A Modelling Study to Examine Threat Assessment Algorithms Performance in Predicting Cyclist Fall Risk in Safety Critical Bicycle-Automatic Vehicle Interactions

Marco M. Reijne*, Sepehr G. Dehkordi#, Sebastien Glaser#, Divera Twisk#, A.L. Schwab*

*Faculty of Mechanical Engineering
Delft University of Technology
Mekelweg 2, 2628 CD, Delft, The Netherlands
email: [m.m.reijne,a.l.schwab@tudelft.n]@tudelft.nl

#Centre for Accident Research and Road Safety
Queensland University of Technology
130 Victoria Park, 4059, Brisbane, Australia
email: [sepehr.ghasemi,sebastien.glaser,twisk2]@qut.edu.au

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1 INTRODUCTION

Falls are responsible for a large proportion of serious injuries and deaths among cyclists [1-4]. A common fall scenario is loss of balance during an emergency braking maneuver to avoid another vehicle [5-7]. Automated Vehicles (AV) have the potential to prevent these critical scenarios between bicycle and cars. However, current Threat Assessment Algorithms (TAA) used by AVs only consider collision avoidance to decide upon safe gaps and decelerations when interacting with cyclists and do not consider bicycle specific balance-related constraints. To date, no studies have addressed this risk of falls in safety critical scenarios. Yet, given the bicycle dynamics, we hypothesized that the existing TAA may be inaccurate in predicting the threat of cyclist falls and misclassify unsafe interactions.

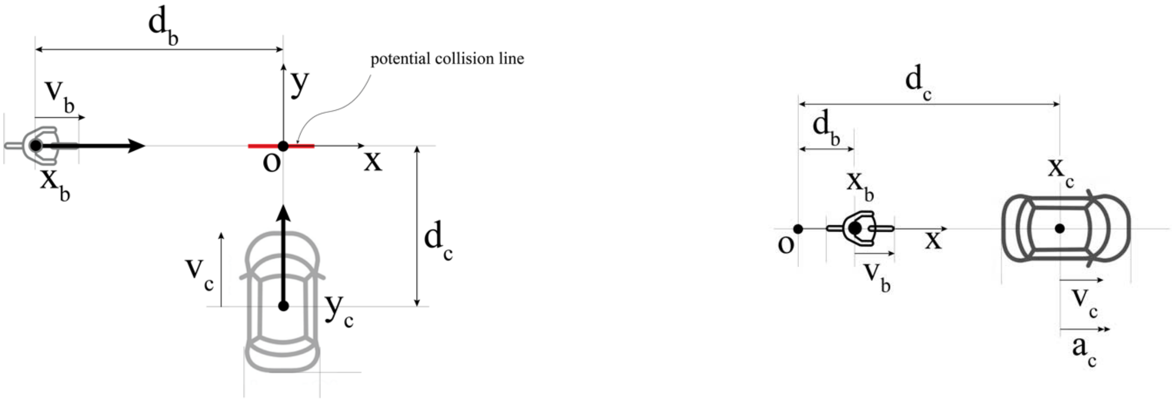
To test this hypothesis, this study developed a simple Newtonian mechanics-based model that calculates the performance of two existing TAAs in four critical scenarios with two road conditions. The four scenarios are: (1) a crossing scenario and a bicycle following lead car scenario in which the car either (2) suddenly braked, (3) halted or (4) accelerated from standstill. These scenarios have been identified by bicycle-car conflict studies as common scenarios where the car driver elicits an emergency braking response of the cyclist [8-11] and are illustrated in Figure 1. The two TAAs are Time-to-Collision (TTC) and Headway (H). These TAAs are commonly used by AVs in the four critical scenarios that will be modelled. The two road conditions are a flat dry road and also a downhill wet road, which serves as a worst-case condition for loss of balance during emergency braking [12].

2 APPROACH

The Newtonian mechanics-based model can calculate for a set of interactions (varying combinations of initial distances d_b, and d_c, and initial speeds v_b and v_c, see Figure 1) whether a fall of the cyclist or collision between the vehicles occurred. For the same range of interactions we determined whether the TTC or H predicted the interaction was safe or unsafe. The predictive performance of the TTC and H was defined as the proportion of misclassifications of unsafe interactions.

3 RESULTS

The proportions of misclassifications of all scenarios, TAAs and road conditions are numerically presented in Table 1 and are visualized in Figure 2 for a crossing scenario on a flat dry road and a TTC threshold of 1.2 seconds. The results show that for a crossing scenario on a flat dry road a TTC threshold of 1.0 and 1.2 seconds misclassified respectively 34% and 9% of the unsafe interactions as safe. This proportion was 22% for a bicycle following a suddenly braking car and a TTC threshold of 2.0 seconds, and 1% for a halting car. For H, the misclassifications were respectively 0% and 4% in these scenarios. For downhill riding on a wet road, the



(a) *(b)*

Figure 1: Top view of two types of bicycle-car interaction: (a) A bicycle-car crossing interaction with the location of the bicycle center, x_b, and the car center, y_c, in reference to the origin O of the global fixed coordinate system. The thick red horizontal line at the origin is the potential collision line. The initial distances from the origin are d_b for the bicycle and d_c for the car. The initial velocities are v_b for the bicycle and v_c for the car. (b) A bicycle following lead car scenarios with the location of the bicycle center, x_b, and the car center, x_c, in reference to the origin O of the global fixed coordinate system. The initial distances from the origin are d_b for the bicycle and d_c for the car. The initial velocities are v_b for the bicycle and v_c for the car. The constant acceleration of the car is a_c, which is negative for the suddenly braking car scenario, zero for the halted car scenario and positive for the accelerating car scenario.

Table 1: Proportions of misclassifications in % between the Newtonian mechanics model and TTC or H for the four critical scenarios and for a flat dry road and a downhill wet road.

	flat dry road		downhill wet road	
Model interaction outcome prediction	safe	**unsafe**	safe	**unsafe**
TTC interaction outcome prediction	unsafe	**safe**	unsafe	**safe**
crossing scenario				
TTC threshold: 1.0 s	0%	**34%**	0%	**35%**
TTC threshold: 1.2 s	0%	**9%**	0%	**11%**
bicycle following suddenly braking car scenario				
TTC threshold: 2.0 s	8%	**22%**	0%	**51%**
H threshold: 1.8 s	19%	**0%**	0%	**17%**
bicycle following halted car scenario				
TTC threshold: 2.0 s	3%	**1%**	0%	**16%**
H threshold: 1.8 s	1%	**4%**	0%	**20%**
bicycle following car accelerating from standstill				
TTC threshold: 2.0 s	21%	**0%**	14%	**0%**
H threshold: 1.8 s	17%	**0%**	10%	**0%**

proportion of misclassifications increased by at least 15%. In contrast, for the accelerating car scenarios, the classifications were too conservative by misclassifying 17 to 21% of safe interactions as unsafe.

4 CONCLUSIONS

The findings of this study illustrate that existing TAAs for AVs, which do not take bicycle specific balance-related constraints into account, cannot accurately predict the threat of a cyclist fall and take decisions that either put cyclists at a high risk of injury or are detrimental for traffic flow. The results of the simple model support our hypotheses, stress the urgency for further study, and justify the investments required to collect data about critical bicycle-car interactions.

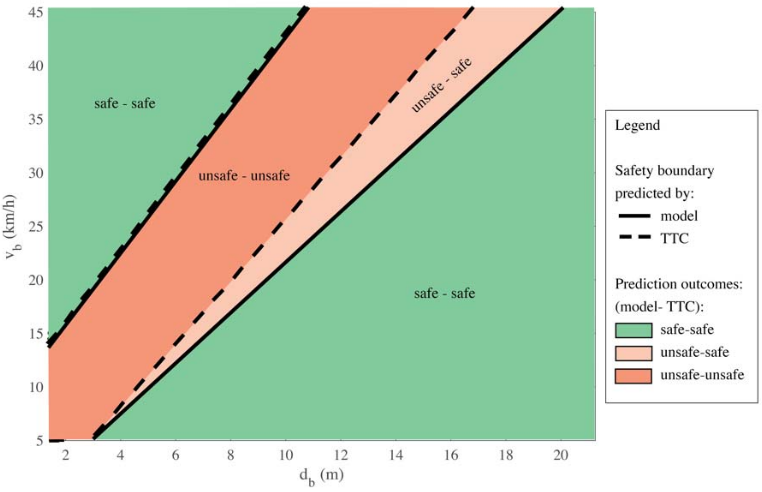


Figure 2. Comparison of misclassifications between the Newtonian mechanics-based model and a TTC with a safety threshold of 1.2 s for the bicycle-car crossing scenario and a dry flat level road. The set of interactions considered are all combinations for an initial position of the bicycle (d_b) between 2 to 21 m and an initial velocity of the bicycle (v_b) between 5 to 45 km/h. All other parameters were kept constant. The green safe-safe area and dark red unsafe-unsafe area are combinations where the prediction of the TTC agrees with the outcome of the model, whereas the light red unsafe-safe area are combinations where the TTC predicts a safe but the model outcome is an unsafe interaction. The percentage as a fraction of the square area are: safe-safe 66%, unsafe-unsafe 25%, unsafe-safe 9% (see Table 1).

REFERENCES

[1] P. Schepers, et al., "An international review of the frequency of single-bicycle crashes (SBCs) and their relation to bicycle modal share." *Injury prevention* 21.e1 (2015), pp. 138-143.

[2] M. Møller, K.H. Janstrup and N. Pilegaard, "Improving knowledge of cyclist crashes based on hospital data including crash descriptions from open text fields." *Journal of safety research* 76 (2021), pp. 36-43.

[3] M. Hosseinpour, T.K.O. Madsen, A.V. Olesen and H. Lahrmann, "An in-depth analysis of self-reported cycling injuries in single and multiparty bicycle crashes in Denmark." *Journal of safety research* 77 (2021), pp. 114-124.

[4] R. Utriainen, S. O'Hern, and M. Pöllänen, "Review on single-bicycle crashes in the recent scientific literature." *Transport Reviews* (2022), pp. 1-19.

[5] P. Schepers and K. Klein-Wolt, "Single-bicycle crash types and characteristics." *Cycling Research International* 2.1 (2012), pp. 119-135.

[6] B. Beck, et al., "Crash characteristics of on-road single-bicycle crashes: an under-recognised problem." *Injury prevention* 25.5 (2019), pp. 448-452.

[7] P. Hertach, A. Uhr, S. Niemann and M. Cavegn, "Characteristics of single-vehicle crashes with e-bikes in Switzerland." *Accident Analysis & Prevention* 117 (2018), pp. 232-238.

[8] R. Fredriksson, K. Fredriksson and J. Strandroth, "Pre-crash motion and conditions of bicyclist-to-car crashes in Sweden." *Proceedings, International Cycling Safety Conference 2014*, Göteborg, Sweden, 18-19 November, 2014, 14 pp.

[9] J. Duan, et al., "Driver braking behavior analysis to improve autonomous emergency braking systems in typical Chinese vehicle-bicycle conflicts." *Accident Analysis & Prevention* 108 (2017), pp. 74-82.

[10] I. Isaksson-Hellman and J. Werneke, "Detailed description of bicycle and passenger car collisions based on insurance claims." *Safety science* 92 (2017), pp. 330-337.

[11] P.D. Fernández, et al. "Description of same-direction car-to-bicycle crash scenarios using real-world data from Sweden, Germany, and a global crash database." *Accident Analysis & Prevention* 168 (2022), pp. 106587.

[12] O. Maier, M. Pfeiffer, S. Scharpf and J. Wrede "Conditions for nose-over and front wheel lockup of electric bicycles." *Proceedings, 2016 11th France-Japan & 9th Europe-Asia Congress on Mechatronics (MECATRONICS)/17th International Conference on Research and Education in Mechatronics (REM),* Compiègne, France, 15-17 June, 2016, pp. 219-224.