# Design of an After-market Lower Limb Protector for Scooters: Preliminary Estimation of Effectiveness

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## I. INTRODUCTION

The number of vehicles on the roads is constantly increasing. In a decade the Powered Two-Wheeler (PTW) circulating park in Europe increased by about 12% (2005-2014) [1]. Despite the PTW crashes reduction by about 37% [2] in the same decade, rider safety is still a concern since it is the mode of transport for which the number of fatalities decreased the least [2]. Previous studies showed that lower limbs are the region of the body with the highest probability of injury in a road crash [3-4]. In addition, the most common vehicle typology involved in a road accident is scooter style (67.5% [5], 38.4% [6]).

The aim of this study is to perform a preliminary assessment of the effectiveness of a new concept of leg protector, designed to mitigate leg injuries reported by riders in side impacts at low speeds. Side impacts represent 26.1% of impact conditions [7], and they have not been sufficiently studied over the past years. The device is conceived for after-market installation on scooters. The study contributes to solve the problem of rider's lower limb protection in road crashes, already studied in the past without a viable solution.

## II. METHODS

To assess the effectiveness of the protector (Fig. 1), five crash test configurations with a car impacting against the scooter were reproduced in a virtual environment. The five configurations differed in the relative heading angle (RHA) between the longitudinal axes of the impacting vehicle (Ford Taurus) (Fig. 2) and the scooter (Piaggio MP3) (Fig. 3) [8-9]. The RHA was set to 45° *(C45)*, 60° *(C60)*, 90° *(C90)*, 120° *(C120)*, 135° *(C135).* In C45 and C60 the car has a velocity component in the forward direction of the scooter. Two different sets of simulations were performed: moving-stationary (with stationary scooter and impacting car at 5*m/s*) and moving-moving (scooter and impacting car at 5*m/s*). Each set was simulated with and without the protector fitted on the scooter. Hybrid III 50$^{th}$ male was selected as the best dummy CAE model compromise for the simulations to calculate the selected injury indices. Being the dummy not validated for side impacts, the evaluation was performed through a comparison of the simulations results with and without the protector.

## III. INITIAL FINDINGS

The results of the two sets of simulations are reported in Table 1. The first set of simulations (stationary-moving) shows that the protector has provided a protection to the lower limbs in each configuration. Only the femur twisting moment in the configuration *C90* remains above the limit value, although it decreased. The injuries to the upper body (head and chest) are equivalent or show a slight increase, but they remain well below the limit value.

In the moving-moving configurations, the protector does not provide the same level of leg protection. Femur twisting moment, tibia index and chest acceleration are above the limits in configurations C60 and C90, and they increase with the introduction of the protector. In the remaining configurations the variations of the biomechanical indices do not vary the injury level. HIC improves in most of configurations, differently from the stationary-moving analyses. In both sets of simulations, the protector has a restraining effect on the rider kinematics during the impact: the rider may have a delayed ejection, with smaller amplitude compared to the base configuration, or no ejection.

**TABLE I**

INJURY ASSESSMENT FOR THE STATIONARY-MOVING AND MOVING-MOVING CONFIGURATIONS: The decrease of the injury indices due to the protector is indicated by minus, while an increase by plus. A colour coding is applied to indicate the value of the indices in the configuration with the protector: green is used for those indices that

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remain below 90% of the biomechanical limit, orange for the indices in the 80-100% range of the limit and red for those ones that exceed the biomechanical limit.

| | Stationary-Moving | | | | | Moving-Moving | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Injury criteria* | C45 | C60 | C90 | C120 | C135 | C45 | C60 | C90 | C120 | C135 |
| *Femur axial force* | - | - | - | - | - | - | + | + | - | - |
| *Femur bending moment* | - | - | - | - | - | - | + | - | - | + |
| *Femur twisting moment* | - | - | - | - | - | + | + | + | - | + |
| *Tibia index* | - | - | - | - | - | - | + | - | - | - |
| *HIC* | - | + | + | + | + | - | - | - | + | + |
| *Chest acceleration* | - | + | + | - | - | - | - | + | - | + |

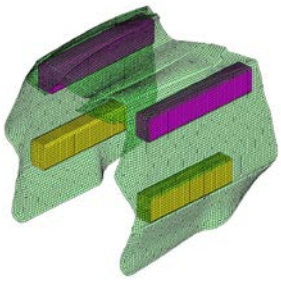

Fig. 1 Leg protector.

Fig. 2 Ford Taurus.

Fig. 3 MP3.

## IV. DISCUSSION

This paper describes the preliminary analysis of a concept for a new leg protector, aimed to reduce lower limb injuries in side impacts at low speed. The results show that lower limb injury indices are improved in stationary-moving simulations, although the protection level in configuration C90 is still inadequate. In moving-moving simulations the protector is not effective in configurations C90 and C60. In all simulations the protector introduces a *retention effect* that globally changes the rider's kinematic.

Upper body injuries are generated in the impact of the specific body region with the car, and not during the initial contact of the car with the scooter. Therefore, these injuries are strongly dependent on the geometry of the car. Nonetheless, in the presented crashes, the modifications to rider's kinematic have shown a detrimental effect on the chest injuries in a specific configuration.

The results identify C90 (stationary-moving and moving-moving) and C60 (moving-moving) as the most critical configurations for the performance of the protector. Their in-depth analysis will provide information to drive the re-design and improvement of the protector.

## V. ACKNOWLEDGMENT

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## VI. REFERENCES

[1] ACEM, Vehicle fleet, 2014
[2] ERSO, Traffic Safety, 2016
[3] Sporner A. et al, SAE International Congress and Exposition, 1990.
[4] Chinn B. P. et al, IRCOBI, 1984
[5] Piantini, IRCOBI, 2016
[6] ACEM, MAIDS report, 2008
[7] ACEM, MAIDS report, 2009
[8] Barbani et al, INT J Crashworthiness, 2014
[9] Barbani et al, INT J Crashworthiness, 2012