Can Experienced Riders Benefit from an Autonomous Emergency Braking System?

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ABSTRACT

Powered two wheelers (PTWs) are becoming increasingly popular in Europe but the risk of rider injury in a traffic crash far exceeds that for car occupants. The European Powered Two wheeler Integrated Safety project (PISa), identified autonomous emergency braking (MAEB) as a priority area for reducing the injury consequences of PTW crashes. This study assessed the potential effectiveness of the PISa MAEB system, specifically in relation to its potential benefit for experienced riders .

A sample of fifty-eight in-depth PTW crashes representing typical European crash scenarios were examined, of which half involved a rider with MAIS 2+ injury. An expert team analysed the data to determine the extent to which the MAEB would have affected the crash. In 39 cases (67% of the sample) the MAEB showed high potential to mitigate the crash outcome.

Results indicated that, not only does the MAEB have potential to help novice riders but could also considerably improve safety for more experienced riders. The results shown here could encourage further development and acceptance of such systems.

INTRODUCTION

Powered two wheelers (PTWs) represent a significant portion of vehicles and trends indicate that numbers are likely to grow. The attractiveness of PTWs from areas of commuting to tourism stems from their relative economy, time efficiency, convenience and fun. Troubling, however, is that riders are 10 to 40 times more likely to be involved in a severe or fatal crash per km travelled than passenger car occupants. Furthermore, as opposed to cars, the trends of crashes and fatalities among riders show little sign of declining (Yannis *et al.* 2012).

Many studies in the past have tried to identify risk factors associated with common rider crashes. These have included: riding motivation, time of day, day of week, time of year, and specific location, among others (Hardy, Schneider *et al.,* Serre *et al.,* Vlahogianni *et al.,* Blackman and Haworth, Shaheed *et al.*). Through identification of risk-factors, it is hoped that PTW riders become more aware of potential risk, and adapt their riding behaviours by being more attentive in certain conditions, or alternatively, undertaking skills training. Rider

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training is often promoted as one of the most promising means of reducing risk, notwithstanding limited scientific evidence for its efficacy (Kardamanidis *et al.* 2010).

Regardless of the potential effectiveness of reducing rider risk through greater risk awareness or skills training, crashes are still likely to occur. When they do, it can be assumed that an imbalance within the configuration of rider, their machine, the environment and/or other road users has transpired. At the very moment of collision, at least one of these factors was either uncontrolled or unable to be controlled by the operator. In such cases, something unexpected has taken place.

In reviewing crash histories, it is apparent that in a large proportion of cases, riders did not perform any braking or avoidance actions at all, prior to the event. In other cases, the reaction of riders was sub-optimal in terms of manoeuvring or appropriateness of chosen manoeuvre (Penumaka *et al.*). Although poor riding skills feature large among the causes of reported crashes, previous studies indicate that experienced riders are far from immune to risk (Harrison and Christie).

With potential collisions unavoidable for even the most experienced of riders, advanced technical solutions should be considered as potential allies whenever it can be proved that they are able to assist in otherwise unrecoverable riding situations. One such example is anti-lock braking (ABS) for motorcycles, which has demonstrated its worth in both Nordic (Rizzi *et al.*) and commuter settings (Rizzi *et al.*).

The attraction of ABS for riders is that it provides a technological solution to a safety issue whilst also appreciating the cultural reality of riders that prevents many from adopting technologies that interfere with the riding experience (Beanland *et al.* 2013). ABS is deployed only in situations of heavy, emergency braking, assisting the rider to decelerate more effectively and in a safer, shorter distance. Furthermore, after wide adoption within the automotive industry, ABS is a trusted technology not specific to PTW, enhancing likelihood of adoption (Huth and Gelau 2013).

A number of previous attempts have been made to identify and summarise effective motorcycle safety technologies (Bekiaris *et al.,* Anderson *et al.*). In particular, a study based on a sample of European crashes (Powered-Two-wheeler Integrated Safety, PISa) indicated autonomous emergency braking (MAEB) as one of the most effective safety interventions[5] (Grant *et al.* 2008). Further investigations indicated that such a system should intervene only in case of a physically unavoidable collision (Savino *et al.* 2012) and the autonomous decelerations must be limited to mild values (Symeonidis *et al.*).

AIM

This work tried to establish whether, and to what extent, experienced riders may benefit from autonomous emergency braking systems fitted to motorcycles.

[5]When considering non collaborative, vehicle embedded safety functionalities.

Figure 1: Prototype vehicle of the PISa project equipped with AB system (in the box: laser scanner mounted in the front fairing).

MAEB

Autonomous Emergency Braking for Motorcycles (MAEB) is a collision mitigation system made up of two major modules. The first is a crash detection component that identifies imminent unavoidable collisions. The second is an ECU-controlled braking module producing an autonomous or enhanced deceleration of the vehicle.

For MAEB systems to work effectively, the obstacle to be avoided must be sensed by the system, and therefore, must be within line of sight of a sensor mounted in the front fairing of the PTW. Although possible, the MAEB as presented here is not designed to avoid crashes, but to reduce potential injury by intervening only when the crash has become unavoidable. The collision is considered to be unavoidable once it cannot be avoided either by braking at max deceleration or swerving at the limit of adherence. For a conservative approach, those extreme manoeuvres are computed in the hypothesis of an adherence equal to 1, irrespective of the actual road conditions. This is because it was assumed that a reliable real-time measurement of the adherence is not yet available. The MAEB operates two functions: (a) a mild unmanned deceleration when operating as autonomous braking (AB) (4 m/s^2) ; (b) an optimal braking up to the maximum feasible deceleration when operating as enhanced braking (EB) (up to 9 m/s^2). The MAEB does not deploy when travelling around curves, with a maximum allowable roll angle of 8˚. In case the rider starts to attempt a lateral manoeuvre (at any time) the MAEB immediately disengages, thus preventing interference with the rider's action. The main characteristics of the MAEB are illustrated in Table 1.

Table 1: Main characteristics of the MAEB.

Description	Value
Detection range	200 m
Detection angle	100°
Max roll angle	8°
Triggering condition of unavoidable collision	Adherence = 1 is assumed
Reference decelerations	4 m/s^2 (AB), 9 m/s^2 (EB)

The prototype of the MAEB is depicted in Figure 1. Further details about the system can be found in (Savino *et al.* 2012, Savino *et al.* 2013b).

METHOD

The applicability of the MAEB was investigated over a dataset of 58 in-depth PTW crashes representing typical crash configurations in Europe (Grant *et al.* 2008). Half of the cases reported a MAIS score 2+ (Figure 2). A diagram showing the impact speed vs. the MAIS value is depicted in Figure 5. The most common crash configurations in the database were crossing scenario cases (CRS), car-following scenario cases (CFS) and single vehicle cases (SV) (see Figure 3). Figure 6 shows a distribution of the MAIS values per rider experience for the sample crashes.

For the cases in which the MAEB was considered applicable, a quantitative evaluation tried to identify the number of crashes in which the system would have activated (and quantitative benefits), considering the behaviour of the rider involved in the crash, but also a range of possible behaviours including early full braking representing an attentive, skilled rider (experienced rider).

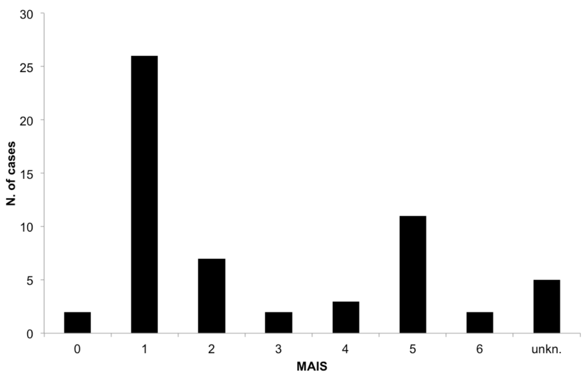


Figure 2: MAIS scores for the in-depth crash cases used in the present study.

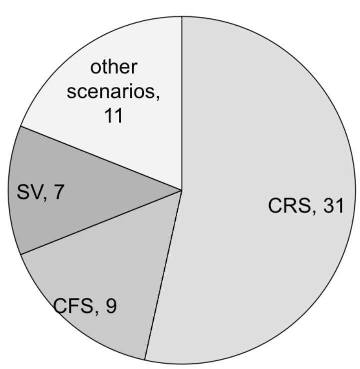


Figure 3: N. of crash cases used in the present study divided into main crash scenarios. CRS: crossing scenario cases; CFS: car following scenario cases; SV: single vehicle cases.

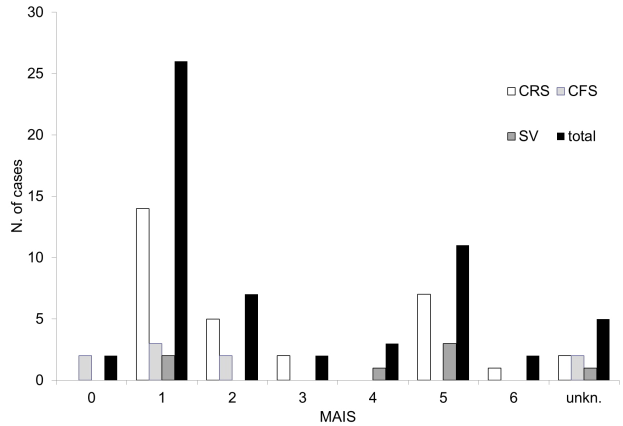


Figure 4: MAIS values per crash scenario type for the in-depth crash cases.

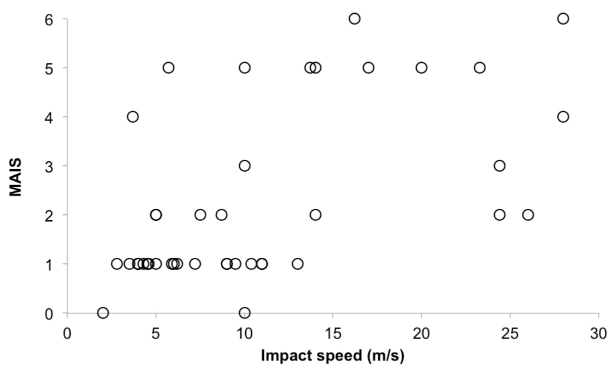


Figure 5: Impact speed vs. MAIS value (where available) for the in-depth crash cases.

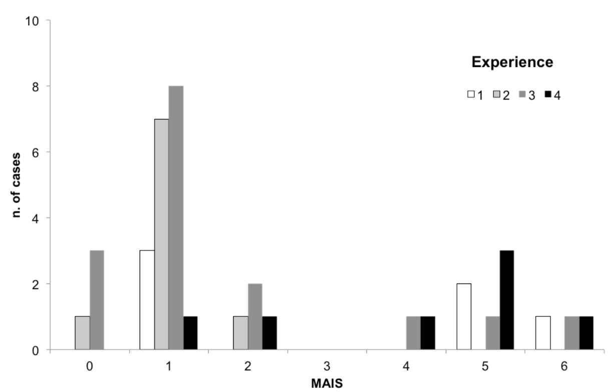


Figure 6: Distribution of the MAIS values per rider experience (1: very little; 2: little; 3: some; 4: quite a lot; 5: great deal).

The hypothesis for this evaluation is that in each PTW crash, the pre-crash configuration of rider, machine, environment, and other road user/s leading to the crash does not vary for a range of rider behaviours. The fact that crashes occur to both inexperienced and skilled riders, alike, support our proposed hypothesis. Once the pre-crash configuration was defined, a series of simulations were run to evaluate the different outcomes produced by different rider behaviours with and without the MAEB.

In the first phase, the investigation discriminated between crashes in which the MAEB would, or would not have, applied. For each crash case, a rating methodology based on a decision tree (Figure 7) was used to assign a probability value from 1 to 4 (Grant *et al.* 2008):

- Score 1: the AB would definitely not have worked.
- Score 2: the AB would perhaps have worked.
- Score 3: the AB would probably have worked.
- Score 4: the AB would definitely have worked.

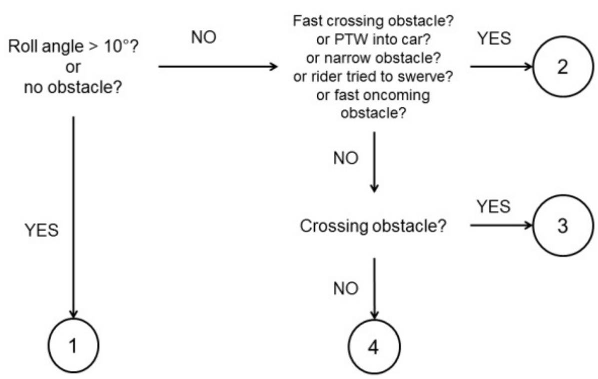


Figure 7: Decision tree

In the second phase, a quantitative estimation of the potential benefits of the MAEB was conducted for the cases scoring 3 or above in the first phase. The estimation of potential benefit used a simplified model simulating the longitudinal dynamics of the PTW and opponent vehicle, as described in (Savino *et al.* 2013b). In each case the lateral dynamics of the vehicles were neglected, with minor error expected in the computed speed reduction.

Quantitative evaluation was conducted considering both the actual rider behaviour in the pre-crash phase and 5 additional hypothetical behaviours (see Table 2).

1. no reaction (nr);
2. late reaction, low braking deceleration (lL);
3. late reaction, high braking deceleration (lH);
4. early reaction, low braking deceleration (eL);
5. early reaction, high braking deceleration (eH) representing an attentive, skilled rider (experienced rider).

Table 2: Characteristics of the set of additional rider behaviours used in the study.

Behaviour	Reaction time (s)	Deceleration (m/s^2)
nr	-	-
lL	2	4
lH	2	8
eL	0.5	4
eH (experienced rider)	0.5	8

Additional hypotheses for the analysis

Autonomous braking may, in principle, act as a warning but this element was not considered. Therefore in all cases it was assumed that the MAEB does not alter rider behaviour (i.e., the rider reacts in the same way and at the same time with and without MAEB).

Opponent vehicles slowly crossing the PTW's path (travelling speed below 5 m/s) were initially considered as fixed obstacles in the simulations. The crossing cases were further analysed to discriminate whether the collision was avoidable or not and specific triggering criteria were used for each simulation.

In some cases, the rider had attempted a swerve manoeuvre or a combination of a lateral avoidance and a braking manoeuvre. When evidence indicated that the PTW was upright (roll angle < 10°) the simulations ignored the riders' steering actions. This was because: (a) the initial swerving action was not actually able to avoid the collision; (b) the autonomous braking component associated with the swerving action does not avoid the crash due to the criterion of physical unavoidable collision, meaning impact speed would be similar to the sole braking action; (c) the ABS functionality included in the MAEB would act to reduce the likelihood of skidding and falling.

In a limited number of cases the in-depth reports lacked in some data and for that values reasonable hypotheses were used to set up the simulations (Savino *et al.*). Those hypotheses were not expected to produce positive bias in the potential benefits of the MAEB.

RESULTS

The MAEB was rated 3+ in 39 cases out of 58. The AB (autonomous braking) and the EB (enhanced braking) functionalities were applicable respectively in 14 and 23 cases. The score values for the most common crash configurations (37 cases belonging to crossing scenario cases - CRS, and car-following scenario cases – CFS) are shown in Table 3. The CFS crashes demonstrated the highest potential applicability of the MAEB system (scores of 4) whereas applicability was less certain with CRS cases (scores of 3). In 17 cases out of 37 the riders did not brake before the impact, and at least five of those (30%) were experienced riders. In 11 out of 17 cases of no reaction, the MAEB revealed to be applicable. At least three experienced riders would have benefitted of an impact speed reduction thanks to the MAEB (impact speed reduction for experienced rider cases: 1.3 m/s; 2.1 m/s; 3.2 m/s).

Table 3 Scores for CFS and CRS cases indicating the main reasons for the score of 3.

Scenario	Description	Score 1 & 2 (n.)	Score 3 (n.)	Score 4 (n.)	Main reasons for 3 instead of 4
CFS	Car-following scenario cases	1	2	6	Swerve attempt
CRS	Crossing scenario cases	4	23	1	Slow obstacle crossing or pulling out

The estimated benefits of the MAEB in relation to impact speed reduction vs. actual impact speed for the CRS and CFS cases are illustrated in Figure 8. Impact speed reduction ranged from 1 to 5 m/s when the MAEB was applicable (between 14% and 50% of the actual impact speed). The MAEB would have activated enhanced braking (EB) in the majority of CFS cases. In CRS, the MAEB would have activated autonomous braking (AB) in half the cases and the EB in remaining cases.

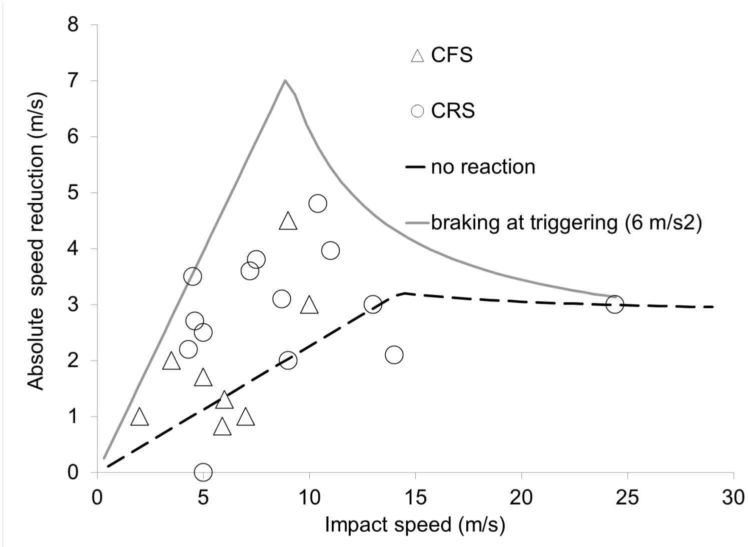


Figure 8: Estimated speed reduction due to the MAEB in the car following scenario (CFS) and crossing scenario (CRS) cases. Additional curves indicate the theoretical values of speed reduction due to MAEB in case of no reaction or medium braking at the triggering poing.

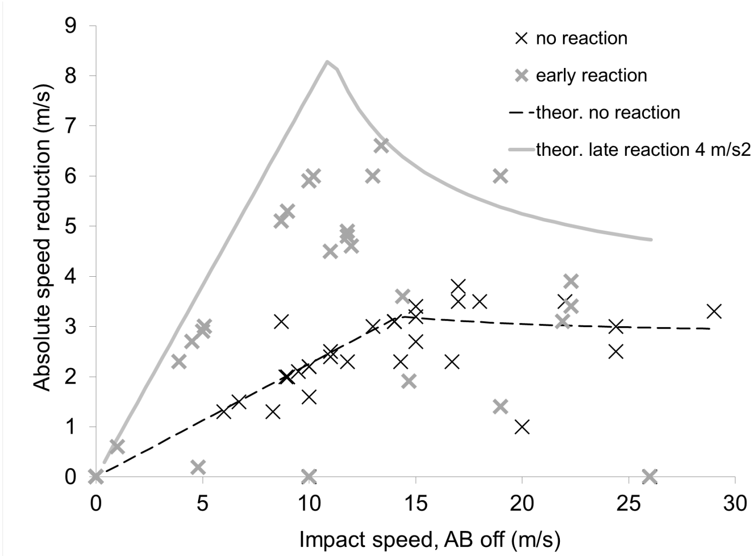
The CRS and CFS were further investigated by considering a range of possible rider behaviours, including early hard braking after the precipitating event (reproducing attentive, skilled rider: experienced rider). A total number of 160 variants of the initial number of CRS and CFS scenarios (respectively 28 and 9) were generated. Results of the simulations showed that earlier and/or more efficient reaction of the rider may have avoided some crashes, and in particular the potential of an experienced rider to avoid 17 out of the 37 cases analysed (46%) (see Table 4).

Table 4: N. of crash cases potentially avoided by the rider with the range of hypothetical reactions (N. collisions avoided by braking/N. remaining collisions in which MAEB was applicable/ total N. of collisions).
lL: late braking, low deceleration lL; lH: late braking, high deceleration; eL: early braking, low deceleration; eH: early braking, high deceleration.

Manoeuvre	CFS	CRS
lL	0/8/9	0/24/28
lH	3/5/9	2/22/28
eL	5/3/9	4/20/28
eH (experienced rider)	6/2/9	11/13/28

Conversely, the simulations also showed that an experienced rider would not have been able to avoid the remaining 20 out of 37 cases (simulations based on fixed pre-crash configurations). In 15 out of those 20 crash cases the MAEB would have potentially contributed to reduce the impact speed (reduction ranging from 1 to 7 m/s). The picture of impact speed reductions for the range of rider behaviours is presented in Figure 8.

Table 5: Estimated speed reduction due to the MAEB in the car following scenario (CFS) and crossing scenario (CRS) cases considering a set of different rider behaviours. Additional curves indicate the theoretical values of speed reduction due to MAEB in case of no reaction or late braking.



In the CFS, impact speed reduction was up to 3 m/s in the absence of rider reaction at impact speeds up to 15 m/s. Late, hard braking would have avoided some of the collisions and the pure AB associated to the reaction of the rider would have produced an impact speed reduction of up to 1 m/s.

In CRS, when the actual impact speed was above 15 m/s, and in absence of a reaction of the rider (pure AB), the observed reduction in impact speed was ranged from 1 m/s to 4 m/s. In these cases, and with additional rider braking reaction, the impact speed reduction produced by the MAEB (EB) was up to 5 m/s.

Table 6: Benefits of the MAEB for the most populated crash scenarios.

Scenario	Description	N. cases/ N. cases MAEB applicable	Mean speed reduction
CFS	Car following scenario	9/8	1.9 m/s
CRS	Crossing scenario	28/24	3.0 m/s
SV	Single vehicle	7/0	-

DISCUSSION

Our results provide support for the potential utility of the MAEB under two main crash scenarios: car following (CFS) and crossing (CRS). Under CFS, enhanced braking (EB) would have been activated in the majority of cases, with the potential to reduce impact speed and crash severity. In the CRS, the effectiveness of the system showed potential benefits, although this was less clear due to the moving obstacle. Greater reduction in speeds at impact were obtained with the EB functionality, providing results of great relevance for the development of MAEB systems, as also suggested by (Roll *et al.* 2009).

These results show that pure AB is of great relevance in reducing impact speed due to the high frequency of cases in which riders showed no evidence of pre-crash reaction (braking, swerving, etc.). This is especially true for CFS.

The results addressed the CFS and CRS cases. Nevertheless, the cases belonging to crash scenarios other than CFS and CRS confirmed the trends showed above (Savino *et al.* 2013b).

The quantitative benefits produced by the MAEB in terms of impact speed reduction may appear limited compared to the actual impact speed. This, however, is mainly due to the necessary timing of an intervention that is at once constrained by the criterion of physically unavoidable collision, and hence, designed to not interfere with the rider's behaviour. It is beneficial to consider that at speeds above approximately 15 m/s, lateral avoidance manoeuvres are more effective than braking manoeuvres (Giovannini *et al.*), whereas the MAEB can intervene only by applying a braking manoeuvre.

A limitation of the present study was to adopt a very simple model for the PTW and to focus solely on longitudinal dynamics. Regardless, the general hypotheses used for the simulations provided support for the potential utility and effectiveness of the MAEB (Symeonidis *et al.* 2012). Furthermore, despite the simplicity of the simulations, a confirmation of the results using a full detailed model of the lateral dynamics (restricted to the car following scenario) was obtained in (Savino *et al.* 2013a).

CONCLUSIONS

The present study investigated the potential benefits of MAEB over a small set of in-depth crashes collected from European databases showing the system's potential to reduce crash impact speed. MAEB was effective in reducing impact speed in both rear-end crash cases and crashes occurring at crossings.

Although the MAEB still requires extensive further research before being applied to the market (in particular to fully understand the effects in real-world crashes and to find solutions to a number of technical issues) our results indicate that, not only does the MAEB have potential to help novice riders but could also considerably improve safety for more experienced riders. Traditionally, PTW riders are far less accepting of autonomous assistance technologies than car drivers. The results shown here could go a long way to encouraging the further development and acceptance of such systems.

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