A passenger car-front optimization using Genetic Algorithm for safety of pedestrian during a vehicle-pedestrian impact

Sankarasubramanian Hariharan, Sudipto Mukherjee, Anoop Chawla

Abstract This paper presents an attempt to optimize the front-end profile of a passenger car based on pedestrian-vehicle multibody crash simulations for pedestrian safety. A single unitary measure for injuries to human body in the form of "injury cost" is used. It is representative of the loss to a human due to a crash including cost for partial impairment and an indicative cost for death. Vehicle front-profile optimization problem is formulated as a single objective minimization problem using by Genetic Algorithms implemented on MATLAB. Car front-end profile is described by 22 variables. A MADYMO ellipsoid based model of a 50th percentile male pedestrian at 50% gait cycle impacted laterally with front of vehicle at 40kmph. Injury cost converged within 10 generations to an optimal value 60% less than the lowest injury cost among ten existing car profiles. Convergence towards one profile indicates that existence of one front-profile which is global optimal and not a local minimum in the range considered.

Keywords optimization, genetic algorithm, pedestrian safety, injury cost

I. INTRODUCTION

In a developing country like India, pedestrians constitute the largest fraction of road crash fatalities [1], although, pedestrian fatalities in developed countries have been found to have reduced according to [2]. It is also observed in [1] and [2] that urban areas have a major share of vulnerable road user fatalities.

It is forecasted that in 2010-2011 sales of passenger cars in India would rise by 23-25% with respect to those in 2009-10 [10]. Passenger cars today are built for quick, safe, comfortable and cheap transport of the occupants of the vehicle. With recent research indicating that protection of vulnerable road users is feasible, car front-end profiles are being designed for legform and headform impact scores. A review of major issues in the existing methods of pedestrian safety evaluation also suggests possible ways to utilize computer models for pedestrian safety research [3]. Mathematical modelling of pedestrian-car impact was identified to have a potential to evolve design of vehicles. Multibody simulations using MADYMO based optimizations of vehicle front-end profiles have been reported [4], [5]. MATLAB coupled with MADYMO was used for optimization of vehicle front profile [4] for head injury minimization. A non-stochastic optimization technique used in [4], which minimised one variable at a time; ignoring dependency between variables, yielded local minimum and not the overall minimum possible within the corridor considered. Genetic algorithm (GA) for optimization with a single objective function combining HIC and thoracic acceleration using weighted coefficients was used by [5]. MADYMO pedestrian dummy (95th, 50th and 5th %^{le}) was used with multiple gaits. It was concluded that enhanced randomness in initial population, increase the population size and better mutation operator for obtaining newer profiles every generation was needed for satisfactory convergence. Parameters like gap between engine and the bonnet also has not been in addressed in the previous optimization studies [4]-[5].

The optimal profile for ensuring pedestrian safety remains an open ended question and can be addressed by improving the constraint set to reflect more practical constraints and validation of the simulation.

II. METHODS

Vehicle-pedestrian crash is modeled for a 40 kmph impact speed in MADYMO. Vehicle front-end is modeled

S. Hariharan is a PhD student in Mechanical Engineering at Indian Institute of Technology in Delhi, India (phone: 011-26596215, e-mail: hariharan.s@mech.iitd.ac.in). S. Mukherjee and A. Chawla are Professors in the Department of Mechanical Engineering at Indian Institute of Technology in Delhi, India.

using 6 hyper-ellipsoids denoting lower bumper, stiffener, leading edge, hood, scuttle and windscreen. This simplified model of car does not have a roof unlike in [5]. The stiff member on top of windscreen, known to be pedestrian unfriendly has been worked around by extending the windscreen glass as in [6]. The MADYMO 50th percentile male pedestrian dummy with hands in front in 50% of the gait cycle as positioned in [8] is considered representative of a pedestrian. A frontal impact of vehicle with the pedestrian experiencing a lateral impact is found to be most frequent scenario from crash databases [7]. Interaction between pedestrian and car body is characterised by using simplified force-deflection curves from [9].

Injury cost estimate of a car is obtained by post processing MADYMO outputs to estimate injury measures and using known limits for the Hybrid III dummy for rating using the Abbreviated Injury Scale (AIS). The AIS levels of injury severity are processed using procedures in ISO: 13232 and an indicative "injury cost" is obtained. It was also found that injury cost thus calculated had a negative linear correlation co-efficient of 0.9 to EuroNCAP pedestrian points of corresponding vehicles, indicating a strong inverse relationship.

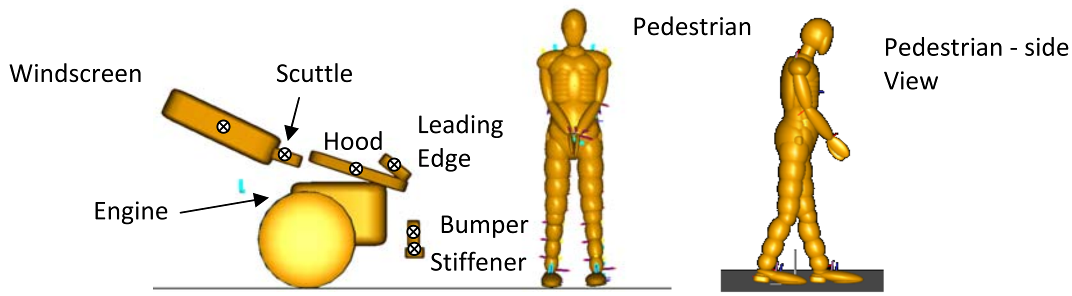

Fig. 1. Typical vehicle-pedestrian model in MADYMO

Problem formulation in SGA

Vehicle front-end geometry is effectively varied by changing ellipsoid dimensions, location and orientation in the simulation. Dimensions are constrained by limits varying from compact car (Suzuki Alto) to large sedan (Honda Accord). A population size of 40 is considered in the GA. Mutation operator is a polynomial of order 20. A crossover operator with probability 0.9 to provide new genes at end of every generation is used. Selection mode is "tournament of 2 without replacement". By default, the initial population is a random sample within the constraint set and resulting profiles are graphically shown in figure 2.

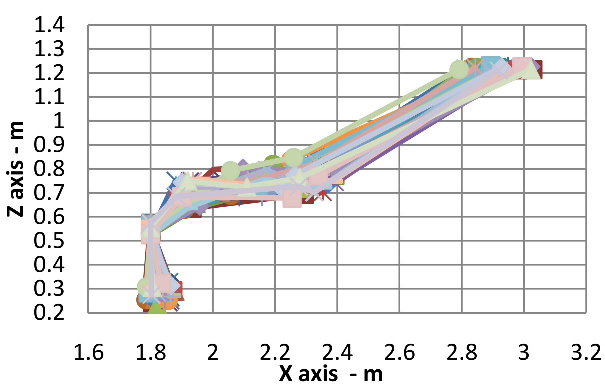

Fig. 2. Initial population spread of 40

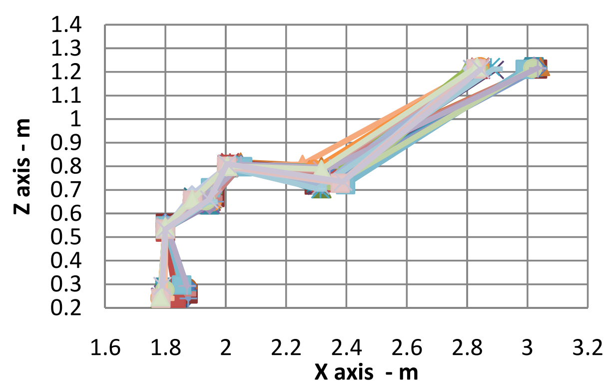

Fig. 3. Final population at end of 10 generations

The figures 2 and 3 show car front profiles formed by lines joining the centres of ellipsoids from stiffener to the scuttle. Typical centres of ellipsoids are indicated by crosses in figure 1. The line joining centres denote an indicative shape of the vehicle profile. For the windscreen, the top most point is connected to indicate the probable height of the vehicle.

III. RESULTS

The breakup of "injury cost" had major share from HIC. This is not surprising since a severe injury in head meant higher AIS score and hence even death which results in very high cost implication. A more severe impact to the lower extremities can lead to a maximum of AIS 3; hence their lower contribution to the overall injury cost. The trend in variation of injury costs for cars, considered as representative samples, have been compared along with the optimal solution generated shown in Table 1. The sedans show a trend of lower upper body injury cost and it can be directly attributed to longer bonnets / hoods which are more compliant. In the kinematics of the crash, compact cars had the pedestrian head hitting the scuttle region, which is a high stiffness region. The “optimal” car shows lower injuries to both upper and lower regions of body.

TABLE I

INJURY COST VARIATION

CAR	Total "injury cost" (USD)	Pelvic and below (USD)	Upper body (USD)
Sedan1	252367	237742	61988
Sedan2	299730	237742	163846
Sedan3	333346	169500	163846
Sedan4	333346	169500	583877
Sedan5	726475	142598	61988
Compact1	274498	212510	583877
Compact2	778609	194732	583877
Compact3	753377	169500	596580
Compact4	791312	194732	648714
Compact5	791312	142598	14625
Compact6	252367	237742	583877
Optimal	52700	38075	14625

Figure 3, shows a rise in hood ellipsoid centre as there is a rigid member (engine) located below the hood. This makes a better sense as engine top surface (height as a mean of population considered) is located near the hood surface. A clearance of around 150 mm is observed, which represents a theoretical value recommended to keep HIC within limits. The leading edge is constrained to impact the pedestrian below pelvis by at least 50mm to prevent pelvic fractures. Hence the shape appears with a sharp rise towards the hood centre. The bumper ellipsoid allowed to vary to around 0.5 m as it was observed in some cars has no separate bumpers.

The variation in injury cost from the first generation to the tenth generation with average of each generation (40) is shown in figure 4. The spread of geometry of cars shown in figure 2 is reflected in the corresponding variation of costs in figure 4. A cross-over operator creates a new set of population every generation combining the characteristics of previous generation. Mutation operator acts to retain some dominant characteristics in the new population from the previous generation. The sustained reduction in the injury cost in generations 2 to 9, seen in figure 4, can be attributed to the role of these operators.

A head injury of AIS 3 has a total injury cost of 61,988 USD while an AIS 5 will have 596,580 USD. This leads to discretization of the injury cost seen in Figure 4. Towards the tenth generation, injury cost is at a level less than 15% of the initial population peak value. The inter-population spread of injury cost is smaller compared to previous generations, indicating convergence to a solution. One can also observe similar "injury cost" values for multiple members of the population. On comparison with figure 3, one can observe that they have converged towards one geometrical shape with minimal variations.

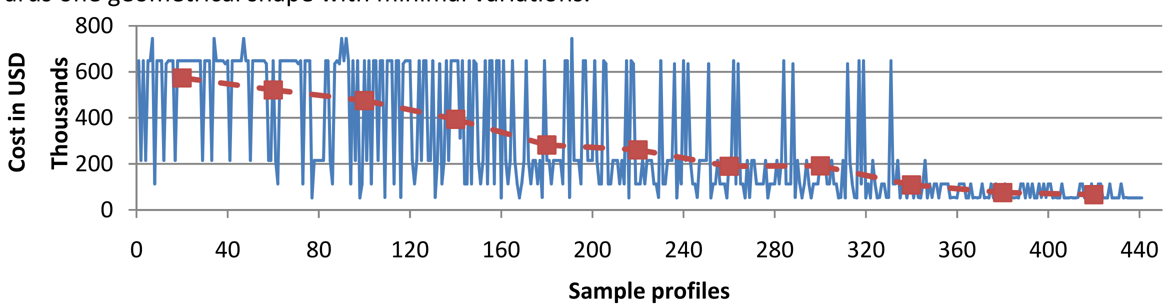

Fig. 4. Variation of objective "injury cost" among samples

IV. DISCUSSION

A combination of head injury criterion (HIC) and thoracic acceleration covering upper body alone was considered for optimization by [5]. A similar convergence towards the end of ninth and beginning of tenth generation, even while considering a larger number of gait stances and sizes of pedestrian anthropometry, was reported. This work is more comprehensive in accounting for the overall safety of pedestrian. Injury cost is calculated on the basis of HIC, neck injury criterion, viscous criterion for chest in side impact, pelvic force, femur-force criterion and tibia index. The optimization problem being reduced to a single objective problem seems to converge to an optimal solution for the profile of a vehicle front-end design.

The injury cost calculated is based on injury measures of Hybrid III dummy and the Side Impact dummy, which may not directly co-relate to the injury of humans. The medical and associated costs are based on motorcycle injury costs calculated from AIS estimated. In addition, the constraint set which now consists of existing dimensions and estimation of engine sizes can be augmented to include constraints for driver safety, visibility and styling features. With a conventional internal combustion engine located forward of the vehicle, the optimal shape may not be favourable in terms of aerodynamic co-efficient for example.

V. CONCLUSIONS

Bio-mechanical injury measures for major body regions are represented in terms of injury cost represent an economic implication to the injured person. When used with the optimization process, substantial improvement in pedestrian protection indicates scope for improvement in front-ends of existing car. Convergence of the optimisation process towards one shape suggests the existence of a single front-end profile forming a "universal" front-end.

VI. REFERENCES

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

[2] IATRD Road Safety 2010 Annual Report, International Traffic Safety Data & Analysis Group, www.irtad.net, 2010.

[3] Graham L, with contributions from WG17 members, The next steps for pedestrian protection test methods*, Proceedings of 19th International technical conference on Enhanced Safety of Vehicles*, Washington D.C., USA, paper number 05-0379, 2005.

[4] Linder A, Clark A, Douglas C, Fildes B, Yang J, Sparke L , Mathematical modelling of pedestrian crashes: Review of pedestrian models and parameter study of the influence of the sedan vehicle contour, *Road Safety Conference,* 2004.

[5] Carter E, Ebdon S, Neal-Sturgess C, "Optimization of Passenger Car Design for the Mitigation of Pedestrian Head Injury Using a Genetic Algorithm." *GECCO '05 Proceedings of the 2005 conference on Genetic and evolutionary computation,* New York, NY, USA, 2005.

[6] Kühn M, Fröming R, Schindler V, Fußgängerschutz, Unfallgeschehen, Fahrzeuggestaltung, Testverfahren, 140, Berlin: Springer-Verlag Berlin Heidelberg .

[7] Fredriksson R, Rosén E, Priorities of pedestrian protection—a real-life study of severe injuries and car sources*, Accident Analysis and Prevention*, 2010.

[8] Kerrigan J, Subit D, Untaroiu C , Crandall J, Rudd R, Pedestrian Lower Extremity Response and Injury: A Small Sedan vs. A Large Sport Utility Vehicle, *SAE*, paper no. 2008-01-1245, 2008.

[9] Rooij L, Bhalla K, Meissner M, Ivarsson J, Crandall J, Longhitano D, Takahashi Y, Dokko Y, Kikuchi Y, Pedestrian crash reconstruction using multi-body modelling with geometrically detailed, validated vehicle models and advanced pedestrian injury criteria, *Proceedings of 19th International technical conference on Enhanced Safety of Vehicles*, paper number 0468-O, Nagoya, Japan, 2003.

[10] SIAM forecast 2010, Society of Indian Automobile Manufacturers, http://www.siamindia.com/upload/SIAM-Forecasts-2010-11.pdf, 2010.