A novel approach for evaluating the potential benefits of motorcycle autonomous emergency braking (MAEB) in real world crashes

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Abstract

Motorcycle autonomous emergency braking (MAEB) was recently identified as a promising safety solution, the applicability of which was estimated to be one third of all motorcycle crashes. Further evaluations are needed to clarify the potential benefits of MAEB in real world crashes. In this paper, a new method is presented. The method involves firstly identifying the types of crash scenarios where autonomous emergency braking is likely to be applicable. Crash types are classified using the Definition for Classifying Accidents (DCA) codes. Secondly, for each selected DCA a number of representative crashes are chosen as reference cases (baseline) from real world motorcycle crashes in NSW and SA. A distribution of slightly modified cases (variants) from the baseline cases is then generated. Adopting the Monte Carlo method, the initial position of the vehicles, the reaction times and the type of reactions are randomly altered in each variant within predefined ranges. The effects of MAEB, in terms of impact speed reduction and changes in impact configuration are then estimated using computer simulations across the distribution of DCA crash types. The estimated outcomes for each DCA can then be extrapolated to provide an overall estimation of the potential benefits of MAEB using mass crash data from SA and NSW.

Introduction

On public roads, motorcycles and mopeds, often referred to as powered two wheelers (PTWs), are widely used for recreational and utilitarian purposes both in developed and in developing countries. Different regions in the world are characterised by different PTW usage in terms of fleet type/age, motivations for riding, and user characteristics. In Australia, as well as in several southern European countries, PTW are used for commuting in urban and suburban areas, as well as for recreational purposes (especially motorcycles), typically in rural areas.

The input of the rider is a major determinant of the performance and safety of the PTW. For example, the rider not only controls the dynamics of the PTW using the handlebars but also has to use leaning movements of the entire body to successfully control the vehicle (Giner, Brenna, Symeonidis, & Kavadarlic, 2008). In quantitative terms, the ratio between vehicle and user mass is much higher than for typical passenger cars (3 to 15 times higher). PTWs are also very different from bicycles, as the ratio between thrust power and vehicle mass is typically much higher for PTWs (25 to 60 times higher). These characteristics of PTW emphasise the importance of human factors for all aspects of riding, including safety. Rider acceptance should also be carefully taken into account in the process of designing PTWs and especially new technologies.

As a mode of transport, PTWs involve a much higher risk of a casualty crash. It has been found that the rider of a motorcycle is 30 to 40 times more likely to incur in serious injuries and fatal crashes than a car occupant per unit of distance travelled (Johnson, Brooks, & Savage, 2008). Reasons for the greater risk include the capacity for high travel speeds (often well above 30 km/h) combined with the lack of protection for the users, the demanding control task, susceptibility to hazardous road conditions, and the low conspicuity of PTW.

Good riding skills and greater riding experience may be beneficial for safe motorcycling. However, expert riders may in some cases consider themselves to be immune from risks (Huth, Füssl, & Risser, 2014) despite the continued involvement of experienced riders in serious crashes caused both by their own and others' errors (Savino, Pierini, Rizzi, Frampton, & Thompson, 2013).

The analysis of real world crashes can provide a picture of possible and frequent types of injuries resulting from PTW crashes (de Rome et al., 2011). Minor injuries are more frequent although the significance of these should not be underestimated, since they can markedly affect the injured rider's life (de Rome et al., 2012).

PTW safety could be improved by improving the vehicle handling and enabling greater vehicle control, in particular for emergency manoeuvres such as braking and swerving. There has already been substantial progression toward safer PTW design in terms of improved tyres, frames and suspensions. These elements have contributed to improve handling through improved interactions with the road surface, which has also proven beneficial for vehicle performance. However, improvements in PTW performance have often come with a greater capacity for higher speeds and thus ultimately higher risks of injuries.

There are a number of rider-focused interventions that could conceivably improve motorcycling safety. One of these is achieving better control skills and road awareness among motorcyclists though improved rider training. Considerable research has been devoted to evaluating the effects of rider training, but despite this, a recent Cochrane review concluded that most of this research was characterised by flawed methodology, which thereby limits the interpretation of the effectiveness of these training programs (Kardamanidis, Martiniuk, Ivers, Stevenson, & Thistlethwaite, 2010).

In recent years, substantial efforts have been directed toward the development of personal protective equipment (PPE). Current PPE provides protection against bruises, muscular laceration, bone fractures and head injuries. However, there are limits to the protection that can be provided to vulnerable road users such as motorcyclists, especially when involved in high speed crashes (de Rome et al., 2011).

Ultimately, crash data indicate that the risk of serious and fatal motorcycle crashes remains for expert riders wearing high standard PPE and riding high performance PTWs. Therefore, additional safety interventions are needed.

In the 1990s an active assistance system initially adopted for airplane wheel brakes and then passenger cars, the antilock braking system (ABS), was introduced into the PTW market. This system has been further developed and refined since then and modern ABS systems are characterised by reduced mass, reduced size, higher reliability and smoother behaviour. ABS can also be integrated with combined braking technologies. A contemporary version of ABS has been claimed to avoid wheel lock and control losses also when the motorcycle is travelling along a curve (Matschl, 2014). A number of independent studies have confirmed the effectiveness of ABS in reducing the risks of serious injuries and fatalities (Rizzi, Strandroth, Kullgren, Tingvall, & Fildes, 2014; Teoh, 2011). However, ABS still requires the rider to brake and apply sufficient force on the braking controls to let the system achieve the deceleration permitted by the road and tyre conditions. Related to this, it has been shown that riders can fail to effectively control their vehicle in emergency situations (i.e. no action at all or insufficient pressure applied on the brakes) (Penumaka, Savino, Baldanzini, & Pierini, 2014).

In this context, autonomous and enhanced emergency braking functionality, herewith referred to as motorcycle autonomous emergency braking (MAEB) may produce additional benefits for the rider beyond those of ABS. According to a study conducted with sample PTW crashes from international datasets, MAEB would potentially apply to 20 to 30% of the crashes (Savino et al., 2014). Potential benefits of MAEB were estimated for these crashes via computer simulations based on the most likely reconstruction of each crash case.

The reconstructions performed in Savino, Pierini, Rizzi, and Frampton (2013), and others, typically involve uncertainty in regard to certain key parameters and crash conditions (initial speeds and positions, type of actions from rider and driver, timing and intensity of actions), which strongly affect the estimated benefits of MAEB, as shown in Savino, Giovannini, Baldanzini, Pierini, and Rizzi (2013).

Hence, the aim of this paper is to outline a method to overcome the apparent limitation in earlier studies of the effectiveness of MAEB by using a large number of possible variants of the adopted baseline cases.

Method

The proposed method consists of the following steps:

1. Identification of crash scenarios where MAEB is likely to be applicable;
2. For each selected scenario, a number of representative crashes are chosen as reference cases (baseline) from real world motorcycle crashes;
3. A distribution of slightly modified cases (variants) is generated from the baseline cases;
4. The effects of MAEB are then estimated using computer simulations;

Step 1: Identification of crash scenarios in which MAEB is likely to be applicable

The crash scenarios are described using the Definition for Classifying Accidents (DCA) codes adopted by VicRoads in Victoria, Australia (VicRoads, 2008). This shortlist of DCA scenarios in which MAEB is applicable is identified considering the applicability of a reference MAEB system (Savino, Pierini, & Baldanzini, 2012). MAEB applies to crash scenarios in which the motorcycle is travelling along a straight or a curve with large radius, i.e. when the motorcycle is upright or leaning with a small roll angle, and the obstacle is visible in front of the motorcycle (narrow obstacles will not trigger the system).

In-depth motorcycle crash investigation cases are categorised using the Definition for Classifying Accidents (DCA) codes adopted by VicRoads in Victoria, Australia (VicRoads, 2008) and then evaluated using the ratings scale shown in ***Table 1***. The evaluation is performed by two researchers while a third researcher resolved classification conflicts. A shortlist of DCA scenarios in which MAEB is applicable is then generated.

Table 1. Rating scale used to evaluate the applicability of MAEB to the crash configurations and their subclasses included in the DCA chart.

Rating	Description	Criteria
1	Would have definitely NOT applied to crashes belonging to this specific scenario	Single vehicle, other vehicle hitting PTW from behind, stationary PTW, not applicable
2	Would possibly have applied (controversial)	Narrow obstacle, PTW along a curved path, head on, other vehicle hitting PTW, side swipe…
3	Would probably have applied (technical challenges still need to be solved)	PTW along a straight path hitting crossing obstacle
4	Would have applied (typical configuration)	Rear-end or fixed obstacle, straight path

Step 2: Selection of representative crashes for each DCA

Four real-world cases representing each DCA identified in Step 1 are selected from available in-depth crash investigation records.

The real world cases were selected according to the following criteria: i) level of details and accuracy, ii) completeness of the information, iii) confidence in the case reconstruction, iv) variance in the basic crash mechanisms among the selected cases. These crashes represent the baseline cases (references) for the following steps. A reference case for each DCA is created in a simulated environment using Matlab® using the information contained in the crash records.

The simulated environment consists of a simplified reconstruction of the trajectories of the host and opponent vehicle centres of gravity (COG) projected on a plane (i.e. a 2D simulation). The direction of the first derivative of the COG position represents the vehicle heading. Position, heading and speed for each vehicle are the inputs for the MAEB triggering algorithm. The method used for the simulation has been described previously (Savino et al., 2014).

Step 3: Generation of a distribution of case variants

As the values adopted for the input variables in the simulation (initial speed, heading, etc.) are derived from information collected through retrospective crash investigation they represent the best approximation of the real crash. However, there is an inherent level of uncertainty around how close this approximation is to the real values. The Monte Carlo method allows this uncertainty to be taken into account by generating alternative values for each variable and therefore generating a set of alternative cases. For each reference case, a set of alternative cases (variants) is generated using modified values for the five following variables: initial speed, initial position, initial heading, reaction time, and intensity of the reaction. The modified variables are randomly chosen considering normal distributions around the baseline values. Standard deviations for each variable are defined case by case based on the level of confidence on the reference case. In practical terms, for each variable of each case a reference value Xr is best guessed. According to the level of confidence in the specific case and for the specific variable, maximum and minimum feasible values, $Xmax=Xr+\Delta X$ and $Xmin=Xr-\Delta X$ respectively, are also defined. The probability that the actual value of the variable was X is assumed to be defined by a normal distribution of mean value $\mu=Xr$ and variance $\sigma=\Delta X/3$. The variant cases are generated assuming that the variations of the five variables are independent from each other. For each reference case, 100 variants were generated.

Step 4: Estimation of benefits of MAEB for each DCA

MAEB is considered to apply either a mild, autonomous deceleration of 0.3 g when the collision becomes inevitable and the rider does not apply any braking action (autonomous braking mode) or an enhanced braking action with a deceleration of up to 0.9 g when the collision is inevitable and the rider is applying suboptimal braking (enhanced braking mode). The potential benefits of MAEB in terms of impact speed reduction are computed by considering the difference in impact speed when MAEB is active and inactive on the bike.

The results of the evaluation are provided in terms of cumulative frequency functions for each case. This approach reflects the fact that the potential benefits of MAEB are linked with the specific crash case and not just the crash scenario.

As a final step, the estimated outcomes for each DCA can then be extrapolated to provide an overall estimation of the potential benefits of MAEB using mass crash data from SA and NSW.

Material

The study selected reference cases from two Australian crash investigation studies, described briefly below.

The Neuroscience Research Australia (NeuRA) dataset contains records for 100 in-depth investigations of motorcycle crashes collected between 2012 and 2014 in NSW. The NeuRA crash investigation program uses an ANCIS like retrospective method where riders were recruited after being admitted to a major trauma hospital. Cases were collected within a 200km radius of Sydney. This method involves in-depth interviews with the rider, detailed review of medical records, and inspection of the crash scene, vehicles and protective equipment involved within two weeks of the crash. Police data was also collected for cases where participants gave permission to access these records (approximately 30% of cases). Investigation data was compiled into crash summaries and reviewed by multi-disciplinary panel consisting of mechanical engineers, traffic engineers, motorcycle safety specialists, behavioural scientists, trauma clinicians and crash investigation experts. Crash circumstances are largely based on witness statements and verified by evidence within the data collected and agreed to by the expert panel.

The Centre for Automotive Safety Research (CASR) at the University of Adelaide has an ongoing in-depth at-scene crash investigation program, which has been operating in its current form since 2006. CASR's investigation team is notified by an automatic paging service every time the South Australian Ambulance Service is called to a crash. The team immediately attends the scene of the crash to begin its investigation. The sample includes any type of road crash within a 100 km radius of metropolitan Adelaide, which results in at least one crash participant being transported to hospital. The information collected for each crash includes: photographs of the scene immediately post-crash, photographs and examination of crash-involved vehicles, interviews with witnesses, interviews with police, an engineering survey of the crash site, drive-through videos of the crash site, police reports, Coroner's reports for a fatal crash, injury data from hospitals and all other crash-related medical information, licensing histories for all drivers/riders, crash history for the crash site, crash history for the vehicles involved, a computerised reconstruction of the crash, and detailed interviews with consenting crash participants about the crash and all relevant background information. Each case is submitted to a multidisciplinary review panel to agree on factors contributing to the crash.

Results

An example of the application of the study method is provided as preliminary results and to demonstrate the potential outcomes of this study.

Let us consider a typical motorcycle (PTW) to car crash scenario (Study Case 1), coded DCA 121 (vehicles from opposing directions, right thru), with PTW being vehicle 2 (see Figure 1) and rated 3 out of 4 from ***Table 1*** indicating MAEB would probably apply.

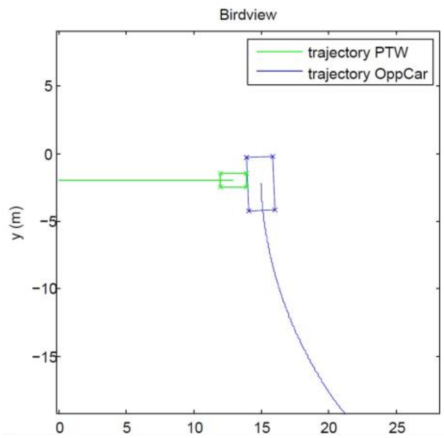

Figure 1. Example of DCA 121 vehicles from opposing directions, right thru, representing one case (Study Case 1).

In this crash case, a rider was travelling on a sports bike along a suburban street. Another vehicle, a 4WD, was travelling in the opposite direction to the rider along the same street. Both vehicles were at a traffic light intersection. The rider set off straight from the lights at approximately 30 km/h once the light changed to green. The 4WD vehicle turned right in front of the rider. The rider had no time to react to the movement of the 4WD and consequently T-boned the left of the 4WD near the A-pillar. The speed of the 4WD was estimated at less than 30 km/h.

This case was modelled in the 2D simulation environment considering the PTW travelling along a straight path, starting from a speed of 0.1 m/s with a constant acceleration of 4 m/s^2, and the car travelling with constant speed of 43 km/h, initially with a relative heading of 90 degrees, along a circular path of 30 m radius. Per the crash report, the rider was assumed not to brake prior to collision. The initial positions of the two vehicles are then adjusted automatically to obtain the collision of the PTW in correspondence to the A-pillar of the 4WD to match the crash configuration identified during the crash investigation. An impact speed of 36.5 km/h for the PTW was obtained in the simulation, which was considered compatible with the information contained in the crash report. A second simulation was then done with MAEB activated. In this second simulation, MAEB identified an inevitable collision between the host PTW and the 4WD 0.27 s before the time of the crash identified in the reference condition. At that point, the MAEB system deployed autonomous braking with a target deceleration of 0.3 g. The final impact speed was 31.0 km/h: MAEB therefore produced an impact speed reduction of 5.5 km/h. Further, the impact point was slightly shifted towards the rear of the car.

Nine variants of the reference case were randomly generated based on the values of the reference variables and an estimate of their variance. The values of the variables used in this example for the variants are provided in Table 2, together with the impact speed values with and without MAEB activated. The cumulative frequency curve of the impact speed reduction produced by MAEB on the set of variants (including the reference case) is depicted in Figure 2. The results show that the potential speed reduction obtained by MAEB can vary between 0.3 km/h to 6.2 km/h however, for this specific set of variants, MAEB produced an impact speed reduction above 4 km/h in 50 % of the cases.

Table 2. Variables adopted for the reference case and variants. The values of the reference case represent μ ± σ. IS: impact speed; ISR: impact speed reduction.

Case	**Initial speed (km/h)**	**Initial impact position (m)**	**Initial heading (deg)**	**Intensity of action (m/s2)**	**Timing of action (s)**	***IS w/o MAEB (km/h)***	***IS w/ MAEB (m/s)***	***ISR (km/h)***
Reference	0+3.6	1.5±1	0±5	4±0.5	0+0.5	*36.5*	*31.0*	*5.5*
Variant 1	0.59	1.86	1.65	4.15	0.321	*33.0*	*28.9*	*4.1*
Variant 2	2.25	1.55	0.65	3.94	0.029	*37.6*	*31.4*	*6.2*
Variant 3	1.32	2.26	0.32	4.07	0.041	*37.6*	*32.4*	*5.2*
Variant 4	1.19	2.41	0.47	3.95	0.150	*34.8*	*32.1*	*2.7*
Variant 5	1.35	1.55	0.09	3.85	0.132	*34.1*	*30.6*	*3.5*
Variant 6	0.65	0.87	-1.29	4.11	0.159	*35.2*	*34.9*	*0.3*
Variant 7	0.62	1.38	1.31	4.01	0.059	*36.1*	*31.6*	*4.4*
Variant 8	1.75	1.22	2.35	3.97	0.266	*33.6*	*32.7*	*0.9*
Variant 9	1.72	1.25	-0.89	4.05	0.088	*37.1*	*31.6*	*5.6*

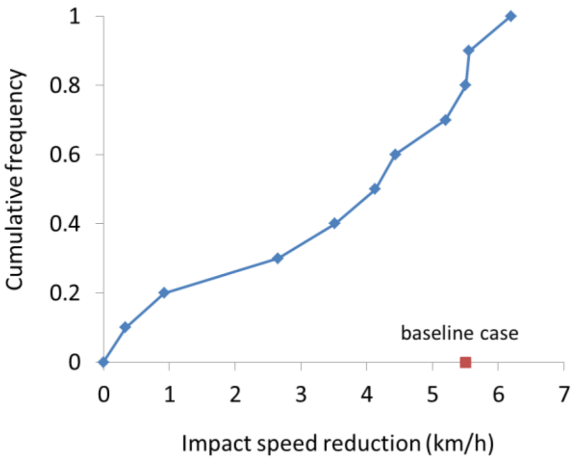

Figure 2. Cumulative frequency curve of the impact speed reduction obtained in a given sample of variations generated from the example baseline case.

Discussion

This paper presents an enhanced method for studying the potential benefits of MAEB that will ultimately be applicable at the population level using the distribution of crashes by DCA in mass crash data. This provides an opportunity for studying the potential effects of a new technology before it becomes available on the market.

Using real world data from Australia, Italy and Sweden, we have previously estimated MAEB can achieve reductions in impact speed of up to approximately 10%, depending on the crash scenario and the initial vehicle pre-impact speeds (Savino et al., 2014). A limitation of the analysis is the degree of uncertainty inherent in the input crash variables derived from retrospective reconstruction of real world crashes. The significance of the analytic method presented here is that it overcomes this limitation. This is achieved using the Monte Carlo method by generating a large number of variants for each reference case and computing the impact speed reduction in each variant. The aggregated results of the simulations provide a level of confidence in the estimated benefits of MAEB for each crash case that could not be achieved simply by simulating individual crashes. The method being used also provides a mechanism for studying the applicability of MAEB across the full range of DCA and a range of crash variations within DCA categories. This is achieved by systematically selecting all the DCA where MAEB is likely to apply and populating each crash scenario with crashes reflecting the range of crash variations within DCA categories from the real world data in the available crash datasets.

There are however some limitations still to be overcome before the potential benefit of MAEB can be truly estimated. The primary limitation is that currently there is no clear correlation available between impact speed reduction and injury reduction for a motorcycle rider. While it is theoretically likely that altering the impact point (i.e. the point of impact between the motorcycle and another vehicle) may also have a positive influence on injury outcome, more work is needed to understand the direction and significance of this influence for the full range of potential impact points.

Finally, while this current work is being conducted using a large number of crashes form NSW and SA and this allows a large range of crashes to be included in the analysis, the sampling method used in the crash investigation data collection methods means that the full range of motorcycle crashes occurring in Australia may not be captured. Extending this analysis to an even larger number of real world crashes would therefore be beneficial.

Conclusions

The estimation of the potential benefits of a new safety technology using a retrospective approach based on real world crash data is affected by the inevitable uncertainty on the data, and the applicability of MAEB varies case from case even within the same crash scenarios. However, the adoption of the proposed method will give the opportunity to evaluate the likelihood of the influence of MAEB in terms of impact speed reduction on a given set of crashes by taking fully account of the uncertainty of the original in-depth crash data.

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