Comprehensive study on crashes with pedestrians on Indian roads

Abstract

Pedestrian crashes are a major safety concern worldwide, especially in India. About one of every ten traffic-related fatalities in the country is a pedestrian. In the year of 2021 in India the total number of accidents with injuries is registered by Ministry of Road Transport and Highway ~1,50,000 persons were killed and around 4,51,000 were injured [1]. They were mainly exposed to risk when crossing and walking on the road in urban and rural areas. The aim of the study was to understand the pedestrian behavior on the road and to identify characteristics of pedestrian crashes in India. Many unique behavior was observed like pedestrian crossed half way and stopped in middle of road. Nearly 10% of pedestrians are fatal each year involving in ~5% of overall accidents in India, This study revels every second pedestrian accident occurred while walking and crossing the road straight. An attempt made to evaluate benefit of in vehicle pedestrian safety systems, as an example Car-AEB (Advance Emergency Braking) pedestrian is selected as one of the available technologies and systematic methodology is derived in order to evaluate the benefit of this product.

Introduction

The aim of the study is to understand the pedestrian behavior on the road and to identify characteristics of pedestrian crashes in India. Overall it was aimed to derive countermeasures out from accident contributing factors to improve traffic safety in India. Bosch Accident Research accesses the accident database of the Road Accident Sampling System for India (RASSI).

The present analysis is based on 1,779 in-depth accident investigated and reconstructed cases from RASSI [1]. Overall 168 crashes involving 207 pedestrians were analyzed. Five different locations involving majorly rural, urban and semi urban areas were covered. As a result, every second pedestrian accident occurred while walking and crossing the road straight, and nearly 12% of crashes occurred while the pedestrian was standing in road.

In 90% of the relevant cases human errors had an important role. The study also found that in addition to the human errors, 45% vehicle-related factors and in 60% of the relevant accidents, infrastructure-related factors were documented.

Looking at Europe, US or Japan prime importance is given for the vulnerable road users and pedestrians, in this context various pedestrian accident mitigation systems in both active and passive safety systems are introduced. To name a few Pedestrian Protection Airbag, Active Hood Lifters Predictive Pedestrian protection system. Rear-end collisions mitigation systems or back over avoidance systems, Advanced Emergency Braking (AEB). It is obvious that in India also such systems will support in mitigation of accidents. An attempt made first time to evaluate the benefit of AEB Pedestrian systems.

Data Sources in India

'Road Accidents in India' by Transport Research Wing of Ministry of Road Transport and Highways, [2] and 'Accidental deaths and suicides in India' by National Crime Records Bureau of The Ministry of Home Affairs [3] are the only two important Official data sets available in India. These datasets are preliminary base for accident research purposes. The official database mainly covers macro level view of the accident situation in India hence the above two reports are not sufficient for detailed analysis of the road traffic accident and driver behavior in India [4].

In order to understand the root causes of accidents, micro-accident data out of in-depth accident investigation is needed. Such data is provided by the RASSI project (Road Accident Sampling System for India [5]). RASSI is a consortium organized project of national and international Original Equipment Manufacturers (OEM) and suppliers. Since 2009, accidents with injuries were surveyed within India around the region of Coimbatore, Mumbai-Pune Express highway, Gujarat and Kolkata fatal accidents recently. Therefore RASSI is also the name of the relational accident database developed to record the scientific data from on-spot accident investigations. The database currently contains more than 1779 accidents with about 800 parameters (including reconstruction data) per accident from four locations across India (Status Aug 2017) [1].

In-depth analysis of Pedestrian crashes in India

The present pedestrian analysis is based on 1779 in-depth accident investigated and reconstructed cases from RASSI. Overall 168 crashes involving 207 pedestrians were analyzed and simulated afterwards [6].

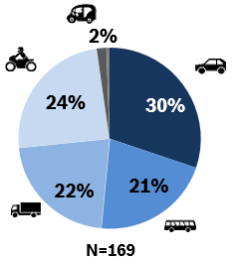

Figure 1. Vehicles involved in pedestrian crash - Collison opponent

Figure 1. Clearly shows out of the sample 168 crashes were at least one pedestrian was involved. The major vehicle involved in this crash is passenger car which is 30% followed by bus 21%, trucks 22%, powered two wheeler (motorcycle) 24%, three wheeler 2% and less than 1% other vehicles tractors and farm vehicles. It is clear that one in every second pedestrian accidents are against commercial vehicles (trucks and buses).

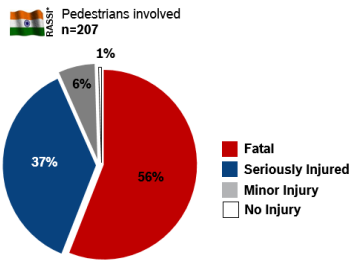

Figure 2. Injury severity of pedestrian involved in crash

Analysis of the RASSI data shows Figure 2 of all injury pedestrians and 56% of fatal, 37 % seriously injured followed by 6% Minor injury. High injury severity is observed when larger vehicle like commercial vehicles and cars involved in pedestrian crashes, every second pedestrian accident is involved with fatal pedestrian from the sampled RASSI data [1]. It is also observed that less than 1% of pedestrian are without injury. This clearly proves that injury risk of pedestrians is very high in India.

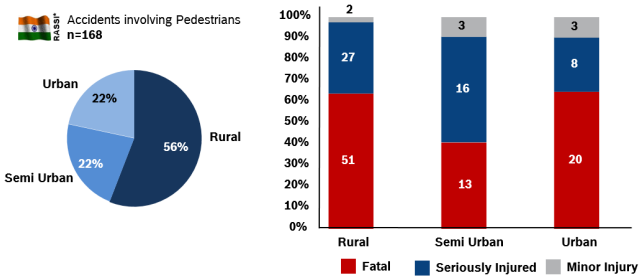

Figure 3. Crash location of pedestrian crash

The distribution of pedestrian accidents involved are classified based on the crash location. 56% of crashes are in rural roads and nearly 44% are from urban and semi urban areas. Every second pedestrian accident in rural roads contributes to pedestrian fatality which is an alarming trend in pedestrian fatality risk. In urban and semi urban areas, the fatality risk of pedestrians is relatively lower in comparison with rural roads. The serious injury risk of pedestrians is relatively high in comparison with fatality.

Pedestrian accidents classification based on type of road is mainly done to clearly identify the pattern of pedestrian accidents rural and urban. This is of utmost importance in order to bring in interventions to mitigate the same. The solutions provided to urban and semi urban areas may not be so beneficial in rural areas. The driving conditions, speed, visibility, and the pedestrian behavior are entirely different for the giving conditions. Hence the type of accident is systematically evaluated based on GDV classification. [7] It therefore provides an indication of the pre-crash situation that led to the accident.

Types of Accidents

Approximately 56% of the crashes happened in rural roads. In these Pedestrian pre-cash behavior can be clearly analyzed through the international GDV (German Insurance Association Accident Classification System) [7]. The top ten percentage share of pre-crash situations are plotted against the accident type.

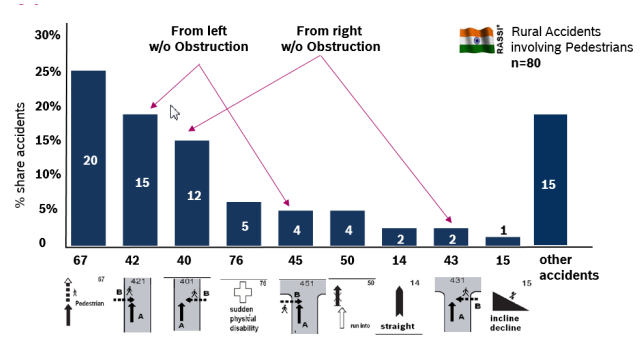

Figure 4. Type of pedestrian crash – Rural

Pedestrians involved in forward moving vehicle accidents, in the direction of the travel of the caused vehicle (Type 67) contribute 25%. It also found that the visibility for the drivers of the caused vehicles was clear with no obstruction. About 22% of the accidents are (Type 42, Type 45). In this case pedestrian is crossing the road from the left with or without obstruction. Nearly 22% of the accidents are (Type 40, Type 43) which is a case of pedestrians crossing the road from the right with or without obstruction. Nearly 8% of accidents are due to sleep or driver drowsiness which is classified under Type 76 - sudden physical disability.

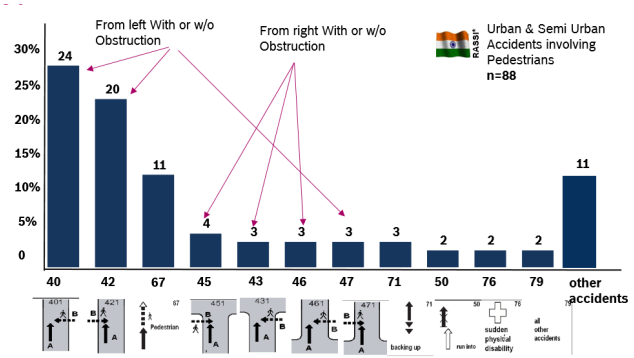

Figure 5. Type of pedestrian crash – Urban & Semi- Urban

Over 44% of crashes are in urban and semi urban road. In this 35% of all accidents are due to pedestrian crossing from the right and 30% are crossing from the left. Pedestrians involved in forward moving vehicle accidents, in the direction of the travel of the caused vehicle (Type 67) contribute 12%. It was also found that the visibility for the drivers of the caused vehicles was clear with no obstruction. Mainly 30% of the accidents are Type 42 and Type 45, the case of pedestrian crossing the road from the left with or without obstruction. Nearly 28% of the accidents are Type 40 and Type 43 which is the case of pedestrian crossing the road from the right with or without obstruction. Less than 2% of accidents are due to sleep or driver drowsiness which is classified under Type 76, sudden physical disability. This clearly shows the precrash maneuvers in rural and urban and semi urban areas are significantly different.

Pedestrian action during pre-crash phase is of utmost importance to understand the behavior of the pedestrian. This information is not easily available or recorded. Systematically each case has been analyzed with all pre-crash parameter along with accident pictures and vehicle movements. Why do pedestrian accidents occur? What was the need of the pedestrian to be on the road? What exactly is the action of pedestrian during pre-crash phase? These questions are answered in Figure 6. Pedestrian actions during pre-crash phase.

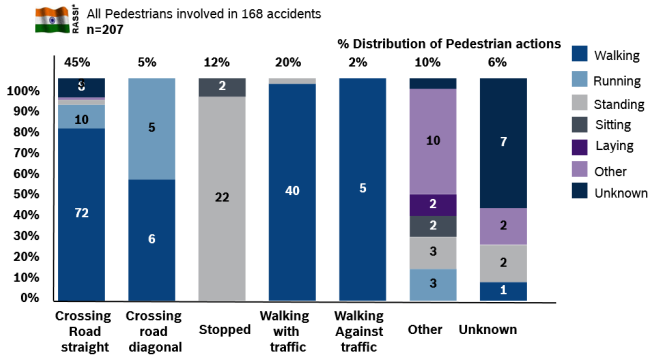

Figure 6. Pedestrian actions during pre-crash phase

Pedestrian are involved in various actions like crossing road straight (45%), crossing road diagonally (5%), walking with the traffic (20%), walking against the traffic (2 %) and stop in the middle of the road (1%). A unique behavior in Indian accidents is observed where close to 12% of the pedestrian crossed half way and stopped in middle of road to allow the vehicle to move on the other lane. This happens mainly in undivided roads. In the western world the driver stops the vehicle and allow the pedestrian to cross and in India pedestrian stops and allow the vehicle to pass. Unfortunately 12% of pedestrian are fatal during this action. In all the above actions pedestrians were walking or running. Nearly 16% of accidents were of another category where the pedestrians were sitting, lying or sleeping on median of the road or periphery of the roads.

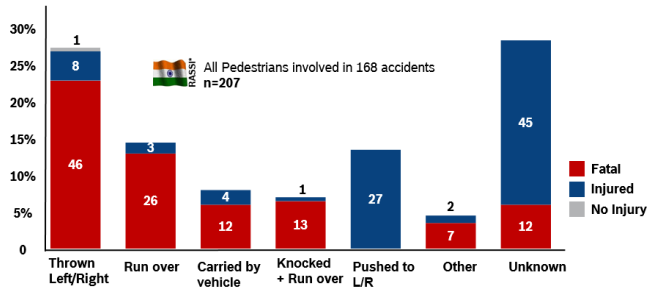

Figure 7. Pedestrian vehicle interactions

After understanding the pedestrian actions on the road it also of utmost importance to understand pedestrian vehicle interaction. An attempt is made to capture the interaction details of pedestrian and vehicle during the crash. It is also observed how exactly the vehicle hit the pedestrian and the aftermath positon of pedestrian. It is seen 30% of pedestrian are thrown to right or left of the vehicle during collision, 15% of pedestrian were run over by the vehicles, 10% of the are carried away by the vehicle either by hooking on the vehicle or by dragging them. Nearly 10% of pedestrians are knocked down on the spot and vehicle run over. In all the above categories 85% of the pedestrians where fatal or seriously injured. 15% of pedestrians were seriously/minor injured. No fatalities are category of accidents where the vehicle was at lower speed which push the pedestrian left or right. These pedestrian vehicle interactions is curial information for the design of vehicle body to minimize the injuries severity of the pedestrians. For example pedestrian run over, thrown left to right and knocked down can all be avoided by implementing suitable pedestrian protection devices on the vehicles.

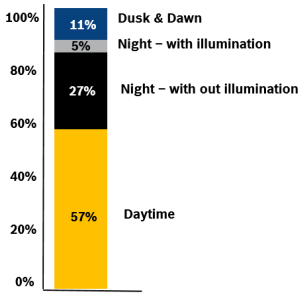

Figure 8. Pedestrian actions during precrash

Generally it's a myth that accidents are mainly at night, no visibility and in the dark. After the in-depth analysis it is found that 52% accidents occur during day time and 40% accidents occurs during night in which 27% of accidents are in dark without any illumination and 8% of accidents are during dawn and dusk. Overall 27% of pedestrian accidents are during night without any illumination.

Pedestrian Accidents Contributing Factors

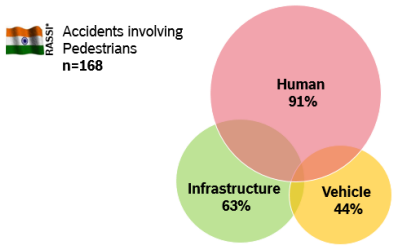

Figure 9. Pedestrian accidents contributing factors

The following tables show the most important contributing factors, which influence the Pedestrian accidents. The contributing factors which lead to the accidents are categorized into human related, infrastructure related and vehicle related. Multiple factors can attribute for the cause of accidents. For the ease of representation, each contributing factor related to the cause is counted and occurrence index is calculated. If particular contributing factors occurs more than 30% in the given sample size, it is considered as high occurrence, 10% to 30% the occurrence index is medium and if the count is less than 10 % the occurrence index is said to be low. The same is represented in the below tables. There is no one reason for each pedestrian accident. Each accident has multi-level contributing factor from either of human, infrastructure, and vehicle or all combined together. When each of contributing factors was isolated through an occurrence index it shows that human error contributed 91%, infrastructure 63% and vehicle 44%.

In human related contributing factors it is majorly observed, that the Pedestrians' dangerous behavior on roadway, Pedestrians' violation of right of way, Pedestrians' walking on the roadway, Pedestrian influenced by Alcohol, Illegal pedestrian entry and Careless crossing of road (Pedestrian) are the major causes.

Human Error – Contributing factor (Accident Level)	Occurrence
Pedestrian dangerous behavior on roadway	High
Driver - Over speeding	High
Pedestrian violation of right of way	High
Pedestrian walking on the roadway	High
Parked-vehicle on road(Partial)	High
Pedestrian inattention	Medium
Driver - Alcohol	Medium
Driver - Sleep/Fatigue/Drowsiness	Medium
Careless crossing of road (Pedestrian)	Medium
Illegal pedestrian entry	Medium
Pedestrian influenced by Alcohol	Medium

Table 1. Human Error – Contributing factor (Accident level) in 91% Pedestrian accidents with casualties in India

Infrastructure related – Contributing factor (Accident Level)	Occurrence
No paved shoulders	High
No pedestrian Crossing (Zebra Crossing)	High
Poor pedestrian infrastructure	High
Lack of pedestrian walking facilities	High
Inadequate warning about accident/parked	High
No lightings on road	Medium

No path for pedestrian	Medium
Poor street lighting	Medium
Vision obstruction due to slow moving bus	Low
Gap in between jersey barrier	Low
Gap in fence at the curb	Low
No lane for pedestrian and bicycles	Low

Table 2. Infrastructure Error – Contributing factor (Accident level) in 63% Pedestrian accidents with casualties in India

No pedestrian crossing (zebra crossing), Poor pedestrian infrastructure, Lack of pedestrian walking facilities, Inadequate warning about accident/parked vehicle are few major concerns in the infrastructure. This has to be significantly redesigned and improved in order to eliminate the pedestrian accidents.

Vehicle Error – Contributing factor (Accident Level)	Occurrence
Cargo not secured (Post Crash)	High
Passenger Compartment Intrusion (Post Crash)	High
Illegal alteration/fitment - Bull bars	High
Vision obstruction due to vehicle interiors	High
Poor braking efficiency	Medium
Protruding/ over-sized cargo	Medium
Vehicle not in good condition	Medium
Very old vehicle	Low
poor vehicle maintenance	Low
Defective-Tires	Low

Table 3. Vehicle Error – Contributing factor (Accident level) in 44% Pedestrian accidents with casualties in India

In many cases Illegal alteration/fitment - Bull bars - which is misunderstood to safeguard the vehicle is creating even higher injury risk to the pedestrian. Protruding/ over-sized cargo and Cargo not secured in the commercial vehicle is also a major concern for the pedestrian safety. Many a time poor braking efficiency contributes to a great extent for the misjudgment of the driver on the estimation of stopping distance.

There can be no “one reason” for the pedestrian accidents. All the three factors shown contributes in one way or the other for crash. In many cases all three factors will be the major contributors. Hence a holistic approach towards the solving the problems has to be established in order to mitigate pedestrian accidents.

In vehicle pedestrian safety systems

Pedestrians are particularly at risk in traffic. In most accidents, the pedestrian collides with the front of the vehicle. Legal requirements and consumer protection tests for pedestrian protection have become significantly stricter in recent years. There are various pedestrian accident mitigation systems in both active and passive safety domain. To name a few in passive safety systems - Pedestrian Protection Airbag which aims to mitigate head impact to hard structure such as A-pillars and windscreen frame, Active Hood Lifters which aims to mitigate head impact to structure beneath the hood i.e. engine, suspension tower battery etc. In Active safety systems, Predictive Pedestrian protection system. Rear-end collisions are among the worst – especially if pedestrians or bicyclists are involved. The predictive pedestrian protection system can prevent such collisions entirely – or, at the very least, considerably mitigate their impact. Predictive emergency braking system: (AEB Pedestrian) This braking system detects that the distance to the pedestrian in front is becoming critically short at a given vehicle speed and it prepares the braking system for potential emergency braking. If the driver fails to react to the critical situation, the system can automatically initiate full braking in an attempt to prevent the collision. The technology used is the fusion of radar sensors and the multipurpose cameras.

An attempt is made to find the field of relevance and benefit for India towards AEB Pedestrian function. In the following sections the methodology is described.

AEB-Pedestrian Example

Accidents involving forward moving passing car collision against pedestrians as first collision is considered for the benefit estimation relevant accident configuration selected are

- At least one car is involved
- The car should be forward moving
- Collison between car against pedestrian

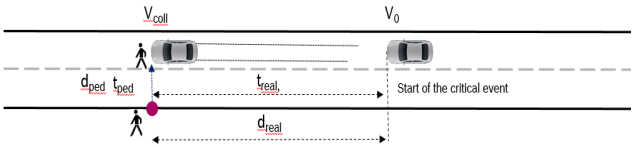

Figure 10. Pedestrian accident representative sketch

The figure 10, shows the car against pedestrian accidents in a representative sketch. The pre-crash position of the car is shown in the diagram. The real case analysis method is explained in steps

- Select all cases of forward moving passenger car with first collision impact as pedestrian
- Measure the distance of the pedestrian d_{ped} from the first visible point until impact point against car (start of the critical event)
- From reconstruction of each case the Initial velocity V_0 ; Collison velocity V_{coll} ; Distance from start of the critical event d_{real} is calculated
- From the constant values of initial velocity Vped calculate the time t_{oed} until the collision point (V_{ped} = Walking* = 1.65m/s, Running*= 3.54 m/s)

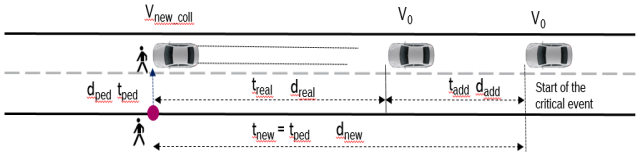

Figure 11. Pedestrian accident representative sketch – AEB pedestrian system benefit estimation

To evaluate the system benefit with AEB-pedestrian, the assumptions are made, the system is equipped with either of one of the sensor configurations like long range radar with range up to 250m or mid-range radar with range of 160m or Stereo video camera which can detect up to 80 m or multipurpose camera with detection range: 2.5m up to 400m. Specific sensor is used in pedestrian detection based on the requirement of detection, for the ease of methodology we assume the senor can detect pedestrian up to 250 m.

To evaluate the system benefit with AEB-pedestrian, the below method is used

- Measure the distance of the pedestrian d_{ped} from the pedestrian walkway to first step on to the street until impact point against car
- From d_{ped} calculate t_{ped} where V_0 is assumed constant
- From $t_{new} = t_{ped}$ calculate d_{new} where V_0 is assumed constant
- From d_{new} calculate $d_{add}$where $d_{add} = d_{new} - d_{real}$. Reposition the car in d_{new} Position and this is considered as new start of critical event position
- Position the car d_{new} & the car is decelerating with AEB-VRU system
- Recalculate the V_{new_coll} new collision velocity of the car, by considering the ideal braking system (deceleration = -7.5m/s^2) and with t_{new} & d_{new}
- From V_{new_coll} new collision velocity, Calculate the new stopping distance and new event time, Calculate d_{stop} with the above parameters
- If new stopping distance is shorter than real critical distance, & the new event time is greater than the real critical event time then the accident is avoided
- If new stopping distance is greater than real critical distance, & the new event time is lesser than the real critical event time then the accident is not avoided, but high severity of the accident will be reduced by reduction in collision velocity
- If new stopping distance is equal to real critical distance, & the new event time is same as real critical event time then no change in accident scenario,
- View angle, range is not considered in the analysis
- Obstructions along the path of the vehicle and the pedestrians are considered in the analysis

New collision velocity

$$V_{coll\_new} = a_{ideal} * t_{new} + V_0$$

Distance gain

$$d_{gain} = d_{real} - d_{add}$$

Time gain

$$t_{gain} = t_{peds} - t_{real}$$

Where

V_0	= Initial velocity of car
V_{coll}	= Collison velocity of car
V_{new_coll}	= New collision velocity of car
d_{ped}	= Distance travelled by pedestrian
d_{real}	= Distance travelled by car in real
d_{add}	= Distance additional - car
d_{new}	= Distance new – car
t_{ped}	= time taken by pedestrian
t_{real}	= time taken by car in real
t_{add}	= time additional - car
t_{new}	= time new – car
-7.5m/s^2	= Deceleration ideal

This method is applied to the all the cases in the available sample and benefit of AEB – pedestrian is estimated. We found out of 1779 cases less than 30 cases were relevant cases for benefit estimation, due to the lack of data and less sample available the AEB Pedestrian benefit estimation method is developed and not projected to India. Furthermore with the limited cases we found in every tenth pedestrian accident is avoided by car AEB pedestrian. In every third pedestrian accident the collision speed is reduced thereby minimizing the severity of the accident for the given sample study.

Pedestrian safety in real word accident situation

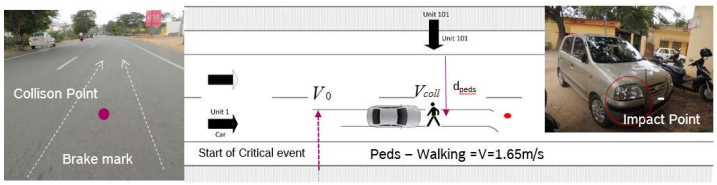

Figure 13. AEB pedestrian system benefit through real world example
RASSI Example case: 91-2013-002-0111[1]

Pedestrian safety in real word accident situation is explained through RASSI example case: 91-2013-002-0111 [6]. Car with was travelling towards North. The pedestrian, a truck driver parked his truck on the roadside and was crossing the road from west to east. Pedestrian crossed road without noticing car which was overtaking another vehicle. Car driver noticed pedestrian and braked hard to avoid, but still had a frontal impact with pedestrian who was thrown off by car to ground. As per the police statement, pedestrian died after reaching hospital. The accident was systematically analyzed with all the in-depth accident parameters and calculated for the avoidance of the same accident if the car was equipped with AEB- Pedestrian. The example calculations is as shown below.

Initial Velocity $V_0 = 54_{Kph} = 15_{m/s}$

Distance Peds $d_{Peds} = 6.45m(measured)$

Time Peds $t_{new} = 3.90_s$

(Calculated based on the distance measured for pedestrian till the impact point)

Collision Velocity $V_{coll} = 34_{kph} = 9.4_{m/s}$

New Coll Velocity $V_{coll\_new} = a_{ideal} * t_{new} + V_0$

Deceleration Ideal $a_{ideal} = -7.5_{m/s2}$

New Coll velocity $V_{coll\_new} = -14.31_{m/s}$

$V_{Coll}, V_{0,\text{Reconstructed}}$

$$V_{coll\_new} = -14.31_{m/s}$$

From new collision velocity calculate the gain in time and gain in the distance

$$d_{gain} = d_{real} - d_{add} = 40.63m$$

$$t_{gain} = t_{peds} - t_{real} = 3.16s$$

If the car was equipped with AEB- Pedestrian the car would have detected the pedestrian movement before the actual intervention by driver and stop the car approximately 40m before the collision point with overall gain in time of 3.2 seconds. Hence Accident is clearly avoided.

In many cases due to the limitation of available stopping distance and poor brake performance despite the car being equipped with AEB-Pedestrian the accident may not be avoided but there is significant reduction in Collison speed with intervention of AEB- Pedestrian.

Summary and Conclusion

- 15,800 pedestrians died annually in India, potential of pedestrian protection systems and VRU safety technology
- Study based on in-depth accident database (RASSI) with 1,179 cases

- The accidents were analyzed from in depth accident data covering 5 different locations involving majorly rural, urban & semi urban
- Every second pedestrian accident occurred in day time, one in three pedestrian accident occurred during night without illumination
- Every second pedestrian accident occurred while walking and crossing the road straight, nearly 12% of pedestrian accident occurred while standing in road
- Maximum fatality in pedestrian seen while thrown out and vehicle run over pedestrians.
- Car – Pedestrian accidents are evaluated based on the reconstruction data
- Crossing pedestrian covers more than 70% of all car-pedestrian crashes (including obstruction), 10% of the pedestrian crash occurs in road junctions
- Filed of effect for AEB relevant pedestrian accident were estimated through RASSI database and common benefit estimation method is established
- With limited cases we estimated One in tenth pedestrian accidents is avoided by Car – AEB Pedestrian, in every third pedestrian accident which is not avoided the collision speed is reduced up to 40- 80% thereby minimizing the severity of the accident, this is only a sample study and cannot be projected to India.
- India is currently using pedestrian protection system regulations for cars (AIS 100)
- AIS -100 deals with Protection of Pedestrian and other Vulnerable Road Users in the event of a Collision with a car

- No active safety pedestrian detection/avoidance system available yet in India
- Sample size and reconstruction data sample size is small to project to whole of India – validation and extrapolation possible on availability of the required sample size

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Acknowledgments

The authors would like to thank the RASSI consortium members 2018 for their support in this project. (RASSI consortium members 2018: JPRI, Daimler, Nissan, Renault, Hyundai, Honda, Maruti, Bosch, Autoliv, Tata, Mahindra).