Pedestrian Injuries in Delhi, India: Analysis of Hospital Data

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Abstract The proportion of pedestrian fatalities in India constitutes the highest percentage of many cities according to previous surveys. Pedestrian involvement rate and details of patterns of injury are not available for the whole country at the time of writing. This work analyses the nature of injury patterns on non-fatal pedestrian cases for Delhi, India (117 out of 120 cases), along with detailed clinical data. The data was collected from patients admitted for emergency care at St Stephen's Hospital, Delhi, over a period of 17 months. Injuries to all the body segments could not be tracked. The study also looks at the correlation of AIS 2008 levels of injury and hospital cost for applications to safety studies using monetised Injury Cost (IC) scale. There was a progressive increase in IC with severity of injury in AIS. This data set gives insight into details of injuries and crash details for pedestrians in an urban environment of India. The data updates and also provides insight into treatment costs in a non-OECD environment.

Keywords hospital data Delhi, pedestrian injury data, Injury Cost, injury data India.

I. INTRODUCTION

Pedestrians account for the highest proportion of road traffic fatalities in Indian cities [1, 2]. The national road traffic injury database for India is based on data collected from local police stations and does not include injury details. The lack of training of the enforcement agencies in coding injuries as per standards has also contributed to the problem. The police database may include a majority of the road traffic fatalities, but non-fatal pedestrian crashes seldom find a mention and the police data is mostly under-reported [2].

Studies on the non-fatal injuries sustained at urban environments assume significance when we try to understand the complete nature of injuries of pedestrians. With the above known limitations in data collection procedures and infrastructure, a study of these injuries at the point of treatment as opposed to enforcement was adopted. In the process, the availability of clinicians trained to grade the severity of injury was assured along with a larger severity spectrum.

The target of this study based on the emergency care unit was to record injuries to various body regions of the injured pedestrians, along with severity in AIS code. The cases were followed through to estimate hospital cost for the treatment. Such a monetisation of threat is based on previous attempts by [13] and [14] and is not the dominant objective of this work. The aim is to establish methodology that ascertains the injury distribution on pedestrian through assessment of professionals trained to treat injuries. Since India has a significantly different societal support mechanism from the countries where the studies were earlier conducted, initial impressions on findings of this alternative measure for automotive crash injury threat will be extended.

II. METHODS

Methodology of data collection

The injury data study was carried out through cases arriving at the Emergency Department of St Stephen's Hospital over a period of 17 months. The hospital is located in an urban environment with a mixed range of traffic. Data related to crash incidence was collected by interview with patients and relatives of patients.

Data collected included details related to condition of case on arrival, emergency treatment followed, vital

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information, recommendations of further treatment, hospital stay and hospital treatment costs. Apart from hospital related data, the following information was also recorded.

1. Vehicle type involved in collision (two- /four-wheeler / truck or bus /tractor).
2. Part of vehicle involved in collision (Front / left / right/ rear-end).
3. Orientation with respect to vehicle before crash.
4. An estimated resting place post-crash with respect to vehicle.
5. An estimation of distance from vehicle post-crash.

Clinical observations at the time of admission of the case and the AIS levels of injury severity were assigned to every case. A total of 120 cases were recorded during the study period. The data collected on hospital costs were processed as potential Injury Cost (IC) for a particular level of AIS. The data collection process for the study is summarised in Fig. 1. The element on correlation of IC with injury severity in AIS was processed at IIT, Delhi.

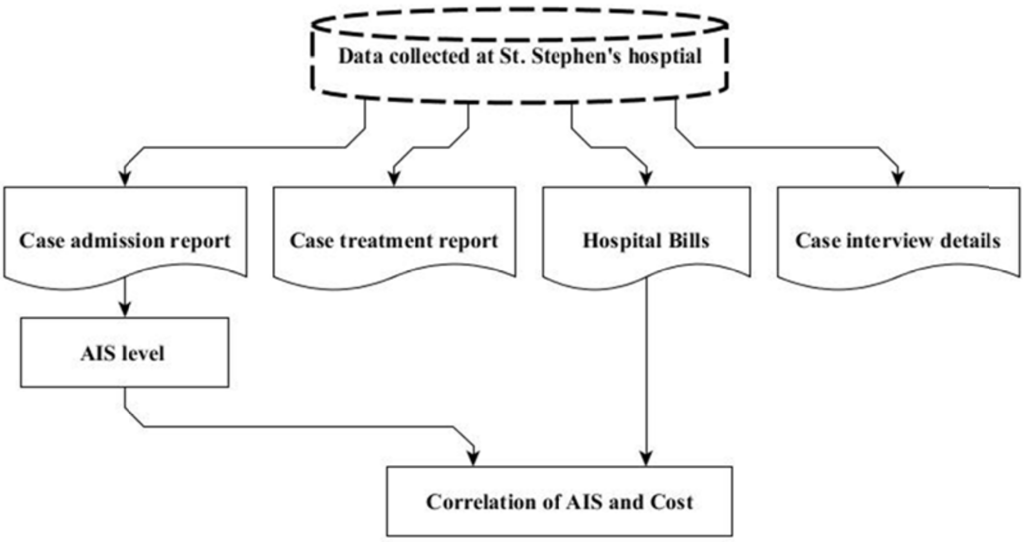

Fig. 1. Overview of data collection and processing methodology.

Methodology for cost implication computations

Hospital treatment data and AIS levels from St Stephen's Hospital were reviewed using the AIS 2008 dictionary. The hospital treatment costs were obtained from duty doctors and the IC value was calculated as the sum of costs incurred under the following headings in the hospital bill:

- admission fee;
- accommodation;
- operation charges;
- theatre charges;
- anaesthesia charges;
- laboratory charges;
- radiology charges;
- pharmacy charges;
- surgical supplies / implants;
- procedures treatment charges;
- pre-anaesthesia check-up;
- gas/oxygen/drugs;
- cardiology charges;
- consultant charges;

- ICU/ High-dependency /post-operation care.

Any discrepancy in the cost implications between the doctors' version and the bill calculations were discussed with doctors and resolved. The discounts to the bill made by the hospital on the basis of the patient being financially unable to pay were not discounted as part of IC calculations. A classification of patients was made under five categories, namely Emergency, In-patients, Out-patients (OPD), Leave against medical advice (LAMA) and Referral to other hospitals. Only those cases which involved "In-patient" in combination with Emergency, LAMA, OPD and external referrals were considered for the list for IC calculations. For cases with multiple injuries to same body region, a Maximum AIS was considered in place of AIS and cases with recorded AIS values in more than one body region were also excluded from calculation.

Handling of hospital cost data for IC

Cases recorded in the study were shortlisted for some specific crash scenario. Working with single crash scenario like frontal or side impact with pedestrians was first step to minimise the variations in injury with variations of causation factors. In this specific scenario of crashes recorded injury to only one body region with maximum injuries recorded in that region was shortlisted for processing IC.

MAIS of a body region was accepted as the indicator of the threat to body region. During IC computations, if body region has three fractures with levels 1, 2 and 3, MAIS for the body region is 3. The IC computation corresponds to the MAIS. A limited assessment based on threat to body region using MAIS a preferred alternative to using AIS of all recorded injuries to avoid known inconsistency in cost computations in literature.

During this work, a sequential averaging method was adopted for computation of the IC corresponding to MAIS level of body region.

III. RESULTS

Pedestrian population involved in crash

The gender ratio of males to females in the sample was 75:25. The major shares of pedestrian cases were in the age range of 21–30 years, followed by 41–50 years (Fig. 2). Children below 10 years were 3% of the sample, whereas their share in the population is 17% in urban areas of India. People above 71 years of age account for 2% of the sample, with a population share of 5% [3].

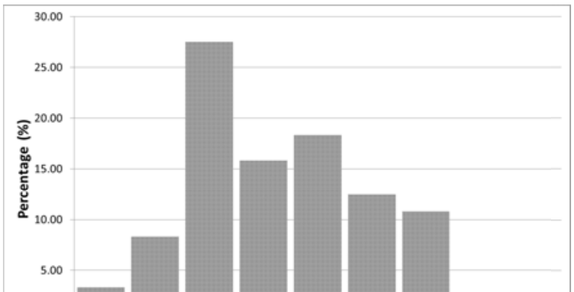

Fig. 2. Age distribution of pedestrians involved in crash.

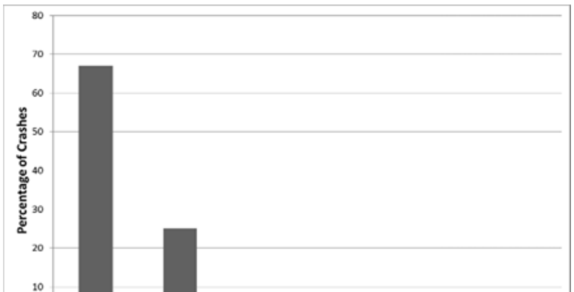

Fig. 3. Types of Crash.

Pedestrian–vehicle interactions

Figure 3 shows the distribution of reported direction of impact, with frontal impacts accounting for 68% of the cases. The distribution of vehicle population impacting the pedestrians is presented in Fig. 4., where the term "2 Wheelers" cover motorised two-wheeled vehicles, "3 Wheelers" covers the "tuk-tuk" or auto-rickshaws, and "4 wheelers" represents cars as well as SUV and multi-utility vehicles. The crashes from the "4 wheeler" category were the most numerous of impacting vehicle types, while "3 wheelers" were the least prominent.

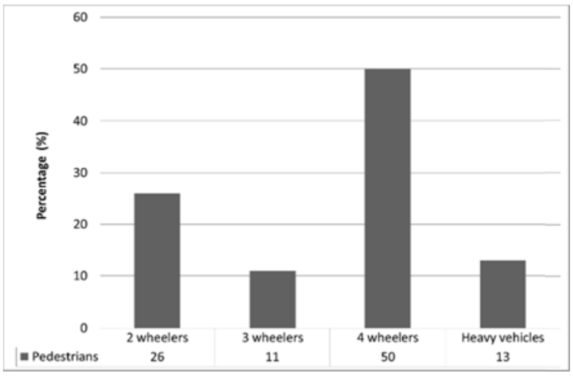

Fig. 4. Distribution of impacting vehicles.

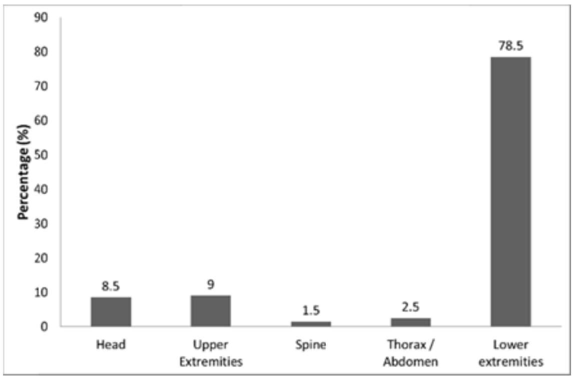

Fig. 5. Distribution of injuries across body regions.

Major non-fatal Injury patterns on pedestrians

An overview of the proportions of injuries coded in AIS is presented in Fig. 5. Lower extremities injuries were 78.5% of total coded injuries and the discussion in this work is restricted to lower extremities injury being the only one to have sufficient number of incidents to be analysed. A summary of the major injuries is presented in Table I. A where "#" has been used to indicate fracture in bones and any additional injury has been mentioned with a "/" sign in Table I. The categories and combinations of injury listed in column 1 were observed from the data collected at the emergency department of St Stephen's Hospital. The category "Three bone #" has been included to indicate following types of fracture combinations of pedestrians:

Against four wheelers

- Closed fracture across bones in left or right leg in combination with type II fractures post dislocation in left or right hip along with acetabulum
- Intertrochanteric fracture to the left or right side in combination with fracture to shaft of femur ad open type II across bones fracture in right or left leg.

Against Heavy Motor Vehicle

- Type III post dislocation in hip in combination with acetabulum and bi-malleolar fracture

TABLE I

Injury patterns of lower extremities of pedestrians correlated with impacting vehicle

Injury Pattern	4W		3W		2W		HMV		Total
	No.	AIS	*No.*	AIS	*No.*	AIS	*No.*	AIS	
Tibia and Fibula #	*12*	[2-3]	*2*	2	*9*	[2-3]	*2*	[2-3]	25
Soft Tissue Injuries	*8*	[1-2]	*2*	[1-2]	*9*	[1-2]	*2*	[1-2]	21
Inter-Trochanteric #	*5*	3	*0*		*1*	3	*0*		6
Pubic Rami #	*3*	2	*0*		*1*	2	*1*	2	5
Shaft of Femur #	*2*	[2-3]	*0*		*2*	[2-3]	*1*	3	5
Neck of Femur #	*2*	3	*0*		*1*	3	*0*		3
Tibial Plateau #	*1*	2	*2*	2	*5*	2	*0*		8
Patella #	*1*	2	*1*	2	*2*	2	*0*		4
Distal Femoral #	*1*	3	*0*		*1*	3	*1*	3	3
Acetabulum #	*1*	2	*0*		*1*	2	*1*	2	3
Lisfranc #	*1*	2	*0*		*0*		*1*	2	2
Trimalleolar #	*1*	3	*0*		*2*	3	*0*		3
Medial Malleolus #	*1*	2	*0*		*0*		*0*		1
SubTrochanter #	*1*	3	*0*		*0*		*0*		1
Metatarsal #	*1*	2	*0*		*0*		*0*		1
Tip of lateral malleolus #	*0*		*0*		*1*	2	*0*		1

Shaft of Tibia #	0		0		1	3	0		1
Tibia #	0		0		1	3	0		1
Bimalleolar #	0		1	2	0		0		1
Hip joint Dislocation/ Acetabulum #	3	[1-2]	0		1	2	1	2	5
Tibia and Fibula # / Calcaneum #	1	2	0		0		0		1
Patella # / Tibial Plafond #	1	2	0		0		0		1
SubTrochanter #/Pubic Rami #	1	[2-3]	0		0		0		1
Inter-Trochanteric #/ Fibula #	1		0		0		0		1
Tibia Plateau # / Compartment Syndrome	0		1	2	0		0		1
Tibia and Fibula # / Compartment Syndrome	0		0		1	2	1	2	2
Tibia and Fibula # / Patella #	0		0		0		1	2	1
Distal Femur # / Proximal Tibia #	0		0		0		1	[2-3]	1
Shaft of Femur # / Pubic Rami #	1	[2-3]	0		0		0		1
Three bone #	2	[1-3]	0		0		1	2	3
Total no. of injuries	51		9		39		14		113

- Fracture, / - combined

Four-wheeler crash cases had maximum number of combined fractures to pelvic region (Acetabulum and pubic Rami) along with neck of femur and Trochanter with 17 out of 51 instances. A combined fracture of Tibia and Fibula was found in 12 out of 51 instances of injuries. Instances of combined dislocation of hip accompanied with acetabulum fractures were observed in 3 cases. Soft tissue injuries were found in 8 out of 51 instances.

Two Wheeler crash cases also had the largest instances of Tibia and Fibula fracture combination with equal proportion of soft tissue injuries (9 out of 39 each). The fractures to the tibial plateau were the next most prominent injury in this category, observed in 5 out of 39 cases.

Heavy motor vehicles caused a higher incidence of injury in Tibia and fibula (2 of 14), hip dislocation with acetabulum and femoral head fractures (3 of 14) and soft tissue injuries (2 of 14).

The most common types of fracture combination observed across vehicle categories, apart from the Tibia and fibula fracture was hip dislocation in combination with acetabulum fracture (5 out of 113). The AIS levels of injury varied between 1 and 3. But, the combinations of fractures were in AIS levels 2 to 3 while soft tissue injuries had AIS level 1.

Cost of lower extremities injuries to pedestrians involved in frontal crash with vehicles

It was observed from Fig. 3 that a frontal crash was the most frequently recorded scenario in vehicle-to-pedestrian interaction. The dataset contained maximum number of lower extremity injuries. A shortlisting of cases for non-fatal frontal crashes with pedestrians involved in frontal crashes yielded 42 out of 117 cases. Elimination of a combination of injuries with lower extremity from the frontal crash cases yielded a total of 27 cases of severity level 2, and 15 cases of MAIS severity level 3. No MAIS severity level 1 cases was observed. An average of the IC for Lower Extremity injury with MAIS level 2 was ₹41,818 and for MAIS level 3 was ₹62,504.

IV. DISCUSSION

Representativeness of the Study

The pedestrian mix in Delhi is heterogeneous, with significant variation of geographical location within Delhi, depending on historical development [4] of the locality and restriction on daytime freight movement. The proportions of pedestrian populations exposed in this study therefore may not represent the overall population of Delhi since this study was limited to one hospital. However, in the absence of more reliable data, this study provides some useful insights into the pedestrian crash-related data in one Indian urban scenario.

Non-fatal pedestrian injuries in Delhi

Soft tissue injuries are expected in all pedestrian–vehicle crashes. The data in Table I might be interpreted to indicate otherwise; but that is not the case. The data in Table I show the number of soft tissue injuries that were not in combination with other bone fracture injuries. The occurrence of 8 soft tissue injuries out of 51 cases indicates that 8 cases did not sustain a bone fracture injury or nerve injury leading to any other AIS coding than soft tissue injury.

Specific combinations of bone fractures around the femoral head and hip joint show the injuries across pelvic / hip region in combination with upper leg to be a more frequently recorded injury.

The age group 20–40 years (37% of population) was involved in 60% of the pedestrian–vehicle crashes recorded. This was not similar to the observations from European in-depth crash database [5], where the population below 20 years of age were most numerous. This is similar to the data presented in the Pedestrian Crash Data Study (PCDS) data analysis of pedestrian crashes in the USA [6], which indicates a mini-peak in age of pedestrians from 6 to 10 years of age and remained high through age group 20–55, with peak at 26–30 years.

Dominant vehicle-to-pedestrian crash scenario

The objective of comparisons with data from USA and European databases in this section is limited to highlight role of composition of the vehicle fleet for India. A crash involving frontal part of vehicle with pedestrians was found to be the most frequent scenario, similar to study findings in the USA [7]. The dominant pedestrian crash scenario observed in GES and FARS databases of the USA was car driving forward. The European In-Depth crash database and GIDAS data [5-8] showed over 89% of pedestrian crashes were recorded with impacts to side of pedestrians from front of vehicle.

The distribution of vehicle population in Delhi is significantly different from urban vehicle fleet of Europe, with a significantly larger share (56% registered vehicles in the year 2012 [9]) of motorised two- and three-wheelers. Within this study, a four-wheeler crash with pedestrians was however found to be the most frequent scenario.

The motorised two-wheeler crashes have been found to be second most frequent causes of pedestrian injuries. This is significantly different from the crash data statistics of Europe discussed by [5]. Most of the available pedestrian crash-related studies of the USA have been around cars and light trucks. A significant comparison is therefore not possible with any other contemporary database. With the predicted increase in the motorised two-wheeler segment in India, potential risks to riders and pedestrians in the future must necessarily factor in the risks posed by two-wheelers.

Three-wheeler crashes have been the most infrequent source of pedestrian crashes in this study, given the large proportion of their road share. Studies on the design of the three-wheeler vehicles by [10] showed that in scenarios other than pedestrian impacting with vehicle mid-lateral plane, the pedestrians would be deflected away from the vehicle rather than being thrown forward. The average operating speed of these vehicles (around 30 kmph) is also a limiting factor in severe pedestrian injuries. A study by [11] on a sub-group of three-wheelers in the city of Ludhiana also observed no pedestrian fatal crashes over the course of five years.

The role of heavy vehicles in non-fatal pedestrian crash cases has been minimal compared to other vehicle categories. An earlier study on pedestrian crashes in Delhi [12] indicated that bus and truck crashes with pedestrians contribute to 60–70% of the known fatal crashes. This change could be due to restrictions imposed on heavy vehicle movement in proximity to the hospital because of the higher probability of fatal crash over non-fatal pedestrian crash if heavy vehicles are involved.

Monetised measure of threat to pedestrian

Cost of injury should include in-hospital treatment cost, follow-up costs and societal impact costs of injury [13]. Only the cost of treatment has been processed in this study, yielding a measure similar to ICS in [14]. The injury cost based perception of threat proposed in [13] and [14] were based on social structures where the emergency care coverage and social support network were well established and monetised. In the Indian context, the societal impact costs of the patients are not easily computed for analysis.

It has been pointed out in literature that a cost-based scale, exclusively based on hospital treatment costs, would lead to scenarios like facial laceration, and then plastic surgery, being computed as a more severe threat than a broken bone in extremities. The IC developed in this study has been based on AIS/MAIS values and not exclusively on anatomical observations and treatment costs. For instances of multiple injuries, MAIS for individual body region was chosen as the indicator of severity of injury as it was observed that injury combinations to particular body regions provided estimates which were more consistent than MAIS computed for the whole body.

For data available in this study, the IC showed an increased financial implication for an increased AIS/MAIS injury. The discussion of IC that follows has been restricted to injuries in one body region and one impact scenario because the data for other body regions was sparse. The drawback of a cost measure related to options of treatment, as noted in the previous paragraph, was not observed in lower extremity injury within this study. For lower extremity, IC-based threat measurement was indicative of relative threat to human from a frontal crash . An increase in AIS 3 severity level of IC over AIS 2 provides initial positive results for exploring further such a methodology for measurement of threat.

It is understood that some injuries have long-term consequences (may or may not be directly linked to cost) which may or may not be completely captured by study of initial hospital treatments of injuries. A societal cost implication was incorporated in [14] to estimate such a long term effect. For India, a formal social support system is not in place; hence such estimation could not be made. The present work therefore could not be extended beyond treatment cost.

The conventional approach to quantify threats to humans is dependent on injury measures processed through injury risk curves for specific AIS levels. In principle, a significant expansion of injury measures would be needed to capture the complete range of injuries causation. Monetisation of threat aims at quantifying the "effect" of crash based on existing medical know-how of treatment and its cost. It is understandable that knowledge of "causation" factors remain essential for injury reduction measures, whereas the same need not be essential for measurement of the effect. Such "effect" based approach nevertheless still needs to be further investigated to estimate primary and long-term monetary implications. It provides an alternate method for a common denominator for injury threat quantification in an interdisciplinary domain.

Limitations of the study

The sample collected is inadequate to make reliable estimates for the whole of Delhi, let alone India. Being a crowded private hospital in the center of Delhi, the proportion of in-patients may be affected by the number of beds available in the hospital rather than proportion of crashes. The details collected from interviews with patients also need to be verified by crash-site analysis in order to confirm descriptions about the crash scenarios.

Limitations on data collections exist on various levels. Since the study was carried out in the supervision of orthopaedic doctors, there could be a bias in lower extremity cases leading to them being highlighted. However, the associated details to other body injuries for the cases have also been documented in the data we analysed.

The non-availability of more severe AIS related cases can be attributed to the following factors:

- A road crash case is treated as a medico-legal case (MLC) in India which strongly discourages private hospitals from admitting severely injured cases.
- Data was collected from time taken for the cases to reach hospital. The cost data on cases where the victim arrived dead is not available on the records we analysed.

The monetised scale (IC) has limitations in being used for policy-making at this stage, because of lack of representation of injury data over the whole body.

V. CONCLUSIONS

The study presents non-fatal pedestrian crash trends for a pilot study with one hospital in Delhi. A frontal crash of a four-wheeler with a pedestrian resulting in Tibia and Fibula fractures followed by soft tissue injury was found to be the most frequent vehicle-to-pedestrian non-fatal crash scenario in this study. An injury cost (IC) measure was found to be indicative of threat to lower limb injury for pedestrian in frontal car crashes. Establishing IC measures over the entire body region to enable mining of hospital cost data to establish injury severity maps is deemed feasible with a populated database. Furthermore, monetised topical databases can be used in combination with Finite Element CAE human models to evaluate threat posed by vehicle fronts based on local exposure statistics, as in [15].

VI. ACKNOWLEDGEMENT

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VII. References

[1] Mohan, D. Traffic safety and health in Indian cities. Journal of Transport and Infrastructure, 2002, ;9::79–94.

[2] Mohan. D., Tsimhoni, O., Sivak, M., J. and Flannagan, M. Road Safety in India: Challenges and Opportunities. The University of Michigan Transportation Research Institute, MI,: 2009.

[3] Census of India 2011. Census of India: Age Structure And Marital Status. 2011.

[4] Tiwari, G. Urban Transport Priorities. Cities, 2002, ;19::95–103.

[5] Neale-Sturgess, C., Carter, E., Hardy R, Cuerden R, Guerra L, Yang J, et al. APROSYS European In-Depth Pedestrian Database. ESV –- Paper No. 07-0177, 2007, Proceedings of 20th ESV Conference, Lyon (France), pp. 1-15.

[6] Jarrett, K. L. and, Saul, R. A. Pedestrian Injury - Analysis of the PCDS field collision data. ESV - Paper No. 98-S6-O-04, Proceedings of 16th ESV Conference, 1998, Ontario (Canada), pp. 1204–11.

[7] Yanagisawa, M., Swanson, E., G. and Najm, W. Target Crashes and Safety Benefits Estimation Methodology For Pedestrian Crash Avoidance / Mitigation Systems (Report No. DOT HS 811 998). Washington, D.C. (USA), 20590,: 2014.

[8] Yang, J., Yao, J. and, Otte, D. Correlation of different impact conditions to the injury severity of pedestrians in real world accidents. ESV –- Paper No. 05-0352, Proceedings of 19th ESV Conference, 2005, Washington D.C. (USA), pp. 1–8.

[9] Delhi Transport Department. "Total vehicles registered year wise 2007 to Sep 2012. "Internet: [http://delhi.gov.in/wps/wcm/connect/doit_transport/Transport/Home/Vehicle+Registration/Total+Vehicle+Registered]., Date updated 30 March 2015. [accessed 30 March 2015].

[10] Mukherjee, S., Mohan, D. and, Gawade, T. R. Three-wheeled scooter taxi: A safety analysis. Sadhana - Academy Proceedings in Engineering Sciences, 2007, ;32::459–78.

[11] Pandey, G., Mohan, D. and, Ramachandra Rao, K. Why do three-wheelers carrying schoolchildren suffer very low fatal crashes?, IATSS Research, 2015, ;38::130–34.

[12] Chawla, A., Sharma, V.,, Mohan, D. and, Kajzer, J. Safer truck front design for pedestrian impacts. Proceedings of IRCOBI Conference, 1998, Goeteborg (Sweden).

[13] Zaloshnja, E., Miller, T., Romano, E. and, Spicer, R. Crash costs by body part injured, fracture involvement, and threat-to-life severity, United States, 2000. Accident Analysis and Prevention, 2004, ;36::415–27.

[14] Zeidler, F., Pletschen, B., et al. Development of a new injury cost scale. Accident Analysis and Prevention, 1993, 25::675–87.

[15] S Ssubramanian, H. S., Mukherjee, S., Chawla, A. and, Goehlich, D. Methodology for estimation of probable location of VRU before impact using data from post-crash analysis. Proceedings of IRCOBI Conference, 2014, Berlin, (Germany).