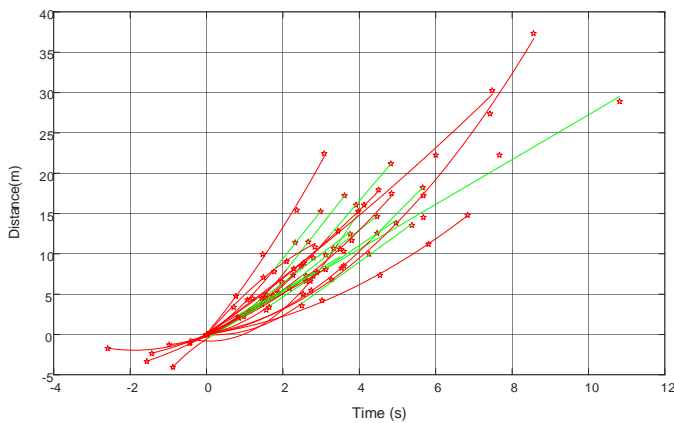*Figure 5.* **Fitted results for six-point ride-out cases.**

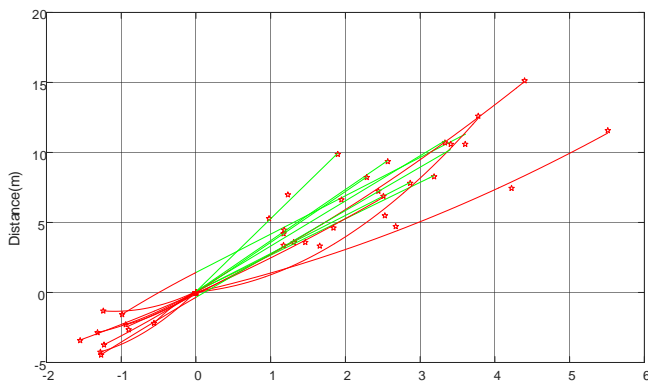*Figure 6.* **Fitted results for five-point ride-out cases.**

Figure 7. **Fitted results for four-point ride-out cases**

Eventually, there are 78 six-point cases shown in figure 5, 22 five-point cases shown in figure 6, and 12 four-point cases shown in figure 7. Based on these data, we have calculated the bicyclist speeds at point 3, point 4, and point 5 for these cases. The results are presented in table 3. Statistical tests show that the speed at point 3 is significantly slower than the speeds at point 4 & 5. There are no significant differences between point 4 & 5. In another word, this tells that at point 3, the bike is still accelerating. At point 4 and 5 the speed is relatively consistent. If the crash test is bike riding from right to left, the speed at point 3 will be more important. If the crash test is bike riding from left to right, the speed at point 5 is more relevant.

Application of the bicycle speeds for PCS testing
Relying on the calculated bicyclist speeds for all the selected cases, we have tried to estimate the bicyclist speeds for five test scenarios, shown in figure 8 with the detailed values shown in table 4.
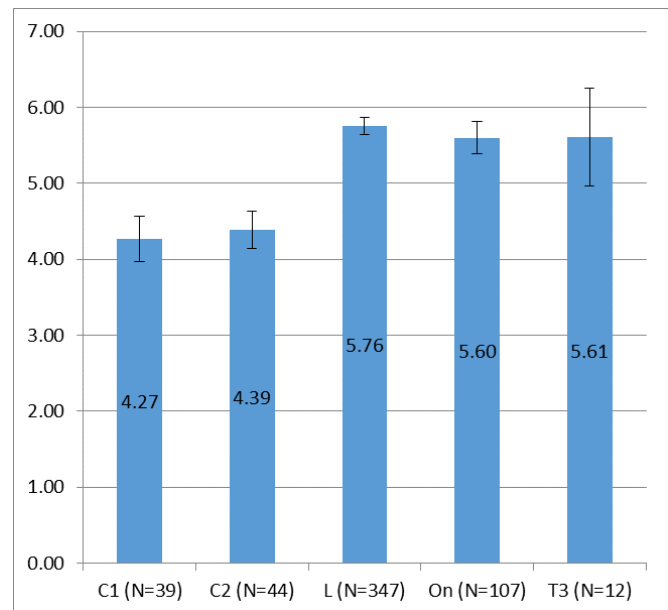

Figure 8. **Bicyclist speeds estimation for five scenarios.**

These five test scenarios include:
- C1: vehicle going straight and bicyclist crossing from right to left
- C2: vehicle going straight and bicyclist crossing from left to right

Table 3.
Bicycle speed at different points for ride-out crossing cases

	Speed at Point 3	Speed at Point 4	Speed at Point 5
Mean(m/s)	2.95	3.77	3.85
Min(m/s)	1.19	1.78	1.38
Max(m/s)	6.78	7.34	7.71
25% Percentile(m/s)	2.22	2.80	2.83
75% Percentile(m/s)	3.45	4.16	4.63
Number of Cases	91	86	86

Table 4.
Bicyclist moving speeds for five test scenarios

Scenarios	Average (m/s)	Average (mph)	St Dev	St Error
C1 (N=39)	4.27	9.55	1.87	0.30
C2 (N=44)	4.39	9.82	1.61	0.24
L (N=347)	5.76	12.88	2.04	0.11
On (N=107)	5.60	12.53	2.17	0.21
T3 (N=12)	5.61	12.55	2.22	0.64

- L: vehicle going straight and bicyclist moving along-the-road in the same direction
- On: vehicle going straight and bicyclist moving along-the-road against the vehicle moving direction
- T3: Vehicle turning left and bicyclist moving along the road against the vehicle moving direction

These bicyclists moving speed estimations have been used in the PCS tests conducted by the TASI research group. Figure 9 and figure 10 show the real testing scenarios with the surrogate bicyclist along the road and crossing the road. Bicyclist speeds were provided by our analysis.

Figure 9. **Surrogate bicyclist crash test when moving along the road**

Figure 10. **Surrogate bicyclist crash test when crossing road**

CONCLUSION

Studying information from TASI-110 car naturalistic driving database, we deduced different bicyclist moving speeds in different scenarios. More detailed analyses were completed for ride-out cases via fitting the data into a two-phase crossing model. These data results have been used by TASI researchers to test bicyclist Pre-Collision Systems. These empirical speed

data can be used to support the development of Pre-Collision Systems and facilitate further research.

ACKNOWLEDGEMENT

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