THROW DISTANCE VARIATIONS IN BICYCLE CRASHES

Mukherjee S, Chawla A, Mohan D, Chandrawat S, Agrawal V

TRANSPORTATION RESEARCH AND INJURY PREVENTION PROGRAMME
INDIAN INSTITUTE OF TECHNOLOGY DELHI

ABSTRACT

This paper investigates correlation between throwing distance and impact speed / point of impact for bicycle-car front-to-side crash. Crashes between a bicycle and a car were simulated using multi body models developed in MADYMO^{TM}. The Hybrid III 50th percentile male dummy model, available from MADYMO library has been used. Crash configurations reported in literature have been used and parametric variations have been done in speed, and point of impact. It is observed that only some configurations show a monotonic dependence of the throwing distance on the car speed.

Keywords*:* Bicycle, Car, MADYMO, Crash simulation, throwing distance, impact speed

CYCLISTS AND PEDESTRIANS are the most vulnerable group in traffic crashes [Carsten et al., 1992]. In the past, studies and developments in the field of crash modeling were mainly directed towards protecting the occupants in motor vehicle crash. Bicycles generally do not have a standardized structure and there is no conformity criterion for the material used, design and construction methods. Hence generic safety standard for bicycle riders have been very difficult to formulate and are not standardized yet. Reconstruction of accidents involving vulnerable road users in general and bicycles in particular, has been gaining importance. The fact that the collection of data starts at the scene of accident post facto, leads to indirect determination of parameters leading to the crash. Some useful correlations are provided by the laws of physics governing momentum conservation, energy dissipation from plastic folding and friction, measurement of skid marks etc. These are however not specific to the bicycle-car interaction. For pedestrian impacts, two important correlations are wrap distance and throw distances. For bicycle crashes also throw distances have been used in the past [Otte, 1980, 1989, 2002]. This paper investigates variations in the throw distance of bicycle riders with the impact parameters to aid bicycle accident reconstruction efforts through Madymo^{TM} simulations. Variations in the throwing distance with the vehicle velocity for various crash configurations have been obtained. Based on the position of the vehicle, the point of impact between the car and bicycle and the distance to which the cyclist is thrown, these variations would help predict the car speed. It is hoped that this data, once calibrated, will be useful for reconstruction of crashes involving bicycles. Similar data is presently used extensively for pedestrian crashes.

CRASH CONFIGURATIONS

In car-motorcycle crashes, such configurations have been standardized in [ISO 13232, 1996]. Similar standards are not available for car-bicycle crashes. The study by the Federal Highway Administration (FHWA) [Tan, 1996] was used as a starting point. In our study we have used the configuration corresponding to the car-front to- bicycle-side impact, which is one of the most prevalent crossing path crashes (Fig. 2).

The final position of cyclist post crash is a primary measure and hence is an important parameter to ascertain the collision speed within the framework of accident reconstruction. For reconstruction, the distance from the collision point to the final position of the body is defined as the throwing distance. In these simulations, the first point of contact of the dummy with the ground is taken as throwing distance as the dummy-ground interaction was not realistic. Fig. 1 (reproduced from [Otte, 2002]) shows the only available correlation for throwing distance in relation to the collision speed for bicycle crashes. A large variation in the throwing distance can be seen. This paper reports the results of variation in throwing distance in front-to-side crashes between car and bicycles with variation of car / bicycle speeds and the point of initial impact between the car and the bicycle. There is significant dependence on these parameters, and the trends in the throw distance follow those in reconstructed

data. Further, the throwing distance is predicted to have non-monotonic dependence on the impact configuration, which could complicate reconstruction attempts.

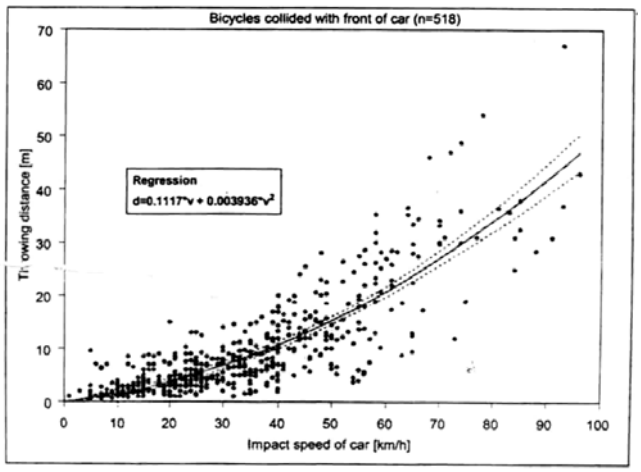

Fig. 1- Throwing Distance of Bicycles in Relation to Impact Speed of Car for Front-to-Side Impact [Otte, 2002]

BICYCLE MODEL The bicycle is modeled as a system of four rigid bodies: the frame, the front fork, and the two wheels. The frame and the front fork are connected by a revolute joint; for which the rotation axis is in the plane of symmetry of the bicycle. Front and rear wheel are connected by revolute joints to front fork and the frame, respectively. Rotation axes are perpendicular to the plane of symmetry. The rider has been modeled using the Hybrid III model from the Madymo library. The results reported from various tests and analysis ([Burgoyne and Dilmaghanjan, 1993], [Gavin, 1996]) have been used to extract the mechanical properties of the wheel. The radial stiffness of the tyre has been obtained from the stress – strain curve for the bicycle tyres [Gavin, 1996].

CAR MODEL The car has been chosen as the Maruti ZEN model, a common car on Indian roads. For the MADYMO input file, the car frame has been modelled as a single rigid body i.e. all ellipsoids are rigidly connected to each other. The vehicle model consists of 4 multi body tree structures, representing the front left, front right, rear left, and rear right vehicle suspension. The front suspension linkages form a double wishbone configuration, with an upper control arm, steering linkage, wheel, and lower control arm bodies. The rear suspension consists of a body to model each of the rear axel and the wheel/tire areas, and represents a simplified suspension configuration. It was found necessary to include the lateral part of car hood, rear door, side and rear windows as the cyclist impacted the lateral part of the car in some post impact situations.

CONTACT INTERACTIONS Multi body contact interactions are defined using the force penetration functions for the dummy with the bicycle, car, pavement and road, for the bicycle with the car and the road, the car with the road and between dummy body parts. Head form impact test data reported in [JNCAP DATA, 2004] for the WAGON R FX, which is similar to the WAGON R car prevalent in India was used to generate load deformation characteristics.

SIMULATIONS OF THE FRONT-TO-SIDE COLLISION

In simulations, the rider impacts the hood, and then proceeds to roll up the windscreen towards the roof of the car. With respect to the car, a lateral movement causing the rider to roll off the side of the car is seen. For higher velocities, the rider may clear the roof, landing at the back of the car. For lower velocities, the rider may be carried on the front end of the car for longer time duration before rolling off. The behavior is qualitatively different at varying speeds, initial impact locations and bicycle speeds.

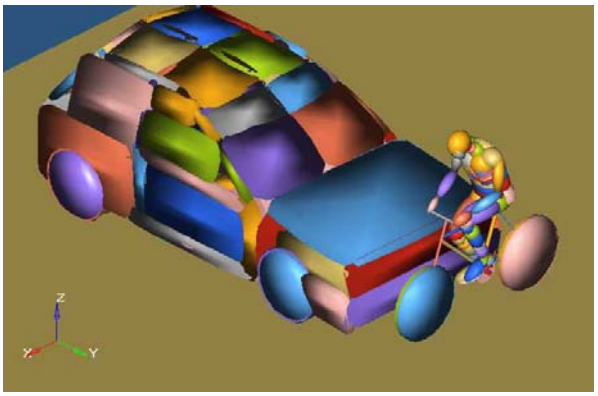

Fig. 2- The Front-to-Side Configuration with impact of midpoint of the car front below the bicycle saddle

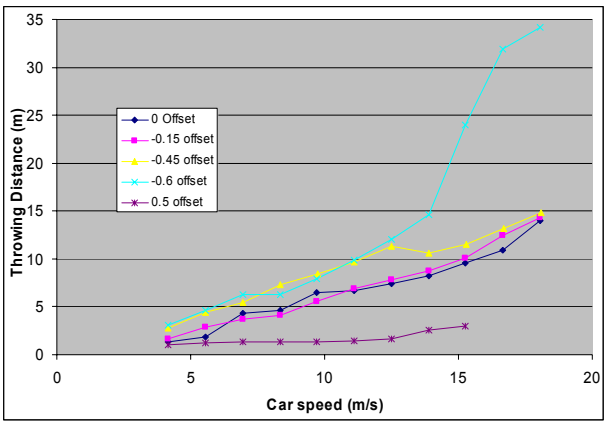

Fig. 3- Throwing distance for impact of midpoint of the car front offset from the bicycle saddle

The simulations were carried out with the speed of the cycle as 10 km/h and the impact speed of car varying between 15 km/h to 65 km/h. The midpoint of the car front impacting below the saddle was defined as a zero offset crash. Positive offset is the distance of the saddle from the midpoint of the car at impact, measured along the direction of bicycle motion. Fig. 3 shows the change in throwing distance for different car velocities at offsets in meters. The sudden changes in slopes of these otherwise monotonically varying curves can be associated with qualitative change in the kinematics of the bicycle rider at certain points. In bulk of the simulations, the rider impacted the bonnet or the windscreen. At speeds above about 13 m/s, the cyclist is thrown to a greater height and goes above the roof of the car. This qualitative change causes the throwing distance curve to change slope. At very low velocities (below about 5 m/s) the cyclist does not hit the car.

Fig. 4 shows variation in throwing distance for bicycle and car speeds of 10km/h and 30 km/h with change in point of contact from -0.9 m to 0.75 m. The throwing distance changed significantly, and obviously went down to zero when there is no contact!

COMPARISON WITH RECONSTRUCTION DATA The throwing distance for all impact positions has been plotted in Fig. 3. If all the offset configurations are considered, there is a significant spread of data, especially at higher velocities. The spread of the throwing distance at 18 m/s (64 km/hr) between 5 and 35 m is similar to the spread between 8 and 35 m seen in the data reported by Fig. 1**.** We may conclude that the large spread in the data reported [Otte, 2002] is predicted in the simulations and can be attributed to changing contact points on the car. It is hence suggested that in reconstruction, a single throwing distance correlation may not be very useful and the contact point with the car be identified for good correlation.

VARIATION IN BICYCLE SPEED Though the bicycle velocity is small compared to the car velocity, its variation does affect the throwing distance. This was investigated by simulating with the car velocity constant at 50 km/h (13.89 m/s) with bicycle speed varying from 5 km/h to 20 km/h (1.39 m/s to 5.56 m/s). The variations in the throwing distance are plotted in Fig. 5 for two different impact offsets (-0.3 and -0.6 m). It was observed that the throwing distance variation with the bicycle velocity has a peak, instead of a monotonic variation. For lower bicycle speeds, post impact the rider gains lesser height, impacting lower on the car windscreen. The rider then tends to roll off the front or side of the car, leading to lower throwing distance. For higher cyclist velocities the cyclist crosses the car (due to a velocity perpendicular to car) earlier, thereby its motion was not significantly influenced by the car impact leading to lower throwing distances.

This analysis suggests that the bicycle velocity at which the throwing distance is maximum will change with the distance of impact from the car centre. The variation in throwing distance with bicycle velocity is estimated to be of the order of 15 m at a car velocity of 50 km/h. The variation due

to change of impact position on the car for the same car velocity is of the order of 10 m from Fig. 4. So we conclude that the variation in throwing distances due to impact position variation is of the same order as the variation due to bicycle speed. The variation becomes more prominent for higher offsets.

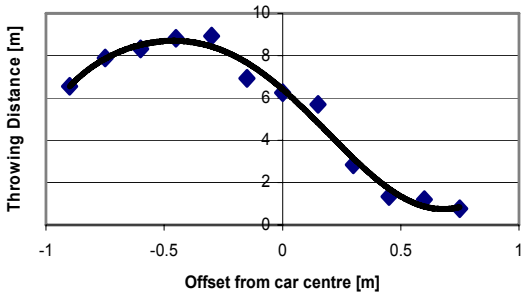

Fig. 4- Variation of Throwing Distance of Bicycle Rider with Change of Offset (for a Car Speed of 30 km/h and the Bicycle Speed of 10 km/h)

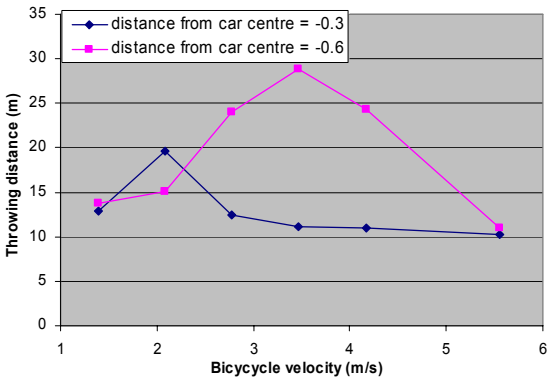

Fig. 5- Variation in Throwing Distance with Bicycle Velocity When the Bicycle Strikes at Distance of -0.3 and –0.6m from Car's Centre

CONCLUSION

The variation of the throwing distance with car velocity and point of impact has been studied through over 100 simulations for bicycle-car crash configurations. The obvious conclusion that the throwing distance generally increases as the car velocity increases, was reinforced. The variation in the point of contact causes significant changes. The trends in the front-to-side impact follow reconstructed data reported by Otte (2002). From the simulations, the large spread in the data reported by Otte (2002) is predicted to originate from variation in the impact configuration. The changes in the trends can be associated with key changes in the nature of the impact visible in the simulations (head impacting car, no impact of rider with car etc.). The study is currently based on only one car model and the interaction between the dummy and the road is not fidelic. Real life data, for example of the type reported by Otte include a larger range of vehicles. The change in throwing distance for other vehicle types is yet to be studied. Further, variation in the bumper and bonnet height could also affect the throwing can distance. These effects also need to be studied.

REFERENCES

1. Burgoyne, C.J. and Dilmaghanian, R. (1993) "Bicycle Wheel as pre-stressed Structure." Journal of Engineering Mechanics, 119 (3), pp. 439-455.
2. Carsten, O.M.J. et al (1992), Drive Project V1031, An Intelligent Traffic System for Vulnerable Road Users. Institute for Transport Studies, University of Leeds.
3. Gavin, H.P., "Bicycle Wheel Spoke patterns and Spoke Fatigue," Journal of Engineering Mechanics, vol. 112, no. 8, (1996) pp. 736-742.
4. ISO 13232, (1996), Motorcycles – test and analysis procedures for research evaluation of rider crash protective devices fitted to motor cycles, International Organization of Standardization, Reference Number ISO 13232-1 to 7: 1996 (E).
5. JNCAP DATA, New Car Assessment Program Japan, Choosing a safer car, March 2004, Ministry of Land Infra Structure and Transport and National Agency for Automotive Safety and Vixtim's Aid, Japan.
6. Otte D; Possibilities and Limitation for protective measures for injury reduction of vulnerable road users, IJCrash 2002, Vol 7 No. 4, pp. 441-461.
7. Otte, D. (1980), A review of different kinematics forms in two-wheel accidents – their influence on effectiveness of protective measures, Stapp Car Crash Conference, SAE Paper No. 801314.
8. Otte, D. (1989), Injury mechanism and crash kinematics of cyclists in accidents – an analysis of real accidents, Stapp Car Crash Conference, SAE Paper No. 892425.
9. Tan, C. (1996), "Crash Type Manual for Bicyclists", Pub. No. FHWA – RD – 96 – 104.