An Overview on Pedestrians and Cyclists Serious Injuries in Urban Accidents

S. Piantini, N. Baldanzini, M. Pierini, M. Mangini, A. Franci, A. Peris

Abstract The Italian national road accident statistics show that for vulnerable road users (VRUs) urban areas are critical, since are the setting for 75% of accidents. In order to gain a detailed knowledge of the real severity of these accidents and the relationship between injuries and causes, it is necessary to gather in-depth data of real-world road accident injuries (i.e. typology, severity and causations). In this paper, 38 vehicle-pedestrian and vehicle-cyclist accidents in urban areas have been analysed from the InSAFE database. All the accidents involved at least one seriously injured person. Results are presented on pedestrian and cyclist: accident configurations, injury analysis, and impacts to injuries correlation. The analysis point out that primarily small and compact cars at an average impact-speed of 40 km/h struck pedestrians and cyclists. Head was the most frequently injured body region with 28% and 54% of injuries respectively for pedestrians and cyclists. The most frequent head injury was epidural or extradural hematoma, principally caused by the impact against the A-pillar and the upper frame of the windscreen. The results of the research are valuable to design next generation of in-vehicle passive protective devices, specifically targeted for VRUs.

Keywords Cyclist injuries, In-depth Investigation, Pedestrian injuries, Vulnerable Road User, Urban accident.

I. INTRODUCTION

Road accidents account for a toll of 1.24 million deaths per year. Worldwide they are the leading cause of death among people 19 to 44 years old, and pedestrian, cyclist and motorcyclist accidents represent half of total road accident fatalities (22%, 5% and 23% respectively) [1]. Safety experts refer to them as vulnerable road users (VRUs) because they are less protected due to their personal characteristic and mode of transport [2]. In Italy, in 2013, pedestrians were associated to the highest mortality index (MI) of 2.68% among VRUs (519 fatalities in 19354 accidents). MI for cyclists (1.41%), motorcyclists (1.68%) and rider and pillion-passenger of mopeds (0.84%) were lower but still not negligible [3]. Pedestrian and cyclists are alike regarding usage of protective devices. While riders use helmet and protective clothing, the majority of cyclists often do not use any protective garment. Pedestrian are the most vulnerable road users due the absence of any protection items. These differences influence the frequency of injury among VRUs. The German In-Depth Accident Study (GIDAS) reports a prevalence of head injury of 50.4%, 35.6% and 16.9% respectively for pedestrian, cyclist and motorcycle riders [4]. The Italian National Statistical Institute (ISTAT) database reported that in 2013, 75% of crashes occurred in urban area, with a fatality rate of 1.04% (1,421 fatalities in 136,438 accidents) [3]. There is clearly a strong need for more research to improve safety in urban areas. Anthropometric Dummies (ADs) and Post Mortem Human Surrogates (PMHSs) have been used to investigate road accident kinematics and injuries, with partially satisfactory results. Limitations can derive from the inability of dummies to accurately reproduce human behaviour and injury typologies [5], while PMHSs differ from alive human beings because of decomposition of tissues, muscles reactivity, and bone mineral density [6]. Computational models have demonstrated a significant accuracy ([7]-[8]) in the evaluation of crash kinematics for specific VRUs (pedestrians), if compared to PMHS, as finite element models with muscle activation are more likely to describe "real life behaviour" than dummies and cadavers [9]. In order to be more accurate all these methods need to be complemented with real road accident data. In-depth Road Accidents Studies (IRASs), integrating accident kinematics with injuries suffered by people involved in the crash, are essential to provide information regarding the real incidence of injury typologies and severities [6]. Mackay [10], in his works, shows the importance of at-the-scene crash

Simone Piantini is a Research Fellow in Mechanical Engineering (simone.piantini@unifi.it), Niccolò Baldanzini is an Assistant Professor of Finite Element Analysis and Marco Pierini is a Professor in Machine Design all in the Department of Industrial Engineering at the University of Florence, Marco Mangini is a physician post graduate school of Anesthesia and Intensive Care at University of Florence, Andrea Franci is a physician specialized in Anesthesia and Intensive Care and Adriano Peris, is the chief of Anesthesia and Intensive Care Unit both in the Emergency Department at Careggi University Hospital.

investigation and traces back the method to the 70s [11]-[12]. IRASs were established in many European countries such as Germany [13]**Error! Reference source not found.**, UK [14] and France [15]. In Italy, IRAS was seldom adopted (MAIDS [16], SafetyNet [17] and DaCoTA [18] projects), while currently there are no on-going researches. Data gathered and analysed using IRAS can be exploited in a wide range of sectors, from vehicle to road design, and medical trauma research [19]. IRAS data are also needed to improve or develop new safety devices for road users [20]-[24][23]. This paper exploits the InSAFE dataset to describe accident typologies, crash parameters, frequency and severity of injuries, suffered by pedestrians and cyclists in urban traffic accidents.

II. METHODS

The InSAFE study is conducted by the University of Florence jointly with the Intensive Care Unit (ICU) of the Emergency Department of the Careggi Hospital. InSAFE has been collecting road accident data since 2009 in the cities of Florence and its environs [25]-[26]. The data collection protocol of InSAFE complies with the guidelines defined by the European funded Project DaCoTA [18]. The supporting team is comprised of engineers and intensive care physicians. The selection criteria for the cases are: urban and non-urban road crashes (all types of vehicle), involving at least one seriously injured person admitted to ICU with a diagnosis of major trauma. Vehicles involved in the crash are thoroughly inspected to collect data on vehicle body deformation and seat-belt usage. In case of Powered-Two-Wheelers (PTWs; i.e. motorcycles and mopeds), analysis is also extended to protective garment and helmet. Furthermore, for each case, retrospective site inspection (photographs and video of the crash scene) is carried out in order to identify relevant pre-crash events such as manoeuvres, braking actions and possible causes for lack of driver attention. When available, verbal statements of the people involved in the crash are also collected. A site diagram of the accident drawn to scale and including the final positions of the vehicles involved, skid marks, debris, the estimated point of impact and trajectory are recorded as well. Collision speeds are computed from vehicular deformation, skid marks and witness accounts, and then validated against pre-crash conditions with specific software (e.g. Virtual Crash [27]). Data from the site of the crash are collected and matched with clinical injuries. All injuries are assessed at the discharge from the Emergency Department of a tertiary level trauma centre. The ICU members of the InSAFE team provide information on injury typologies and severities codified with the Abbreviated Injury Scale (AIS 2005 version [28]) by total body CT scans and X-ray. The anatomical scores used are the Injury Severity Score (ISS) [29] and the New Injury Severity Score (NISS)[30]-[31], while the physiological scores are the Glasgow Come Scale (GCS) and the Revised Trauma Score (RTS)[32]. A biomechanical correlation among injuries and causes is conducted for each case by a panel of physicians and engineers.

In the period 2009-2014, the InSAFE team collected 206 serious road accidents, of which 94 cases (45.6%) were fully reconstructed and studied (Table 1). In the 94 accidents, 233 people were involved: 2 (0.9%) died on-scene, 97 (41.6%) were seriously injured (admitted to ICU), 42 (18.0%) were road users slightly injured (with MAIS≤2) and 92 (39.5%) were not injured. Fifty-two of 94 cases were accidents involving pedestrian and cyclists. Out of the latter set, 38 accidents involved a car or a van against a pedestrian or a cyclist. The present in-depth analysis focused on 27 vehicle-to-pedestrian accidents and 11 vehicle-to-cyclist accidents (Table 2). For each subset, an overview of the road layout, light and weather conditions at the impact site was made. The analysis was carried out with a thorough description of the injury typologies and severities and the relative injury mechanisms.

TABLE 1

ACCIDENT TYPES AND FREQUENCIES OF FULLY RECONSTRUCTED ACCIDENTS (SOURCE: INSAFE DATABASE)

Type	N.	%
Single Vehicle	9	9.5
Vehicle-Pedestrian	38	40.5
Vehicle-Cyclist	14	15.0
Vehicle-Vehicle	33	35.0
Total cases	94	100

TABLE 2

ACCIDENT TYPES AND FREQUENCIES INVOLVING VRU (SOURCE: INSAFE DATABASE)

Type	N.	%
Cyclist-Pedestrian	1	1.9
PTW-Pedestrian	7	13.5
Car-Pedestrian	***22***	***42.3***
Van-Pedestrian	***5***	***9.6***
Bus-Pedestrian	3	5.8
PTW-Cyclist	3	5.8
Car-Cyclist	***10***	***19.2***
Van-Cyclist	***1***	***1.9***

Total cases	52	100.0

III. RESULTS

A. Accident configurations and outcome

Within the dataset considered in this study, 27 accidents involved 29 pedestrians, and 11 accidents involved 11 cyclists. Among VRUs and motor vehicle occupants, 91 people were involved: 41.8% (38; 27 pedestrians; 11 cyclists) were seriously injured, 6.6% (6; 2 pedestrians; 1 riders; 3 other road users) were slightly injured and 51.6% (47) were uninjured. Nine (23.7%) of the 38 seriously injured died within 30 days of the event. For vehicle-pedestrian crashes, the impact point far from the crossroad was prevailing (85%) and they occurred at the crosswalk in 63% of the cases. Vice versa, the majority of accidents involving cyclists occurred close to the crossroad (73%). Both for pedestrian and cyclist accidents, weather and light conditions at the time of the crash were mostly sunny (74%) and daylight (63%). In the vehicle-pedestrian crash subset, the pedestrian was frequently struck on his/her side when crossing the road. The analysis of the driver's behaviour prior to the crash shows that the vehicle speed was of 53.5 km/h (SD 13.4), average value, and that all the drivers made a braking action before the impact.

Between the two subgroups of pedestrian side impacts on the right and left hand side, the impact speed and the injury outcomes are very similar. The mean impact speed is 43.0 km/h for right side impact and 42.3 km/h for left side impact, with the median ISS of 20 and 22, respectively (Table 3). Both right and left impact, the fifty percent of the sample shows the median NISS of 27.

TABLE 3

PEDESTRIAN IMPACT POINT, IMPACT SPEED AND SEVERITY

Pedestrian impact side	N.	%	Mean impact speed [km/h] (SD)	Median ISS	Median NISS	ICU-LOS* (SD)	Mean Age (SD)
Front	1	3.5	28.0 (0.0)	10	22	2.0 (0.0)	66 (0.0)
Right side	7	24.1	43.0 (18.7)	20	27	10.0 (7.7)	56.0 (34.7)
Left side	21	72.4	42.3 (12.7)	22	27	10.3 (8.7)	53.5 (22.9)
Total people	29**	100	42.0 (14.2)	22	27	9.9 (8.3)	54.1 (25.1)

* ICU's Length Of Stay (LOS)

** Two cases involved more than one pedestrian

The most frequent vehicle-cyclist crash configuration was the side-collision (82%), where the cyclist was hit sideways (Table 4). Concerning the injury outcomes, the latter configuration led to a median ISS of 26 and a median NISS of 41 when the cyclist was stuck sideways. In the head-on-collision subset, in which the cyclist hits the other vehicle frontally, the median ISS is 28.5 (range 24-33), while the median NISS is 45.5 (range 43-48).

TABLE 4

CAR/VAN-TO-CYCLIST ACCIDENT CONFIGURATIONS

Type	N.	%	Mean impact speed [km/h] (SD)	Median ISS	Median NISS	ICU-LOS* (SD)	Mean Age (SD)
Side collision**	9	82.0	41.7 (14.5)	26	41	4.6 (5.9)	45.9 (26.8)
Head-on collision**	2	18.0	50.5 (6.4)	28.5	45.5	5 (5.7)	44.5 (40.3)
Total people	11	100	43.3 (13.6)	26	43	4.7 (5.6)	45.6 (27.2)

* ICU's Length Of Stay (LOS)

**Car/Van-Cyclist accident configuration: side and head-on collisions for the cyclist

Thirty-three percent (9/27) of the vehicles involved in the previous subset of crashes were city-cars (i.e. Toyota Yaris, Opel Corsa), while the remaining vehicle types were small-cars (22.2 %) (i.e. Fiat Panda, Smart For-Two), small-vans (i.e. Renault Kangoo, 11.1%) and compact-cars (i.e. Audi A3, Renault Mégane, 11.1%) (Table 5**Error! Reference source not found.**).

Table 6 shows the pedestrian trajectory typologies [33]. The most frequent was the Wrap trajectory (51.7%) followed by the Fender vault (27.5%) and Forward (10.3%) trajectories. The mean impact speed was very high since the accidents took place in a urban environment. A statistical analysis confirms a relationship between pedestrian trajectory and impact speed (Cramer's V gave a V = 0.7 and a p-value < 0.01). The analysis of variance (ANOVA) shows that the average values of the impact speed of each category of trajectory are statistically distinct (F-test = 5.1, p-value < 0.01; test computed on categories with more than 1 accident)[34].

TABLE 5

VEHICLE CATEGORY TYPES AND FREQUENCIES

	Pedestrian		Cyclist		Total	
	N.	%	N.	%	N.	%
City car	9	33.4	5	45.4	14	36.9
Small car	6	22.2	2	18.2	8	21.0
Compact car	3	11.1	3	27.3	6	15.8
Large car	2	7.4	-	-	2	5.3
Executive car	1	3.7	-	-	1	2.6
Large SUV	1	3.7	-	-	1	2.6
Small Van	3	11.1	-	-	3	7.9
Large Van	2	7.4	1	9.1	3	7.9
Total	27	100.0	11	100.0	38	100.0

TABLE 6

PEDESTRIAN TRAJECTORY CATEGORIES

Trajectory	N.	%	Mean impact speed [km/h] (SD)
Wrap	15	51.7	43.3 (8.8)
Fender vault	8	27.5	37.0 (12.5)
Forward	3	10.3	35.7 (24.0)
Roof vault	1	3.5	69.0 (0.0)
Somersault	1	3.5	68.5 (0.0)
Other*	1	3.5	28.0 (0.0)
Total	29	100.0	42.0 (14.2)

*in this case, the pedestrian was crushed against a traffic light.

The impact speed and the pedestrian projection distance measured on the accident scene are well correlated (Rho's Spearman (r_s) = 0.9; p-value < 0.01), as shown in Fig. 1**Error! Reference source not found.**. The data scatter is mainly due to the variability of data collection and the effects of the variability of vehicle-pedestrian impacts. Despite this variability, a linear regression shows a strong dependence between the pedestrian impact speed and the throw distance, giving an $R^2 = 0.87$ and a p-value < 0.01. The relative equation is:

$$\text{Impact\_Speed} = 8.92 + 1.43\ \text{Throw\_Distance} \tag{1}$$

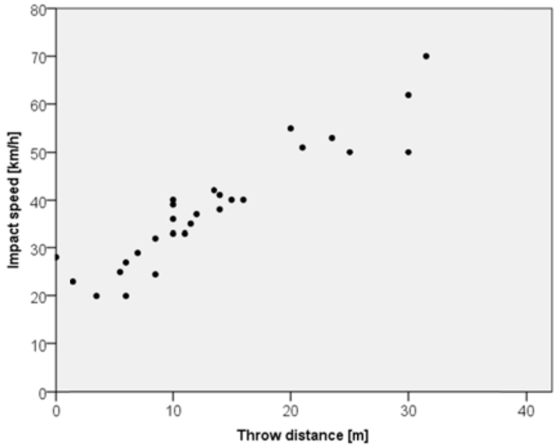

Fig. 1 Relationship between vehicle impact speed and pedestrian projection distance.

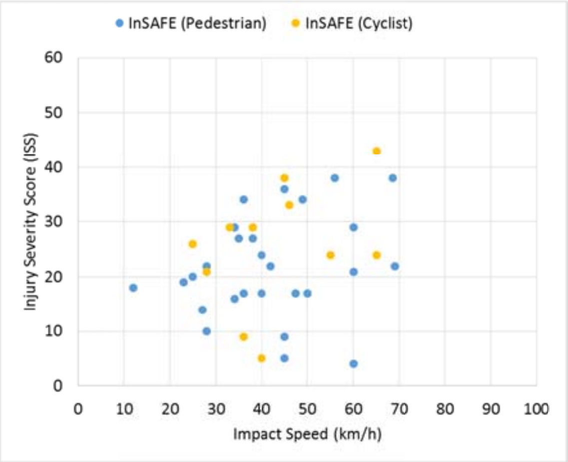

Fig. 2 Injury Severity Score vs. Impact Speed in the InSAFE database.

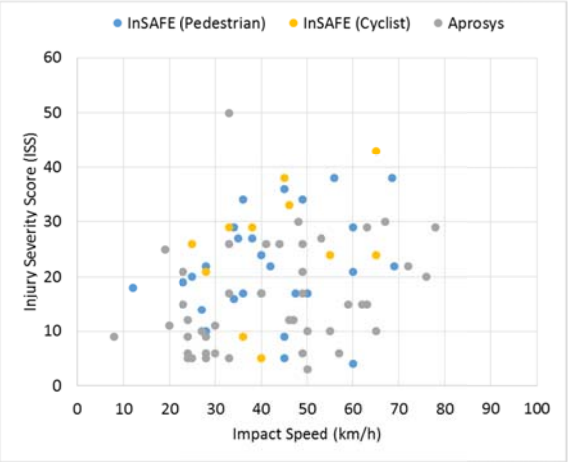

Fig. 3 Injury Severity Score vs. Impact Speed in the InSAFE database and APROSYS database.

The correlation among the pedestrian's ISS and vehicle's impact speed is weak: r_s 0.34 with a p-value < 0.1 (Table 7 and Fig. 2). The value was obtained coding the ISS and the impact speed on a scale with three (0-15, 16-30, 31-75) and five (0-15, 15.1-30, 30.1-45, 45.1-60, 60.1-75) levels, respectively. Fig. 3 shows as InSAFE's data are very similar with those of the APROSYS in-depth database [35]. The InSAFE data are all included in the APROSYS point cloud.

An analysis of injuries based on MAIS shows that no statistically significant correlation exists between the impact speed and the overall MAIS. Nevertheless, there is a low correlation between the impact speed and the abdomen MAIS (r_s=0.32, p-value < 0.1) and extremities MAIS (r_s=0.36, p-value < 0.1) (Table 7).

TABLE 7

SPEARMAN CORRELATION BETWEEN PEDESTRIAN IMPACT SPEED (RECODED WITH A 5-LEVEL SCALE) AND MAIS

		MAIS head-neck	MAIS face	MAIS chest	MAIS abdominal	MAIS extremities	MAIS external	MAIS overall
Impact Speed	r_s	0.18	0.08	-0.12	**0.32**	**0.36**	-0.01	0.26
	Sig. (2-tiles)	0.37	0.68	0.55	**0.10**	**0.07**	0.94	0.19

B. Injury analysis

In the analysed accident set 38 out of 40 pedestrians and cyclists were seriously injured during impact with the vehicle: 2 suffered a MAIS2 (5.3%), 16 (42.1%) a MAIS3, 13 (34.2%) a MAIS4, and 7 (18.4%) a MAIS5. Within this group 9 people (23.7%; 4 pedestrians and 5 cyclists) suffered fatal injuries (death within 30 days of the event). The ISS ranged from 4 to 43: 80% of the values were above 15 and 20% above 30. Twenty-nine pedestrians reported 82 head injuries (54, AIS3+), 37 thorax injuries (18, AIS3+), 36 spine injuries (3, AIS3+) and 61 lower limbs injuries (11, AIS3+). Cyclists (11) reported 61 head injuries (47, AIS3+), 4 thorax injuries (3, AIS3+) and 9 lower limbs injuries (2, AIS3+) (Fig. 4). Both pedestrians and cyclists suffered injuries mostly to head and face, with pedestrians also sustaining injuries at lower limbs and spine. In terms of maximum injury severity, cyclists suffered a MAIS5 event in 45.5% of cases, while this percentage dropped to 20.0% for pedestrians (Fig. 5). As a result of the sustained injuries, people spent between 1 to 32 days in the ICU (average value 8.06, SD 7.63) and between 4 to 104 further days in the hospital (average value 25.7, SD 24.8).

Head, Thorax and Abdominal injuries: the most frequent pedestrian head injuries were to the cerebrum (53) followed by spinal bone fractures (35), head fractures (27) and pelvic rib fractures (26) (Table 9). Twenty-one of the 29 pedestrians sustained 54 AIS3+ head injuries, which comprises epidural or extradural hematoma, from moderate (AIS4) to severe (AIS5), brain swelling (AIS5), laceration (AIS3 and AIS4) and subarachnoid haemorrhage (AIS2 and AIS3). There were 13 vault fractures (from AIS2 to AIS4) and 11 base fractures (AIS3), while there were 12 orbit fractures (AIS2) at the face and 7 at the maxilla (AIS2) with one case of LeFort I. In the thorax and abdomen regions, the most common injuries were rib fractures with the rupture of almost 3 ribs (12), pulmonary contusions (13) and pneumothoraxes (5).

Concerning the cyclists (Table 8), the most frequent injuries were in the cerebrum (40) and head fractures (19). Ten out of 11 cyclists sustained 47 AIS3+ head injuries, 6 of which had an AIS5, namely: 1 diffuse axonal injury, 2 large subdural hematoma, 1 intracerebral hematoma, 1 brain swelling and 1 brain stem compression. Common injuries were also subarachnoid haemorrhage (6, AIS3), pneumocephalus (5, AIS3), and medium and small subdural hematoma (4, AIS3 and AIS4). In addition there was clinical evidence of 8 base fractures (AIS3), 6 vault fractures (AIS2), 10 fractures to the face region (maxilla, orbit and zygomatic bone) with only one case of LeFort I.

Spinal injuries: in the pedestrian subset, there were 36 spinal injuries with a severity between AIS2 and AIS3. Six of the 29 pedestrians sustained injuries to the cervical spine (10 injuries): 5 cases had fractures of the spinous and transverse process (AIS2), 2 cases had odontoid fractures (AIS3) and 1 a cord contusion (AIS3). Three people reported 15 thorax spinal injuries, all of which were fractures of the transverse process, with the exception of one fracture of the vertebral body (AIS2). Six pedestrians sustained 11 lumbar spinal injuries with 6 transverse process fractures, 4 vertebral body fractures and 1 spinous process fracture. There were 12 spinal injuries sustained by the cyclist's subset: 6 to the cervical spine and 6 to the thorax spine. While in the thoracic spine there were transverse (2) and spinous (4) process fractures, in the cervical spine there were facet fractures (3), pedicle fracture (1), transverse process fracture (1) and lamina fracture (1).

Upper/Lower limbs and Pelvis injuries: 61 of the 292 injuries sustained by pedestrians were to the lower limbs and only six injuries were to the upper limbs. In the latter there were fractures to the scapula (3, AIS2), humerus (2, AIS3) and ulna (1, AIS2). At the pelvis there were 4 fractures with an incomplete disruption of the posterior arch (AIS4), 1 with a complete disruption of the posterior arch and pelvic floor (AIS4), 15 isolated fractures with the posterior arch intact (AIS2), 2 with an incomplete disruption of the posterior arch (AIS3) and 4 fractures NFS (AIS2). Of the 61 lower limbs injuries, 47 were AIS1 or AIS2 injuries, and there were 3 acetabulum fractures, 10 fibula fractures, and 10 tibia fractures with 3 tibial plateau fractures.

In the cyclist's subset, the prevailing injuries were to the pelvis (3 of 11 injuries) and the acetabulum (2 of 11 injuries). The most serious were the proximal fracture of the femoral head (AIS3) and the pelvic fracture with incomplete disruption of the posterior arch (AIS3).

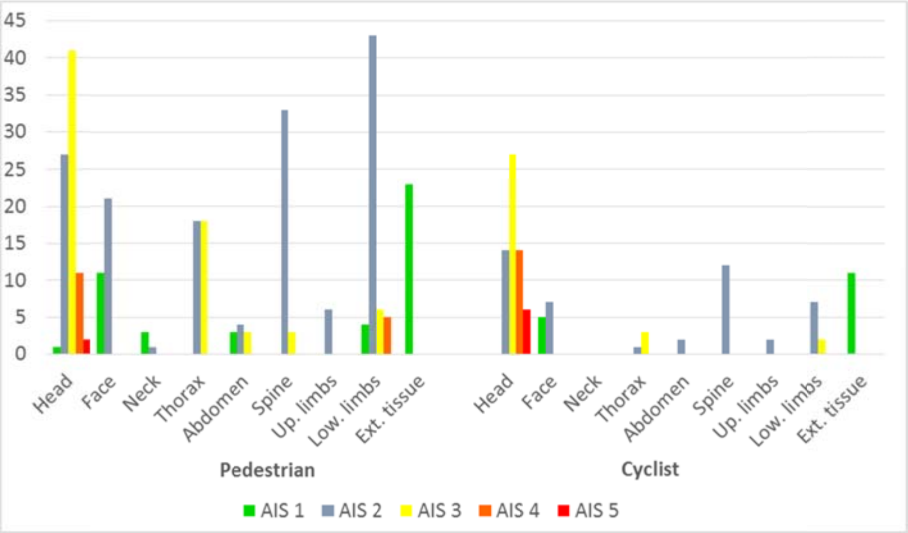

Fig. 4 Number of injuries by AIS level and AIS body region and Road User type (pedestrian and cyclist; source: InSAFE database).

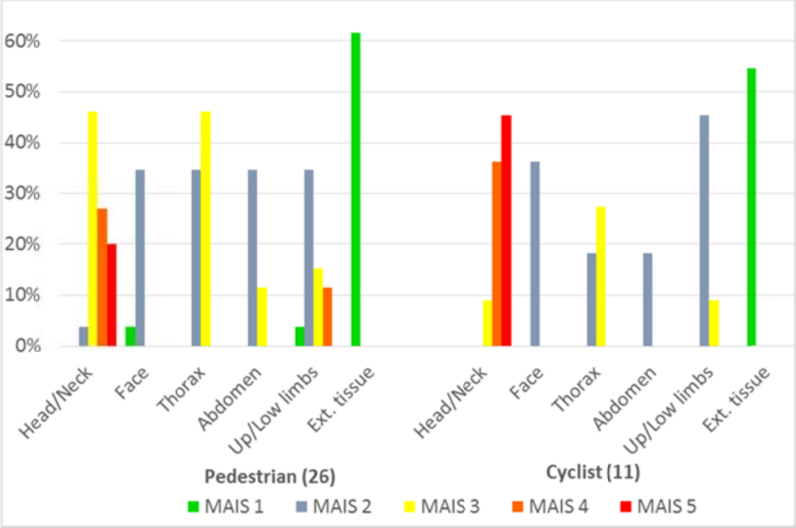

Fig. 5 Proportion of maximum injury severity by body region and road user type.

C. Impacts to injuries correlation

In the vehicle-pedestrian road accidents, 29 pedestrians hit the car as showed in Fig. 6. After the first impact with the bumper and the Bonnet Leading Edge (BLE), the A-pillar area was the car segment most frequently struck, followed by the upper frame and the windscreen. The car zones more accountable for head injuries were the A-pillar (red squares) as well as the area around to the upper frame and the lower frame. The 11 cyclists struck the car more frequently on the upper frame area and on the windscreen (Fig. 7).

Of the 292 pedestrian injuries, the majority were due to the ground impact (76, 26.0%), followed by windscreen (33, 11.3%), upper frame (27, 9.2%) bumper (25, 8.6%) and BLE (22, 7.5%). In the vehicle-cyclist impacts, the ground (30, 26.5%) and the curb (9, 8.0%) were the most common causes of injuries (Fig. 8). On the other hand, in the first impact with the vehicle, the upper rail frame, the windscreen and the bonnet were the most dangerous areas, with 7-8 injuries and 5-6 AIS3+ injuries respectively (Fig. 9).

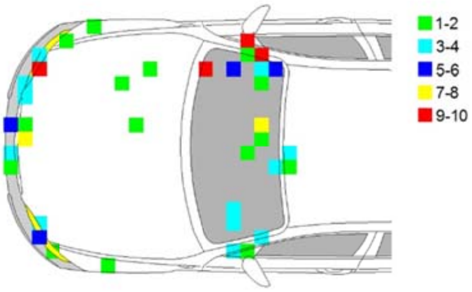

Fig. 6 Frequency of head/neck/face and lower limbs injuries for Pedestrians.

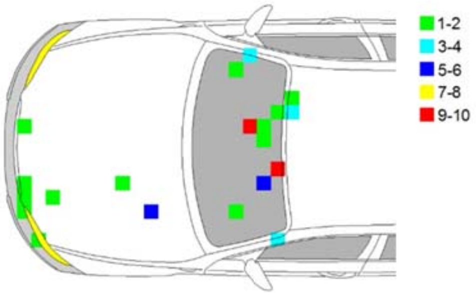

Fig. 7 Frequency of head/neck/face and lower limbs injuries for Cyclists.

Fig. 8 shows the frequency and spatial collocation of AIS2- and AIS3+ pedestrian head injuries grouped by interval of two injuries. The A-pillar and its neighbouring windscreen area produced a variability of the injuries both in term of numbers and severity. The same point on the right A-pillar accounts both AIS3+ that AIS2- injuries with the same frequency range (3-4). Both for pedestrians and cyclists, the windscreen frame is the part of the car most responsible of injuries. For pedestrians the bumper and BLE is an harmful, while for cyclists the bonnet and the windscreen are critical, due to a different impact kinematics (the cyclist have an higher impact point with the vehicle and consequently an higher trajectory). Of course, in both subsets the ground is highly relevant in terms of injury mechanisms (Fig. 10).

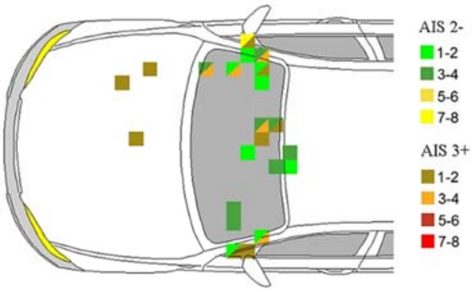

Fig. 8 Frequency of head/neck/face AIS2- and AIS3+ by point of impact for Pedestrians.

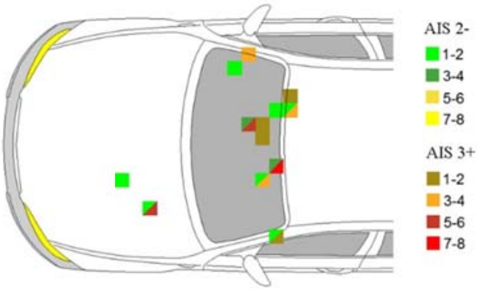

Fig. 9 Frequency of head/neck/face AIS2- and AIS3+ by point of impact for Cyclists.

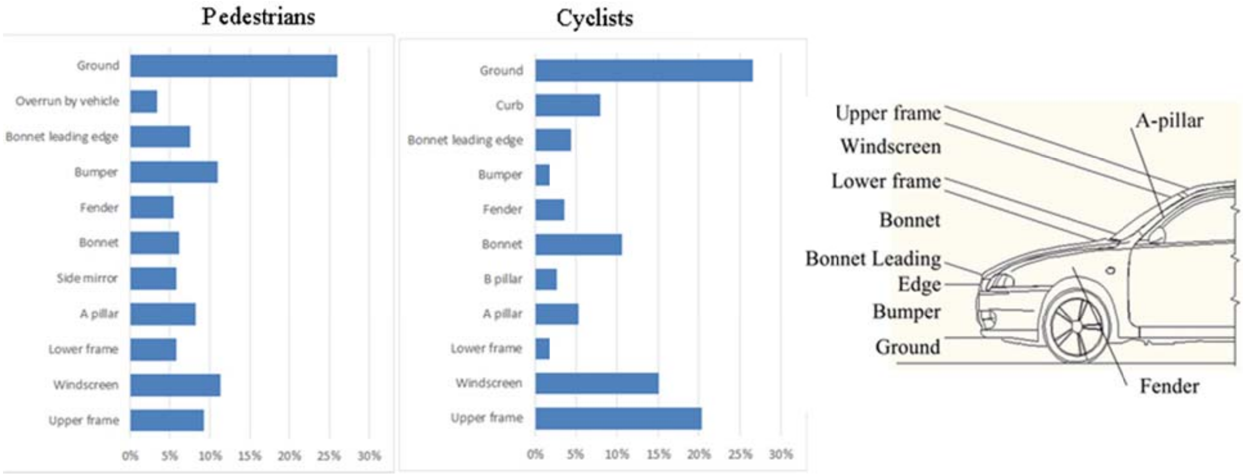

Fig. 10 Percentage of injuries caused by specific vehicle contact points (pedestrians and cyclists).

IV. DISCUSSION

This paper describes the typologies of vehicle-pedestrian and vehicle-cyclist collisions involving seriously injured pedestrians and cyclists (i.e. admitted to ICU), and the relative injury typologies, which occurred on urban roads. In the period 2009-2014, 52 road accidents involving VRUs were recorded (Table 2). The analysis was performed on a subset of 38 road accidents with car/van impacting into a pedestrian/cyclist, namely: 27

vehicle-pedestrian and 11 vehicle-cyclist cases. Urban accidents with seriously injured pedestrians mostly occurred far from intersections (23, 85.2%). Within this subset 56.5% of accidents occurred far from a crosswalk, thus in unexpected conditions for driver-pedestrian interaction. The motor vehicles most frequently involved in these crashes were city, small and compact cars as well as vans. These categories effectively correspond to the most typical vehicles on Italian urban roads, so there is no deviation from the average circulating car sample.

The analysis shows that the most frequent car-pedestrian crash configuration is the pedestrian struck by the front of the vehicle. In detail, data show an asymmetrical configuration: in a right-hand drive environment, most pedestrians were stuck on their left side by the right front corner of the vehicle. A hypothesis could be the limited and short time since perception of the pedestrian by the car driver, to perform the avoidance manoeuvre when the pedestrian crossed from the right-hand side. In fact a longer reaction time is allowed when the pedestrian is crossing from the left-hand side. Ashton et al. [12] also found similar results. From the pedestrian side there were also oversight errors that brought him/her to cross the road without the necessary attention to the surrounding vehicles. These accident causation factors were also found by Mackay [36]. Impact speeds in right and left-hand side accidents are statistically equivalent, and close to the maximum legal speed on urban roads. This datum suggests that: 1) with an average value of 53.5 km/h, the vehicle's speed in urban environment is too high; 2) in both configurations the driver reacts too late to implement an effective braking action; 3) there is primarily a perception failure of people involved in the accidents. In both subsets, the pedestrians suffered a median NISS of 27, while the median ISS is slightly different in the two subsets: 20 and 22, respectively for right side and left side struck.

In vehicle-cyclist accidents, the cyclists were more frequently hit sideways. Despite the fact that the average impact-speed was slightly lower than the impact-speed of the pedestrian subset, the mean outcome score was more severe. In fact, although the kinematics of the accident was very similar, the cyclist generally hit the vehicle in an upper and stiffer point (commonly at the upper frame or at the windscreen area close to the frame). Increased accident severity was reflected also in the indexes: median ISS 22 vs 26, and median NISS 27 vs. 43. The mean age of the pedestrians was greater than that of the cyclist (55 vs. 46 years).

In the vehicle-pedestrian accidents, the head-neck-face region and the lower limbs were the body areas most exposed to injuries with 82 and 61 instances, respectively, out of the 292 total injuries. This result is in line with available literature [36]. In terms of severity, head and thorax were the body segments most seriously injured, with 54 and 18 AIS3+, respectively. The most common head injuries were epidural and extradural hematoma (moderate and severe), brain swelling and lacerations, while the vault fractures represented the most serious skull fractures (from AIS2 to AIS4). In car/van accidents, head injuries were mainly correlated with head/A-pillar impacts, head/upper frame and head/windscreen impacts. These findings confirm previous works by Foret-Bruno et al [37] and Carter et al [38]. The A-pillar was the car part most responsible both for the numerosity and for the severity of the injuries (AIS2+). The windscreen area closest to its frame, due to the higher stiffness, it was more dangerous (both in term of injuries and severity), while the central part of the windscreen causes less severe injuries (AIS2-). Anyway, there were also some head/upper frame impacts that had produced minor injuries (AIS2-). The lower severity was attributed primarily to the reduction of the speed of impact of the head in the contact with the upper frame thanks to a preliminary contact of the shoulder and/or arm (shielding effect). Despite the bonnet was less responsible of head injuries, all the impacts were associated to serious injuries (AIS3+). The related typologies of traumas were a predictable effect of the absence of any protective device worn by person or installed in the vehicle. The specific impact locations confirm the possibility to reduce or avoid serious injuries thorough the deployment of active or passive safety devices (Fredriksson and Rosen [20], Rosen et al. [39]). The most serious thoracic injuries were pneumothoraxes, while the most frequent spinal injuries were spinous and transverse process and fractures to the vertebral body. Injuries at lower limbs accounted for 18% of the total pedestrian injuries, while the most frequent and severe ones were localised in the pelvis (from AIS2 to AIS4). The latter injuries were related to the primary contact with bumper and BLE. The most severe ones were also associated with a higher level of car frontal damage (in the area of BLE), suggesting a correlation with the vehicle speed. Also for cyclists The head-neck-face region was the most injured area. The head suffered 47 AIS3+ injuries and 6 AIS 5. The spinal injuries were all localised in the cervical and thoracic sections. In contrast to pedestrians, lower limbs reported a smaller number of injuries due to the cyclist's higher centre of gravity on the ground level and thus to the different relative position compared to the car BLE height.

As a concluding remark, it is worth noting that impact with ground accounts for more than 25% of injuries reported by pedestrians and cyclists. The importance of the pedestrian-ground impacts was well described in literature [40][41]. The percentage of injuries assigned to impact with the ground within this study are in-line with data available in literature [42]-[43][44].

V. CONCLUSIONS

In this paper, 27 pedestrian and 11 cyclist urban accidents from the InSAFE in-depth database were studied in order to identify accident configurations and impact points, and to correlate the injuries with the causes.

The results indicated that pedestrians and cyclists were primarily struck by small and compact cars on urban roads. The impact speed was medium to high (above 40 km/h). The median ISS was 22 for pedestrians and 26 for cyclists. In both cases, the head was the most frequently injured body region, with 28% and 54% of injuries respectively for pedestrians and cyclists. In addition head was also the most severely injured body region with 66% of AIS3+. Cyclists reported a higher percentage of serious injuries to the head compared to pedestrians, due to the more frequent impacts on the upper part of the windscreen. Differently pedestrians were also seriously injured to the pelvis area. For both user categories the secondary impact with the ground was the cause of about 25% of the reported injuries. The data analysis provided a distribution of the impact locations on the vehicle, highlighting specific areas of intervention for an effective cost-benefit approach to injury reduction. Results also suggest the introduction of active safety systems (e.g. Autonomous Emergency Braking System) in support of driver actions. In fact the uneven distribution of pedestrian accident configurations suggested a lack of perception and a limited reaction capability of the driver in the scenario with a pedestrian crossing from the right-hand side.

Limitations to the study derive from the small dimension of the sample, which hampers a statistical validation of the results. Nonetheless the frequency analysis identified possible trends in line with previous studies and in particular with the findings of the APROSYS project.

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VIII. APPENDIX

TABLE 8

CYCLIST'S INJURIES GROUPED BY BODY SEGMENT, ANATOMIC STRUCTURE AND ORGAN

Body Segment	Anatomic Structure	Organ	N	%
Head	Internal organs	Brain stem	1	0,9%
		Cerebellum	1	0,9%
		Cerebrum	40	35,4%
	Skeletal	Base (basilar)	8	7,1%
		Skull	5	4,4%
		Vault	6	5,3%
Face	Skeletal	Maxilla	2	1,8%
		Orbit	5	4,4%
		Zygoma	3	2,7%
	Whole area	Skin/subcutaneous/muscle	2	1,8%
Upper ext.	Skeletal	Carpus	1	0,9%
		Ulna	1	0,9%
Spine	Cervical	Spinal bone	6	5,3%
	Thoracic	Spinal bone	6	5,3%
Thorax	Internal organs	Lung	2	1,8%
	Skeletal	Rib cage	2	1,8%
Abdomen	Internal organs	Kidney	1	0,9%
		Pancreas	1	0,9%
Lower ext.	Skeletal	Acetabulum	2	1,8%
		Femur	1	0,9%
		Metatarsal	1	0,9%
		Patella	1	0,9%
		Pelvic ring	3	2,7%
		Tibia	1	0,9%
External	External	Soft tissue (skin)	11	9,7%
		Total	113	100,0%

TABLE 9

PEDESTRIAN'S INJURIES GROUPED BY BODY SEGMENT, ANATOMIC STRUCTURE AND ORGAN

Body Segment	Anatomic Structure	Organ	N	%
Head	concussive injury	Cerebral	1	0,3%
	internal organs	Cerebrum	53	18,2%
	skeletal	Base (basilar)	11	3,8%
		Skull	4	1,4%
		Vault	13	4,5%
Neck	vessels	Vertebral artery	1	0,3%
	whole area	Skin/subcutaneous tissue/muscle	3	1,0%
Face	skeletal	Mandible	1	0,3%
		Maxilla	7	2,4%
		Nose	5	1,7%
		Orbit	12	4,1%
		Zygoma	4	1,4%
	Whole area	Skin/subcutaneous/muscle	3	1,0%
upper ext.	Skeletal	Humerus	2	0,7%
		Scapula	3	1,0%
		Ulna	1	0,3%
Spine	Cervical	Spinal cord	1	0,3%
		Spinal bone	9	3,1%
	Lumbar	Spinal bone	11	3,8%
	Thoracic	Spinal bone	15	5,1%
Thorax	Internal organs	Esophagus	2	0,7%
		Lung	11	3,8%
		Thoracic injury	7	2,4%
	Skeletal	Rib cage	15	5,1%
		Sternum	1	0,3%
	Whole area	Injuries to the Whole Thorax	1	0,3%
Abdomen	Internal organs	Liver	2	0,7%
		Spleen	4	1,4%
	Vessels	Other named arteries	1	0,3%
		Vascular	1	0,3%
	Whole area	Skin/Subcutaneous/Muscle	3	1,0%
Lower ext.	Joints	Ankle joint	1	0,3%
		Knee joint	1	0,3%
	Muscles, tendons, ligaments	Muscle	1	0,3%
		Muscle, tendon, ligament	3	1,0%
	Skeletal	Acetabulum	3	1,0%
		Femur	1	0,3%
		Fibula [malleoli]	10	3,4%
		Pelvic ring	26	8,9%
		Tibia	10	3,4%
	Vessels	Femoral vein	1	0,3%
		Other named arteries	1	0,3%
		Other named veins	1	0,3%
		Popliteal vein	1	0,3%
	Whole area	Amputation [traumatic]	1	0,3%
External	External	Soft tissue (skin)	23	7,9%
		Total	292	100%