Potential of Improved Passenger Car Front End Design for Head Protection to Reduce Serious Injuries of Vulnerable Road Users in India

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I. INTRODUCTION

Worldwide about 1.2 million people die in road traffic each year [1]. Middle and low-income countries account for 90% of these fatalities. Vulnerable Road Users (VRUs), consisting of pedestrians, motorised-two-wheelers, and cyclists stand for half of these fatalities. India alone accounts for 17% of global road traffic fatalities, of which 47% are VRUs.

Six opportunities were highlighted for making Indian roads safer, one of them concerning safety for pedestrians and other non-motorists. The countermeasures suggested were separation of motorised and non-motorised traffic on arterial roads, and improving front-end design of vehicles for pedestrian friendliness [2]. German data [3] showed that 60% of pedestrians with severe (Abbreviated Injury Scale (AIS) of 3 and higher) head injuries originating from car impacts can be addressed if protection is provided up to Wrap Around Distance (WAD) of 2100 mm. An increased WAD to 2300 mm was highlighted to cover 90% of pedestrian head impacts. The study [4] estimated reduction of pedestrians with severe (AIS3+) head injury to be 34%, after all vehicles being equipped with passive safety countermeasures. The severity of the impact can also be lowered by lowering the vehicle speed. Fatality risk at 50 km/h impacts is almost two times higher than at 40km/h, and almost five times higher than at 30 km/h [5]. These study results [3–5] are based on pedestrians in Germany; generalisation to other countries and other VRUs is not obvious.

The aim of this study is to estimate the effectiveness of improved head impact protection in reducing serious head injuries, and lowering maximum injury severity among VRUs in India.

II. METHODS

This study used the Road Accident Sampling System India (RASSI) [6] database for crash data. RASSI is an in-depth road accident database in India. It is similar to other international databases such as National Automotive Sampling System – Crashworthiness Data System (NASS-CDS), German In-Depth Accident Study (GIDAS), and Co-operative Crash Injury Study (CCIS), but it is designed and developed to reflect Indian conditions. One of the example is “UTYP” variable in GIDAS which is also available in RASSI as “PRECREV” variable. The codes in “PRECREV” variable is similar to “UTYP” but it reflects Indian scenario. The basic inclusion criteria for RASSI cases are: 1. Accident must involve at least one motorised vehicle; 2. Crash spot must be on public road within the study area. Currently RASSI collects data in five cities: Coimbatore, Pune, Ahmedabad, Kolkata, and Jaipur. Jaipur was added last, and no data from Jaipur was used in this study. Injuries in RASSI are coded as per AIS 2005 conventions with 2008 update. Unweighted RASSI data was used for this paper, as commonly-agreed upon weighting procedures for RASSI data need further development.

Currently available head impact protection systems for VRUs are designed for passenger cars, and therefore this study focused on passenger cars impacting VRUs. Passenger cars in this study did not include sports utility vehicles (SUVs) due to their different frontal design. RASSI data from April 2014 – March 2016 with total 863 road accidents were queried for VRUs impacting the frontal area of a passenger car. The frontal area was defined as general area of damage being front and principal direction of force as 11, 12, and 1 o’clock, or general area of damage as left side or right side and principal direction of force as 12 o’clock i.e. VRU coming from front of the car and colliding with either side which leads the VRU to contact the frontal area of passenger car (sideswipe). This resulted in 103 VRUs (32 pedestrians, 68 motorised-two-wheelers, and 3 cyclists). In RASSI, impact speed is calculated by crash reconstructions in PC-Crash software or by hand calculations. Impact speed is coded as

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unknown where information required for reconstruction is not sufficient. To estimate the effectiveness of improved head impact protection, cases with unknown impact speed and no injury records were excluded. This resulted in 41 cases involving 52 VRUs. Further selecting only VRUs with MAIS3+ injuries gave a sample of 38 VRUs. This sample was used to estimate the effectiveness of improved head impact protection in lowering maximum injury severity as described further on. To estimate the effectiveness of improved head impact protection in reducing serious head injuries, all VRUs with AIS3+ head (head and face) injuries were identified from these 38 VRUs irrespective of injuries to other body regions. This gave a sample of 24 VRUs.

Head Impact Protection Effectiveness method

To estimate the effectiveness of improved head impact protection to an extent achievable by VRU airbags and hood lifters in reducing AIS3+ head injuries, equation (1) from literature [4] was used,

$$Eff_{passive} = \frac{1}{N}\sum_{i=1}^{N}\delta_i^{passive} e(v_i) \tag{1}$$

where $Eff_{passive}$ is improved head impact protection effectiveness, N *is* total number of VRUs, $e(v_i)$ is protection level, and $\boldsymbol{\delta}_i^{passive}$ is delta function which will be one if a VRU is helped by improved head impact protection and zero if not helped. Protection level $e(v_i)$, is maximum (100%) up to an impact speed of 40 km/h. and then decreases linearly to zero until 70 km/h, beyond which protection level is considered zero as shown in Fig. 1.

A passenger car with improved head impact protection would avoid head impacts to stiff members such as the bonnet area, A-pillars, windscreen area up to WAD 2100 mm (approximately half of windscreen area) by cushioning the impact (for example with VRU airbags) or by increasing deformation space (for example with hood lifters). Thus, the protected zone was defined as the area enclosed between 50% of windshield and 75% of bonnet from windshield base, marked with blue lines as shown in Fig. 2. The area outside this zone was referred as unprotected zone for this study. Fig. 2. also shows head impact locations on passenger car (N=9) for the sample of 17 VRUs from 38 VRUs as explained later whereas other impacts are from ground (N=6), side surface (N=1), and multiple impacts i.e. impacting windshield first and later having impact with ground (N=1).

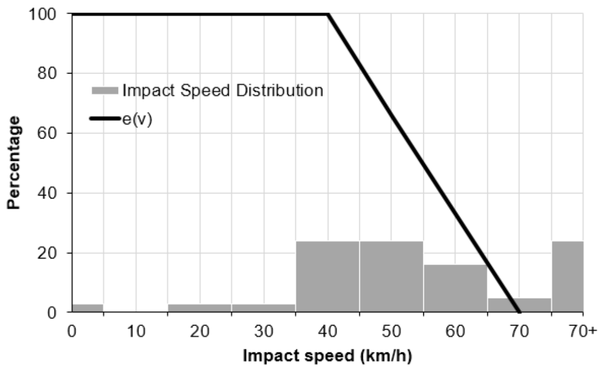

Fig. 1. Protection level of improved head impact protection, *e(v);* and Distribution of impact speed for MAIS3+ injured VRUs.

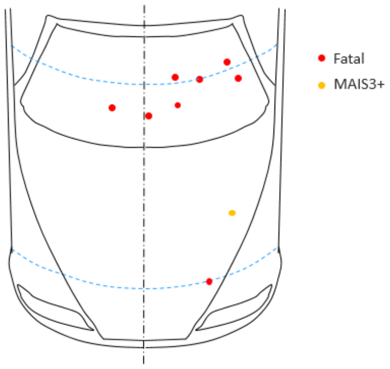

Fig. 2. Protected zone defined in frontal area (area between blue dotted lines), along with evident VRU head impacts on passenger car.

A VRU sustaining an AIS3+ head injury and impacting in the protected zone was considered as helped by improved head impact protection; $\boldsymbol{\delta}_i^{passive}$= 1. If a VRU was impacted outside the protected zone, it was considered not helped by improved head impact protection; $\boldsymbol{\delta}_i^{passive}$= 0. Besides impacting completely inside or outside the protected zone, a VRU might also have multiple impact, both in- and outside the protected zone. Impacting inside the protected zone first, improved head impact protection would probably help: some energy is absorbed, and the secondary impact is mitigated. However, for simplicity, it was assumed that a VRU with impacts both in-and outside the protected zone would not be helped; $\boldsymbol{\delta}_i^{passive}$= 0.

To calculate the effectiveness of improved head impact protection in reducing AIS3+ head injuries, equation (1) was applied directly to a sample of 24 VRUs.

Furthermore, to estimate the effectiveness of improved head impact protection in lowering maximum injury severity, VRUs having highest injury severity to head (head and face) were considered from 38 VRUs. This resulted in 17 VRUs which had highest injury severity to head and lower injury severity to other body regions. $\boldsymbol{\delta}_i^{passive}$ and $e(v_i)$ were evaluated for these 17 VRUs as described before, and remaining 21 VRUs were considered directly as not helped by improved head impact protection; $\boldsymbol{\delta}_i^{passive}$= 0. Equation (1) was then applied to the sample of 38 VRUs.

Statistical Method

The Bootstrap method was used to derive confidence intervals. To explain the Bootstrap method in detail, let us consider a sample of "N" units having values 1, 2, 3, 4, 5, …, n(N). The calculations such as effectiveness, percentage, etc. are performed on these "N" units. Further, another sample is created from these "N" units having the same sample size while the values could be repeated such as 1, 1, 2, 3, 3, …, n(N). The calculations are performed again on the new sample. To create a smooth bootstrap distribution, the process of creating samples of the same size by randomly choosing values from "N" units where repetition is allowed, and performing calculations on those samples, are repeated 10,000 times. Finally, 95% confidence intervals are created by restricting lower and upper limit on 2.5th and 97.5th percentile of the 10,000 calculated values. We applied this method to the sample of 24 VRUs and 17 VRUs to calculate 95% confidence interval for effectiveness, and for the share of VRUs sustaining AIS3+ head injury only due to the impact in the protected zone.

III. INITIAL FINDINGS

The distribution of all injuries may be misleading since one body region could have multiple injuries whereas other body regions may not have that many injuries. To avoid this, in MAIS3+ sample (N=38) we counted one injury per body region which signifies that one individual each body region was counted only once. Fig. 3(a) shows distribution of one injury per body region for MAIS3+ injuries where 63% of VRUs sustained head injury (from windshield, ground, hood, side surface, tires and wheels), 5% - face injury (from windshield, and ground), 45% - lower extremity injury including pelvis (from hood, front bumper, hood edge, other exterior, tires and wheels), 29% - thorax injury (from windshield, hood, ground, hood edge, tires and wheels), and 5% – spine injury (windshield, tires and wheels). The percentages do not sum to 100%, since some VRUs had multiple injured body regions. Main injury source for these MAIS3+ injuries were windshield, roof-rail, A-pillar, hood, and ground, as shown in Fig. 3(b).

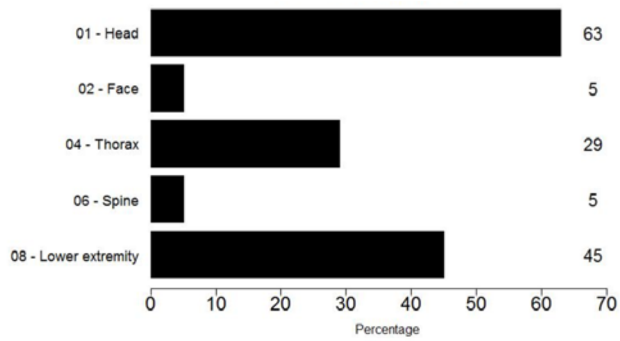

Fig.3a. Distribution of MAIS3+ injured body region for VRUs

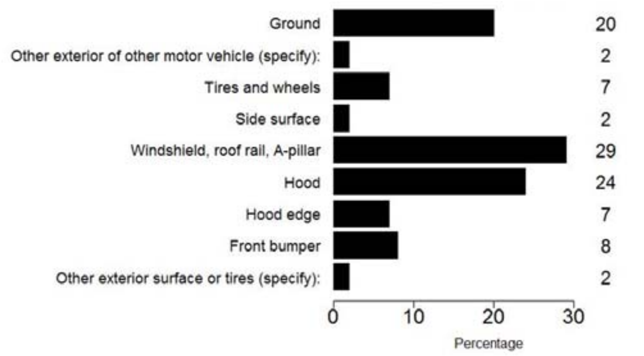

Fig. 3b. Distribution of MAIS3+ Injury sources for VRUs

Head Impact Protection Effectiveness

In the sample of 24 VRUs with AIS3+ head injuries, 50% (95% CI: 30 – 70%) of VRUs sustained head injury only due to the impact in the protected zone. From Eq. (1), the effectiveness of improved head impact protection was estimated to be 27% (95% CI: 12 – 42%). Hence, 27% of VRUs originally sustaining AIS3+ head injuries will sustain only AIS2- head injuries.

In the sample of VRUs with AIS3+ head injuries and the highest injury severity to the head (N=17), 41% (95% CI: 18 – 65%) of VRUs sustained AIS3+ head injury only due to an impact in the protected zone. Further the remaining 21 VRUs were considered as unaffected by improved head impact protection. From Eq. (1), the effectiveness of improved head impact protection in lowering maximum injury severity for VRUs with MAIS3+ (N=38) injuries was 12% (95% CI: 3 – 21%).

IV. DISCUSSION

This study did not consider effectiveness in reducing injury severity for the impacts which were outside the protected zone. To understand how this affects estimating effectiveness, the protected zone was re-defined by area enclosed between the top edge of the windshield (100%) and 75% of the bonnet, from the windshield base. The effectiveness of improved head impact protection in reducing AIS3+ head injuries increased from 27% to 33% (95% CI: 17 – 49%), and effectiveness in lowering maximum injury severity for VRUs with MAIS3+ injures increased from 12% to 16% (95% CI: 6 – 26%).

Some AIS3+ head injuries resulted due to an impact in the middle area (shown in Fig. 2.) of the windshield were fracture, laceration, haemorrhage, hematoma, and edema. These injuries could be due to various factors such as properties of windshield, impact speed, age of VRUs, etc. However, we assume that improved head impact protection will help to reduce such injuries. This study ignored the effect of improved head impact protection on other body regions such as effect on thorax due to increasing distance between hard object in the engine compartment and hood by hood lifters.

It is evident from Fig. 1. that impact speeds greater than 70km/h are not considered in the protection level. Reducing the impact speed would increase the effectiveness of improved head impact protection. For example, reducing speed from 75km/h to 40km/h would increase the effectiveness of improved head impact protection from *no protection* to *full protection*. This was also highlighted using experimental data [7] where risk to have AIS3+ head injury at impact speed of 40km/h was 97% and 100% when impacting lower windshield area and A-pillar, respectively. Incorporating improved head impact protection such as hood lifters and VRU airbags reduced the risk to 18% and 6%, respectively. There was also further reduction possible using different version of improved head impact protection. Further, the effect of relative speed on the effectiveness of head impact protection was not considered.

The estimated effectiveness assumed that improved head impact protection is available in all impacts and works with all the ambient changes. This may not be the case if the improved head impact protection is provided by hood lifters and VRU airbags, which may have some activation thresholds. This study did not investigate practical issues of redesigning front-end structures to be more pedestrian friendly or to implement hood lifters and VRU airbags. However, hood lifters and VRU airbags have been implemented before and the potential shown here makes a case to take all efforts to implement them also in India.

Improving head impact protection of passenger cars to levels achievable with hood lifters and VRU airbags has the potential to substantially and significantly reduce serious injuries. This study estimated a reduction of 27% of AIS3+ head injuries which is similar to the effectiveness estimated for pedestrians in Germany of 34% [4], and lowering maximum injury severity for 12% of VRUs in India impacting the front of a passenger car.

V. REFERENCES

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