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Benefit Mapping of Anti-Lock Braking System for Motorcycles from India to Indonesia

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Abstract – *Around 1.3 million people die every year on the world's roads of which 285,200 are users of motorised two or three wheelers. In Indonesia, the number of traffic accidents has also increased by an average of 13% annually (2009-2013). This leads to socio-economic loss of approximately 255,864 million rupiah (Rp). The European Transport Safety Council (ETSC) analysis shows the risk of a motorcyclist (Powered Two Wheeler – PTW) being involved in a fatal accident is 20 times greater compared to a car driver travelling along the same route. This research reveals interesting facts about the Indonesian PTW accident situation through mapping the benefit of Anti-Lock Braking System (ABS) for PTWs from India to Indonesia – although there is no in-depth data available to carry out thorough accident research study. One estimation is that every fourth accident with injuries involving a motorcyclist on Indonesian road can be avoided by a PTW with ABS (assuming a 100% installation rate of such device). This result is in line with other international studies claiming the avoidance potential of PTW with ABS.*

Keywords: Powered two wheeler (PTW), rider behaviour, investigation, accident database, Anti-Lock Braking System (ABS), ABS benefit mapping, Indonesia

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1.0 INTRODUCTION

According to the latest Global Road Safety Report from the World Health Organization (WHO), 23% of all road traffic fatalities worldwide involve riders of motorised two or three wheelers (WHO, 2015). The distribution of such fatality percentage is higher in the South-East Asian and the Western Pacific regions (WHO, 2013) – as seen in Figure 1. This puts the issue of motorcycle accidents as the focus of road safety worldwide. The relatively low price of motorcycles and their low fuel consumption are among the reasons for the motorcycles to gain popularity and presence in the ASEAN region (Association of Southeast Asian Nations) (Md

Isa et al., 2011). Consequently, traffic safety for Vulnerable Road Users (VRUs) which also comprise users of motorised two or three wheelers will become more important in the future.

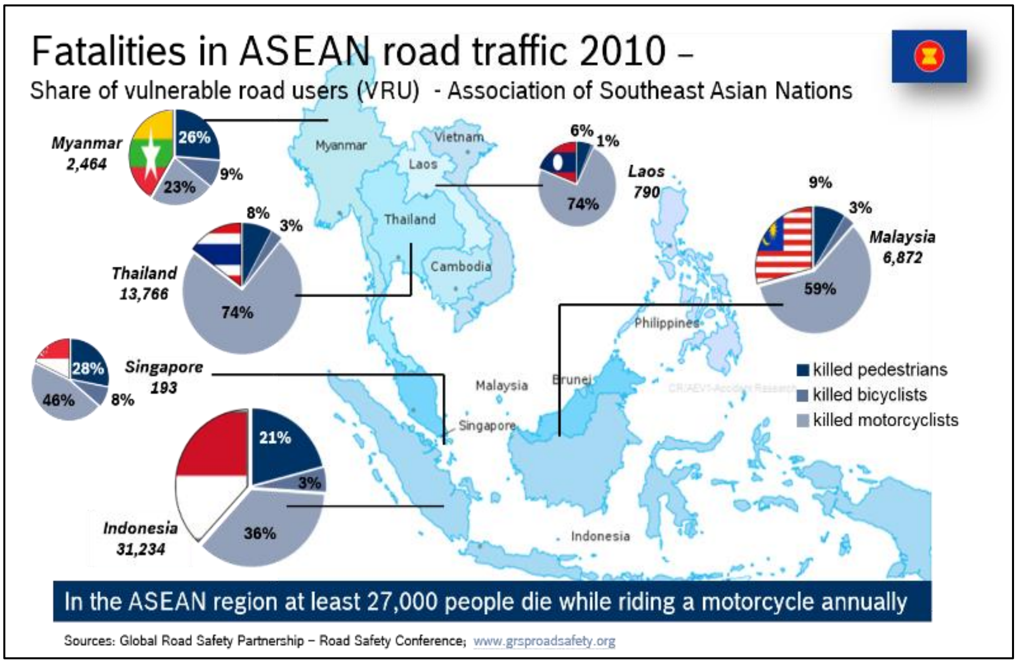

Figure 1: Fatalities in ASEAN road traffic accident 2010

Public transport service in Indonesia is lacking in many aspects especially safety and punctuality, with long waiting time and untidy bus fleet. Old vehicles are still being used for public transport in many locations while small buses ferry passengers in many Metropolitan Cities. These factors lead to the growth in powered two wheeler (PTW) market in Indonesia (Indonesian Country Report, 2009). Having a closer look at Indonesian accident data, it can be clearly seen that the motorcycle segment has the highest fatality rate. Overall in 2013, about 84,733,000 motorcycles were registered in the country (AJTP Information Center, n.d.). According to official statistics, 26,416 traffic fatalities occurred with 9,500 people (36%) killed on Indonesian roads while riding a motorcycle (WHO, 2013).

The overall aim of this study is to estimate crash avoidance potential of a state-of-the-art technology like the PTW Anti-Lock Braking System (ABS) for Indonesia. The major scope is to map the benefits of PTW ABS from India to Indonesia. This methodology is implemented due to lack of availability of accident data in Indonesia and after taking into account the similarity between motorcycle riders' behaviour during pre-crash phase in real accident scenarios. Results of a previous study on the benefit estimation of Motorcycle ABS conducted in India were used as a baseline for the benefit of such technology (Lich et al., 2015). A specific methodology is developed to transfer the results from India to Indonesia. It is therefore the first estimation of how such safety devices could be beneficial in order to reduce traffic fatalities on Indonesian roads.

2.0 ACCIDENT DATA

This section will explain Indonesia and India accident data.

2.1 Indonesia Accident Data

Despite the high number of road accidents in Indonesia, relevant data and information remain difficult to obtain. They need to be collected from various sources such as the police, hospitals, and also insurance companies. In order to understand the root causes of accidents, more detailed data is needed which could then be analysed to understand the major issues and provide potential solutions to the problem. Besides vehicle safety, infrastructure related issues and education skills can be derived out of accident data.

Official statistics regarding accidents in Indonesia are available in national reports. More detailed information on accident causes, accident conditions and consequences are roughly obtained. Initiatives like the 'Indonesia Infrastructure Initiative' launched by the Integrated Road Safety Management and funded by the Australian AID have started to collect slightly more detailed information on crashes (IndII, n.d.). Nevertheless, there is a lack of engineering data attached to the available reports. To address traffic safety related issues like infrastructure, driving behaviour and benefit of vehicle safety systems, more detailed accident data is needed.

As per the type of road users with respect to all fatalities in 2013, nearly 36% (9,500) riders and passengers were killed while on PTW (Figure 2), followed by 35% (9,200) deaths involving trucks and buses with pedestrians coming in third with 25% deaths (6,600) (WHO, 2013).

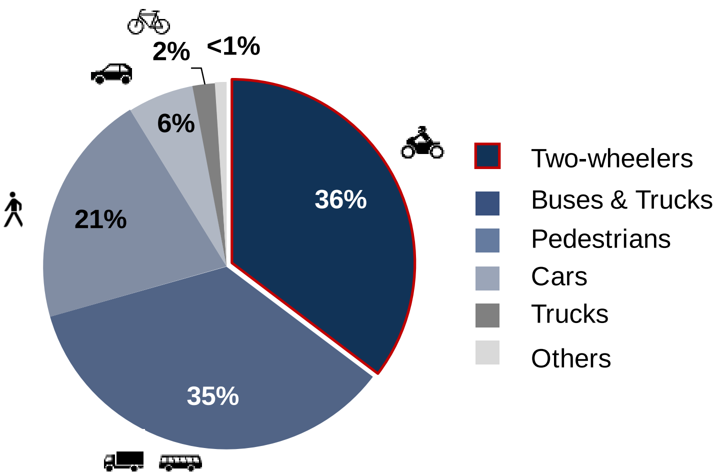

Figure 2: Traffic fatalities in Indonesia by type of road users from 26,416 deaths in 2013

2.2 India Accident Data (Used for extrapolation to Indonesia)

Since only official statistics are available, it is more difficult to conduct in-depth investigation of PTW rider behaviour; which was previously the same situation faced in India. In-depth accident data is collected within the RASSI project (Road Accident Sampling System for India) (RASSI, 2014). Since 2009, accidents with injuries were surveyed within India around the region of Coimbatore, Mumbai-Pune Express highway, Gujarat and recently, in Kolkata. Currently, up to 400 accidents per year are studied through detailed on the spot analysis. Each reported accident is reconstructed by using pictures, scaled sketch and injury information gathered from local hospitals and stored in a database record. Furthermore, pre-crash information on respective driver or rider and pedestrian behaviour is gathered through the accident investigation on the spot. Hence, RASSI is also the name of the relational accident database developed to record scientific data from this in-situ accident investigation. In its current status, the database contains more than 1,200 accidents with about 750 parameters (including reconstruction data) per accident throughout India (Status Jan 2015).

The objective of PTW research is to gain a better understanding of how PTW riders operate the brakes and manoeuvre their motorcycle to avoid an accident (braking, steering); especially if they use conventional brake systems in emergency braking situations. It aims to ascertain the type of brake (front or rear braking, or both) riders use when faced with an emergency situation. Is the braking stable or unstable? Is the braking power sufficiently applied to avoid falling down prior to the collision?

The braking patterns of Indian PTW riders were analysed with minute details using 556 cases from RASSI database involving 234 PTW accidents with casualties. The PTW ABS accident avoidance potential was estimated afterwards based on detailed single case analysis using evidence and coded variables from the data collected from the accident scene. Subsequently, the benefit results from India are mapped to Indonesia.

3.0 MOTORCYCLE ANTI-LOCK BRAKING SYSTEM

A major cause of accidents involving motorcycles is the instability of the bike due to wheel locking as a result of strong braking or braking on a low friction surface. Due to fear of a locked wheel, riders tend to not fully apply the brakes even when needed in emergency situations; which contribute to an even higher number of crashes. In addition, in case where emergency braking is applied, they apply the full brake power at the rear or front brake which causes instability of the PTW and might result in a rider falling down. In a study carried out in Germany on a representative sample of 228 motorcycle accidents between 2001 and 2004, nearly every second accident occurred as a result of not applying the correct brake power. This included either not enough or too much brake power (Zimmermann & Georgi, 2009).

By avoiding the locking of wheels in critical braking manoeuvres, ABS overcomes the above mentioned problems (principles shown in Figure 3). The rider would not have to worry about applying full brakes, thus gaining valuable time before an impending collision and achieving maximum possible deceleration. As a result, ABS can avoid an accident and significantly reduces collision speed. As wheel-lock is prevented, optimal traction is maintained and the vehicle remains controllable even during extreme braking operations.

3.1 Motorcycle Anti-Lock Braking System – Working Principle

The base for a motorcycle ABS, with for instance two brake channels (front and rear circuit), consists of two-wheel speed sensors and a hydraulic unit with attached electronic control unit (ECU) – see Figure 4. The speed sensors are located on each wheel and deliver the information of wheel rotational speed (including lock up of the wheel) to the ECU. When the system detects a considerable difference between the rotational speeds of the two wheels during a braking manoeuvre, an indicator of an impending wheel lock, it actuates the valves in the ABS unit to reduce hydraulic pressure to the brake of the affected wheel. The closing of the valves reduces the braking force on the affected wheel; enabling it to rotate faster. Conversely, if the controller detects a stable wheel, hydraulic brake pressure to the wheel is increased so the braking force is reapplied, slowing down the wheel again. This process is repeated continuously and can be detected by the driver via brake pedal and lever pulsation, which is a characteristic of the ABS.

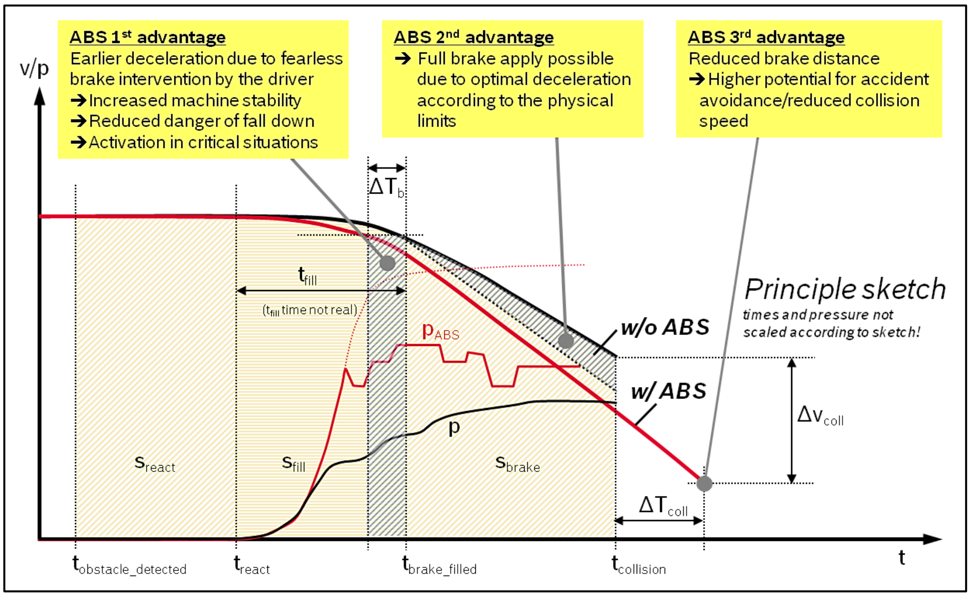

Figure 3: Benefit of motorcycle ABS

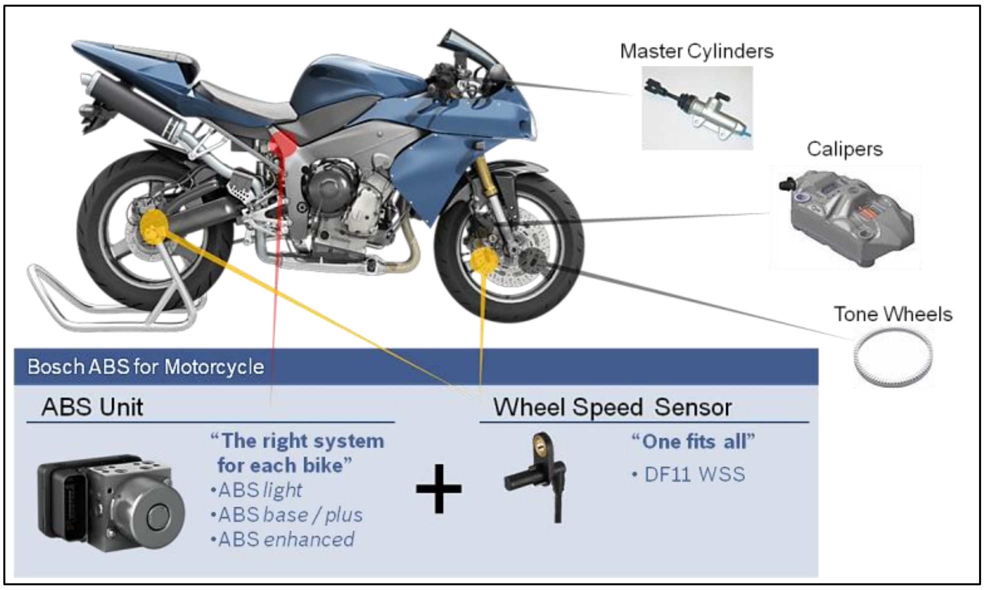

Figure 4: Base components of Motorcycle ABS

3.2 Motorcycle Anti-Lock Braking System – Prior Art

Overall, the ABS increases the potential of accident avoidance as shown in various studies worldwide. In a Bosch analysis on German accident data, it is estimated that 26% of all motorcycle accidents with injuries or fatalities in Germany could be prevented if all bikes were fitted with ABS. In another 31% cases, the average collision speed could be reduced by two thirds (Zimmermann & Georgi, 2009). The ABS benefit has additionally been confirmed by several institutions including the Insurance Institute for Highway Safety (IIHS) in the United States and Swedish Road Administration (Vägverket). An IIHS study showed that motorcycles above 250cc equipped with ABS were 37% less likely to be involved in fatal crashes (Teoh, 2011). In addition, a study of the Swedish Road Administration came to a conclusion that 48% of all severe and fatal PTW accidents above 125cc could be avoided due to PTW ABS (Rizzi et al., 2009).

In their study, Wedagama and Dissanayake (2009) investigated the influence of accident related factors on motorcycle injuries on two arterial roads in Bali. Multinomial logit (MNL) models were projected considering three severity classes such as slight injury, serious injury and fatal injury as response variables using local police data as explanatory variables. Analysis showed that there were four variables associated with motorcycle injuries. The same could be mapped to type of accidents.

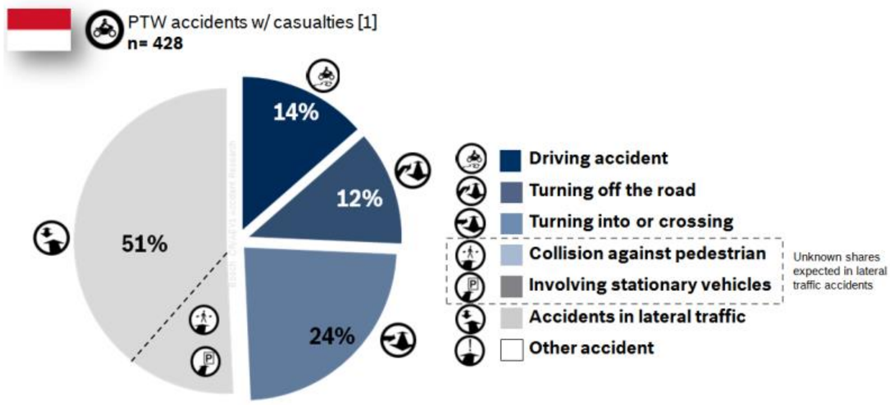

Figure 5: Type of accidents for PTW

The type of accident describes the conflict situation which resulted in the accident. It is the first step to identify root causes of accidents during pre-crash phase. Every accident can be classified by different accident types which are defined in an accident classification system. According to such classification, an international comparison of accident situations can be made. Figure 5 provides an overview of the major conflict situations in which PTW were involved in accidents on two arterial roads of Bali.

"*Collisions in lateral traffic*" recorded the highest percentage of approximately 51%. Such an accident occurs due to conflict between road users moving in the same or in the opposite direction, i.e. a head on collision against an oncoming vehicle. It is assumed that a certain amount of crashes against parked vehicles or pedestrians are categorised in this type of accident. The overall amount was not available at the time of this study.

"*Turning into or crossing*" recorded 24%. This type of accident occurs due to conflict between a turn into the vehicles pathway or crossing road user without priority and a vehicle with priority. This applies at road crossings, junctions and farm tracks as well as access to properties or parking lots.

Another major conflict situation is identified at crossings. "*Turning off the road*" constitutes 12% of such conflict; whereby a turning accident occurs when there is a conflict between a turning road user and a road user coming from the same direction or the opposite direction (pedestrians included). This applies at crossings, junctions of roads and farm tracks as well as access to properties or parking lots.

Nearly 14% is for driving accidents and the major cause is loss of control. These include typical crashes whereas either speeding or overestimation of one's driving skills leads to a loss of control. These accidents can mainly be avoided by a motorcycle ABS.

4.0 BENEFIT MAPPING

This section includes methodology, and example of benefit estimation – "India Real-World Accident Case", as well as "Estimated Mapped Benefit of Motorcycle ABS in Indonesia".

4.1 Methodology

In order to estimate the benefit of PTW ABS, real time rider's braking behaviour pattern helps in understanding the braking behaviour during pre-crash phase of PTW riders. Nevertheless, to maximise the benefit for ABS as a safety function, few assumptions are made: (i) PTW rider applies brake to avoid the collision; (ii) No fall down – ABS helps to keep the motorcycle in stable position hence fall down will be avoided; (iii) Collision speed and brake distance are recalculated by taking hypothetical rider reaction and reaction from reconstructed values into account; and (iv) Maximum deceleration achievable considering street condition, friction and brake system out of on-spot investigated parameters.

Judgment is based on the evidence from the crash site including identification of avoidance manoeuvres prior to crash, brake marks with and without lockup and steering, collision points and final positions. Furthermore, the type of braking as well as deceleration level by rider initiated braking is established. Finally, the collision speed, the distance to stop, availability of free space on either of the lanes and other relevant parameters are considered in drawing the result for the benefit of PTW ABS. The methodology is summarised in Figure 6, and the data is evaluated according to the following steps: (i) The official database availability in both countries is selected and the common data availability is observed; (ii) General distributions are determined from in-depth accident database, and the same check for availability of the key parameters, if not the relational ratio is determined; (iii) Based on the above relation, the field of effect is calculated though mapping of India data; (iv) Determining the share of benefit for each distribution and the same is transferred to Indonesia by applying the share of benefit of each ratio; and (v) Benefit estimations can therefore be transferred from one country to another country provided the minimal accident statistics is available.

In addition, the following additional assumptions are taken into account: (i) Assuming cases from RASSI database being representative for rider behaviour of PTW accidents in ASEAN countries; (ii) Avoidance potential will be constant within a certain category of accident type; and (iii) Projection of PTW ABS benefit out of India for each category by using official statistics from the country in focus e.g. Indonesia.

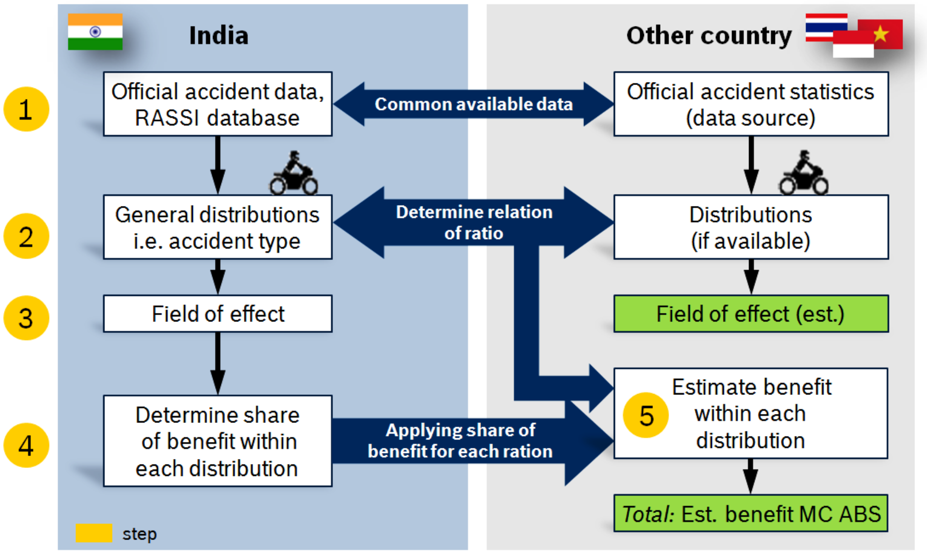

Figure 6: Applied transfer methodology for PTW ABS benefit

The relevance of each accident for a PTW ABS was mapped. This was done by excluding accident scenarios which were not relevant for braking or in which the collision was not necessarily linked to an Anti-Lock Braking System, e.g. rear end collision against a motorcycle. Other root causes were also identified and used as exclusion criteria. The following selection was applied: (i) PTW was at standstill or hit at the rear by other vehicles; (ii) Side sweep contact (first contact to PTW) in lateral forward movement; (iii) Panic stopping in the middle of road; (iv) Accelerating or wrong lane driving (intentional) to avoid long travel to change the lane in the medians; (v) Accidental fall due to potholes or ditch; (vi) Alcohol impaired driving; (vii) Sudden physical disability of the driver; and (viii) Sleepiness (falling asleep) or distraction.

Thus, the so called *'field of effect'* for PTW ABS is defined as *"All relevant accidents involving a powered two wheelers whereas anti-lock brake intervention is possible"*. The benefit of PTW ABS is seen either when an accident was avoided or mitigated in terms of reduced collision speed. To assess the benefit of this system, a new braking distance s' and collision speed v_{coll} was calculated by using reconstructed and gathered parameters out of the in-depth database. The method of recalculating the new stopping distance and the collision velocity is based on dynamic equations similar to the literature by Lich et al. (2015).

The analysis was based on 556 completed cases from RASSI database on Indian highways. This data was mapped to Indonesia by using several parameters including type of accidents, braking characteristics, velocity change, and injury severity. The benefit related to each parameter was transferred to Indonesia, through benefit projection. Figure 7 shows how the parameter from India was mapped with benefit to the same parameter of Indonesia.

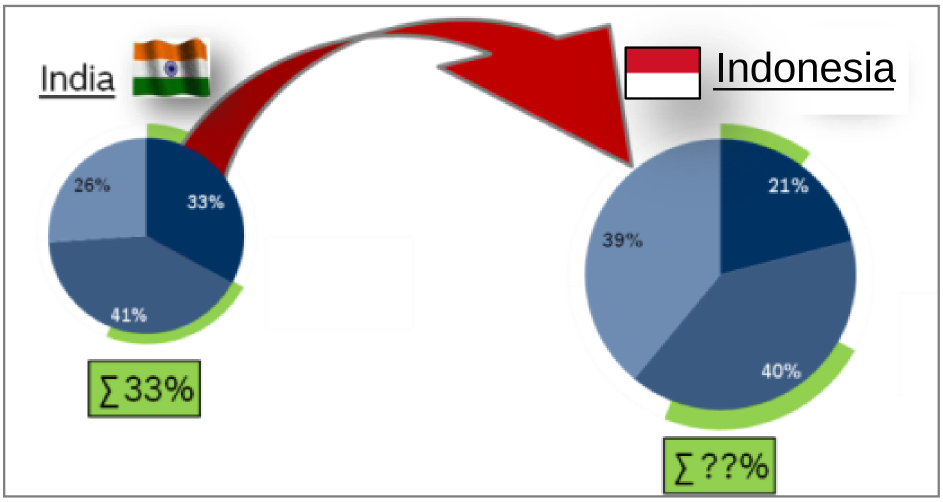

Figure 7: PTW ABS Benefit Mapping from India to Indonesia

4.2 Example of Benefit Estimation – India Real-World Accident Case

The methodology was assessed based on an example case from the RASSI database (case no. 91-2012-02-0155) in which two motorcycles (Unit1, Unit2) were involved:

"Both vehicles were travelling South on the National Highway NH 209. Weather conditions were dry and clear during the afternoon. Unit2 was speeding and due to inattention, the rider didn't recognise that Unit1 was slowing down. After he realised the situation, rider of Unit2 tried to avoid collision by applying full brakes, yet collided with Unit1 due to complete wheel lock. More than 15 m dark tyre mark from the avoidance manoeuvre as well as the collision was clearly visible on the scene. After the impact, both vehicles were dragged towards the right side of the lane. Figures 8 and 9 show the in-depth accident investigation based on scaled sketch, brake marks and accident evidence."

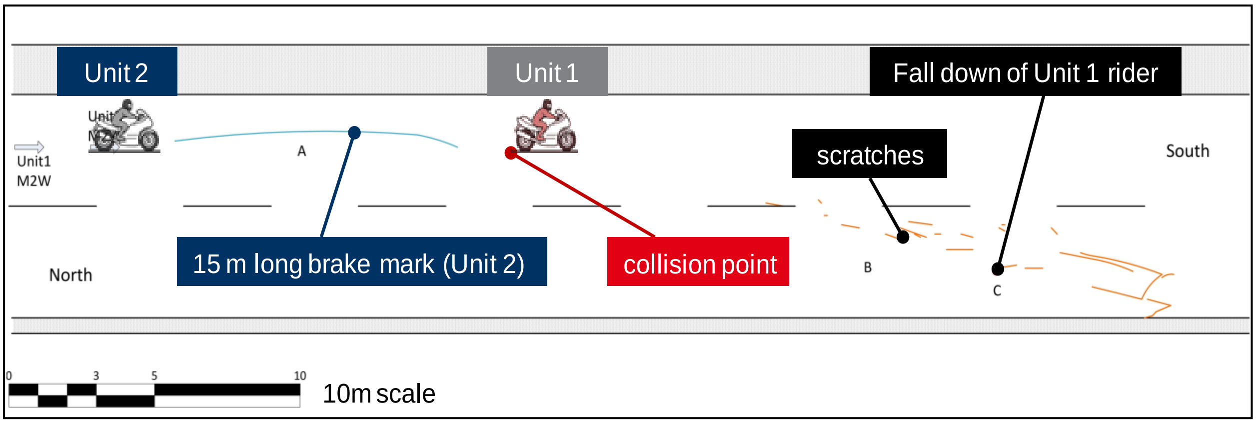

Figure 8: Scaled sketch RASSI case no.91-2012-02-0155

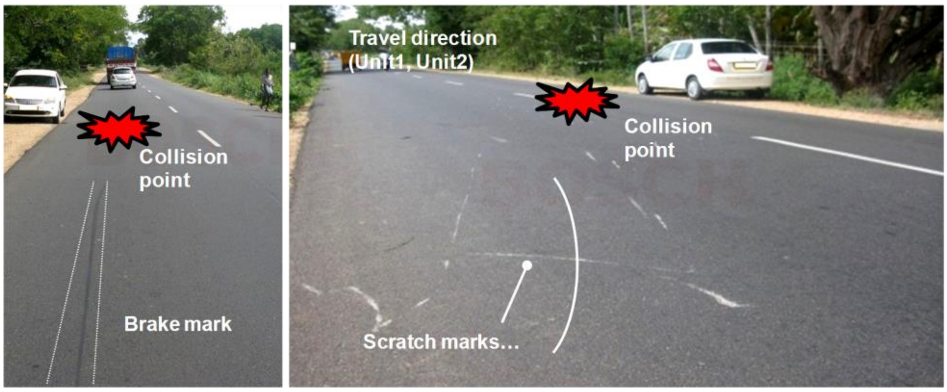

Figure 9: Accident scene including brake and scratch marks and collision point of example case

The method of recalculating the new stopping distance and the collision velocity is implemented for the case.

$$v_0 = 55.7\,\frac{km}{h} = 15.49\,\frac{m}{s}$$

$$v_{coll} = 27.9\,\frac{km}{h} = 7.75\,\frac{m}{s}$$

$$s_{total} = s_{falldown} + s_{brake} \qquad (1)$$

$$\left.\begin{array}{c}\mu = 0.75 \\ \text{street surface: dry} \\ PTW_{type}\text{: code 31}\end{array}\right\} a'_{max} = -\,8.5\,\frac{m}{s^2} \qquad (2)$$

Reconstructed values according to in-depth accident data results in a new recalculated braking distance of:

$$s' = \frac{v^2 - v_0^2}{2 \cdot a'} = \frac{\left(0\,\frac{m}{s}\right)^2 - \left(15.49\,\frac{m}{s}\right)^2}{2 \cdot \left(-8.5\,\frac{m}{s^2}\right)} = 14.12\text{ m} \qquad (3)$$

Comparing it against the reconstructed distance, the calculation is as follows:

$$\Delta s = 14.12\text{ m} - 15\text{ m} = -0.9\text{ m} < 0\text{ m} \;\rightarrow \textit{Accident avoided}$$

In the above case v_0 is the initial velocity of the PTW and was reconstructed to approximately 56 km/h. As soon as the rider detects the obstacle, he reacts by braking with traction time at the expenditure of s react distance. The rider brakes at the time t brake and the s brake distance approximately 15 m and no fall down prior to the collision. Assuming the best braking on the available road surface condition, the deceleration is nearly up to 8.0 to 8.5 m/s^2. If a different road surface condition was observed throughout the investigation (e.g. wet surface), the overall maximum achievable deceleration was adapted to values on wet surface e.g. 6.5 m/s^2. Further, the PTW type (e.g. <125cc) was also considered due to the fact that different brake systems are available and limitations are seen in the overall brake performance.

From the reconstructed values out of in-depth data, the new stopping distance turns out to be 14.12 m. Hence the actual stopping distance without ABS was 15 m, with the result of a collision. The calculation of new braking distance assuming $v_{coll} = 0$ and with no fall down. The recalculated braking distance is less than the measured real distance s (including fall down), hence the accident is avoided by using a PTW ABS.

4.3 Estimated Mapped Benefit of Motorcycle ABS in Indonesia

After applying the methodology for each accident type, the overall accident avoidance potential by a PTW ABS (2-channel) is shown in Figure 10 (assuming 100% penetration). The results of analysis from 556 RASSI accidents were transferred to 428 motorcycle accidents from the study "*analysing motorcycle injuries on arterial roads in Bali using a multinomial logic model*" by Wedagama and Dissanayake (2009).

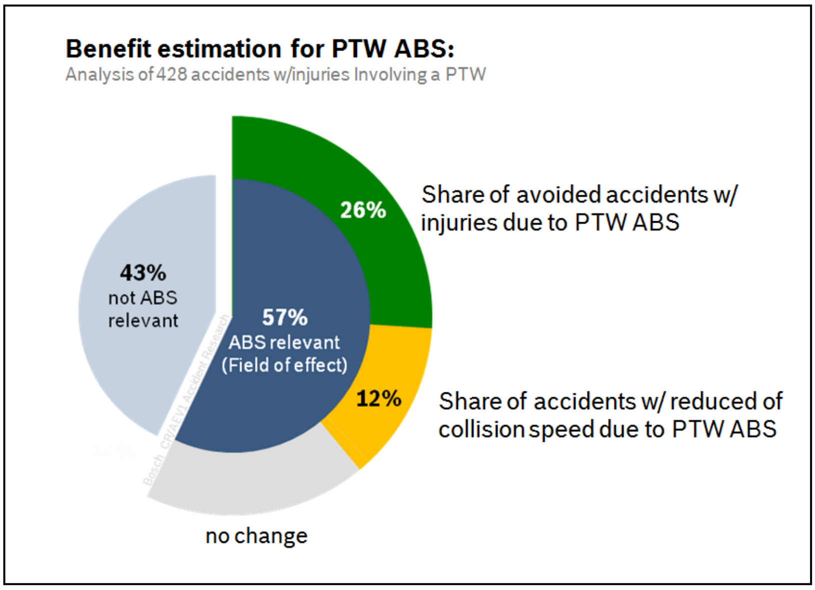

Figure 10: Mapped ABS benefit for PTW accidents in Indonesia

First of all, it is clear that two out of three crashes with casualties involving a motorcycle could be avoided by a motorcycle ABS (field of effect). This is in line with results from other studies mentioned above. Twenty-six per cent (26%) of accident avoidance was estimated out of this mapping procedure. Nearly every fourth fatal crash in Indonesia involving a motorcycle could be avoided by a PTW ABS.

Though not all the accidents can be avoided by ABS, nearly 12% of PTW fatal accidents in Indonesia could have a possible reduction in collision speeds thereby minimising the severity of the accidents. This would lead to reduced injury severity of the PTW riders. In the remaining 19% of cases, no change of the accident situation is seen based on the result of the current database used. This might change with the availability of detailed information in Indonesia. Overall, this is one of the first estimates for benefit of PTW ABS in Indonesia.

The following are limitations to this study:

(i) Detailed accident information in Indonesia was unavailable or inaccessible to the authors. The results assumed rider behaviour and traffic situation similar to India (mapping of accident avoidance potential from PTW ABS study in India).

(ii) The analysis was based on data from Bali. The estimation could have been influenced from other accident related factors in Indonesia and could change the overall analysis.

(iii) In order to validate the results of the analysis, further studies on a larger scale should be made to confirm the results. If more detailed data are accessible to the authors, the overall result could change further.

5.0 CONCLUSION

This study is aimed at explaining the current accident situation of powered two wheelers (PTW) in Indonesia. Furthermore, the accident avoidance benefit of a 2-channel PTW Anti-Lock Braking System (ABS) was estimated for Indonesia by mapping results from India. The following are key findings of the study:

(i) 26,416 people have died in traffic accidents in Indonesia with every third victim killed while riding a PTW. Major conflict situations in lateral traffic (51%) and at crossings (24%). Alcohol influence is estimated for every fourth accident. Thus safety awareness and enforcement must be taken into account in future. The in-depth data is not available in official statistics, thus in-depth accident investigation on the spot is essential to determine the root causes of accidents in Indonesia.

(ii) Field of effect of PTW ABS in Indonesia is determined at 57% ─ in other words three out of five crashes with casualties involving a PTW could be positively affected by ABS. The benefit of PTW ABS in Indonesia is estimated at 26%. In other words, every fourth accident with casualties involving a PTW in Indonesia (assuming 100% installation of two-channel ABS) could be avoided. In addition to PTW accident avoidance, reduction in collision speed is estimated in every 6th accident of PTW ABS. With PTW ABS, a wheel lock is prevented while applying full brake power. Thus a fall down or flip-over is avoided. This will ensure both motorcycle as well as rider are kept stable. The vehicle speed is also significantly reduced and upright seating position of the rider will reduce severity.

(iii) Safety awareness and enforcement must be further enhanced in order to increase traffic safety in Indonesia (e.g. use of helmet, less alcohol usage).

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