SIMULATION OF 2-WHEELED RIDER TO CAR ACCIDENT SCENARIOS, USING AN ADAPTED LS-DYNA PEDESTRIAN HUMANOID.

W.M.McLundie,
School of Engineering,
Cranfield University, UK.
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ABSTRACT

To provide a foundation for understanding 2-wheeled accidents in greater detail, a pedestrian finite element humanoid model developed by Ford is being adapted to examine 2-wheeled rider to car crash scenarios. The paper will describe the systematic approach to construction and correlation of the total system, and areas of interest that are worthy of further investigation.

Bicycles and powered two-wheelers are mixing with increasing numbers of cars and trucks in the emerging markets of the world. The paper will show the statistical relevance of 2-wheelers in global transport terms. Additionally, if you include the possibility of more people taking to two wheels in the West (due to issues such as congestion charging), the potential for a large increase in the already significant numbers of rider casualties needs to be recognised by all those involved in road transportation safety. This paper will discuss the current situation in terms of available accident statistics for 2-wheelers and the societal trends that point to the need for more research in this area.

INTRODUCTION

A World Bank study estimates that by 2020 Road Traffic Accidents (RTA's) will have moved from 9th to 3rd in the global table of the burden of disease[1]. The total global figure is difficult to calculate reliably, however one estimate suggests that 1 million people are killed and between 23-34 million people are injured every year[2]. From these 70% of those killed or injured will be in the developing world, and out of this proportion the majority are pedestrians, cyclists or two-wheeled motor vehicle (TWMV) riders[3].

In the developed world, the reduction of death and injury on the roads has been expedited by improved trauma care, road infrastructure, legislation and occupant protection to name but a few, however approximately 43,000 deaths and 3.5 million injuries occur in Europe alone. Figures 1 and 2 show the proportion of killed and injured by road user group across several countries. It is clear that in countries with a strongly motorised culture, the majority of injuries and deaths are still due to vehicle occupant injuries. Generally pedestrians are the next most important road user group, however when two-wheelers are taken as a whole they are statistically the next most relevant. The paper will describe the trends in several countries and why two wheelers should be considered in the West as well as in the developing world.

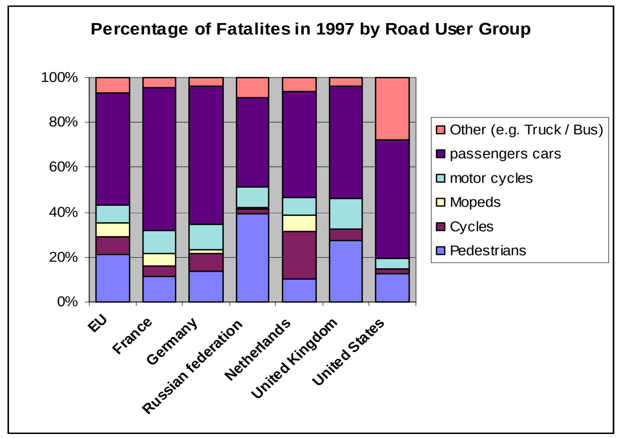


Figure 1 – Fatalities by Road User Group

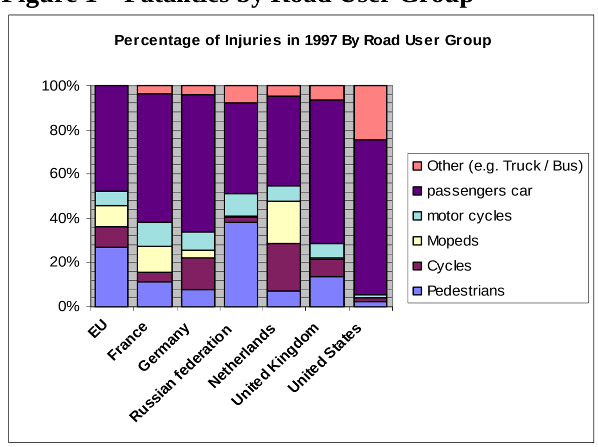


Figure 2 – Injuries by Road User Group

With the advance of computer-aided engineering (CAE) the ability to model accurately both the vehicle's, and the occupants' crash response has developed greatly in the last 15 years. The use of dummies, or anthropomorphic test devices, (ATD's) for occupant crash correlation purposes has made this task easier to achieve, by having a specific 'performance envelope' to aim for. Obviously it is impossible to predict the response of every different human being, however, these devices when used in their most complex form give an acceptable parametric response to an agreed international standard for a specific test (e.g. side impact).

In the case of pedestrian and other "vulnerable road user" (VRU) tests, a variety of different dummies have been used, with differing results. Many have used HYBRID II or III dummies (used as an occupant device for frontal impact) as a basis and then heavily modified the hips, and legs in order to try and get a more representative kinematic response. A new-generation dummy used in pedestrian applications has been developed by Honda and GESAC[4]. Called 'POLAR' it has a detailed knee structure, and an on-board data acquisition system (allowing the dummy to be used in a test and the result not be affected by cables attached to transducers). As for motorcyclists, some work in the UK at TRL has used the OPAT dummy, however in order to achieve a much better biofidelic correlation, compared to existing occupant devices, the IMMA (International Motorcycle Manufacturers Association) funded a research programme[5] that has produced the Motorcyclist Anthropomorphic Test Dummy (MATD). This is based on a HYBRID III dummy, but has some important adaptations including handlebar-grasping hands, a curved lumbar spine section (in order to get a realistic rider position) and an on-board data acquisition system (similar to the POLAR dummy).

Work has been undertaken by TNO to look specifically at cyclist injuries using HYBRID II 50%-ile dummies, which showed that when compared to tests on cadavers, the dummies showed significantly less flexibility in the lateral plane[6].

Underlying the use of all present dummies for modelling VRU's is their inability to give an accurately repeatable result in a given vehicle impact test regime. For this reason the decision was made to move to a series of independent impactors for pedestrian safety. In the WG10[7] and WG17[8] reports produced by EEVC, full details are given of these impactors and the parameters that vehicles should achieve to mitigate injury at head and leg speeds of 40 kph. Cyclists were also included as a target group of vulnerable road users, in this new set of standards aimed at improving pedestrian safety.

The aim of this paper is to discuss the issues surrounding the decision to specifically examine two-wheelers as a subject for accident simulation and suggest some reasons why this global accident population will grow in the longer-term.

The paper will go on to discuss simulation methods used in accidents involving vulnerable road users (VRU's), and the initial progress in accident simulation for 2-wheelers using LS-DYNA, in terms of approach, method, results and conclusions.

ACCIDENT AND INJURY TRENDS

Vehicle occupant statistics, particularly in the Western world, are increasingly more reliable year on year, with better detail to an agreed international standard. For instance, a road traffic accident fatality in the EU varied depending on the home country's definition of how long the injured party survived the accident[9]

Data for two-wheeled riders is variable depending on the country and due to the nature of the vehicle. For instance in some countries, cyclist accident data is included with that of pedestrian. Additionally, because the accident scene is easier to clear than that of the likes of a car to car accident, a great deal of information can be lost from the accident location. Measures have been taken by industry to improve the understanding of these events, such as IMPAIR in Germany[10], or 'On The Spot' Investigations sponsored by the UK Department of Transport, Local Government and the Regions (DTLR). However, the best way in the future for mapping the exact causation and effect of such crashes may be through the use of inner-city CCTV cameras, suitably de-sensitised by government authorities, for research purposes.

Fatalities

From Figure 3, it is interesting to note that the European average in particular, pedestrian fatalities are declining at a rapid rate, even without any attempt to introduce more 'pedestrian friendly' designs for road vehicles. Even in the rest of the developed world this trend is still downwards overall. This is possibly due to better road infrastructure and improved management of traffic in built up areas.

Figure 4, however, shows a different picture – cyclist fatalities in the West do have a generally downward trend over the last few years, but the rate of decline is nowhere near that of pedestrians. In the case of the UK, if you also include the fact that the cycling riding populations have diminished

As far as TWMV's are concerned, Figure 6 shows the trend has been downward until recently when the fatality rate has either flatten or risen slightly. This is particularly marked in the case of the US where pressure groups in several states (e.g. Arkansas) have repealed state laws enforcing helmet use.

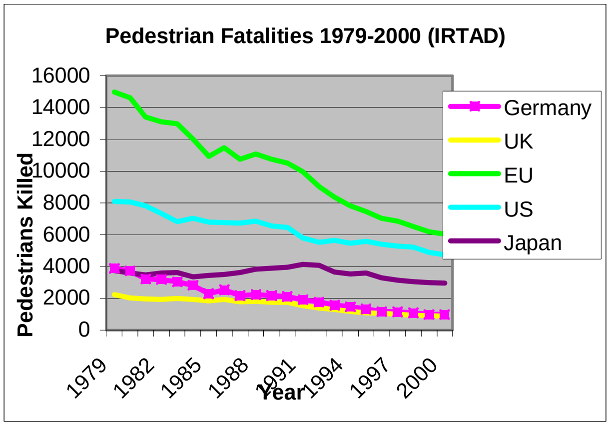


Figure 3 – Pedestrian Fatalities 1979-2000

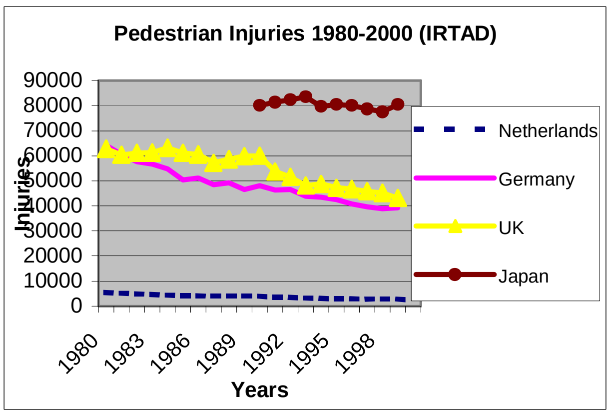


Figure 4 – Pedestrian Injuries 1979-2000

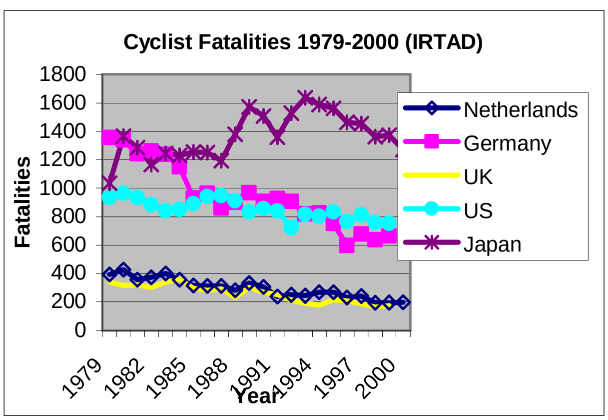


Figure 5 – Cyclist Fatalities 1979-2000

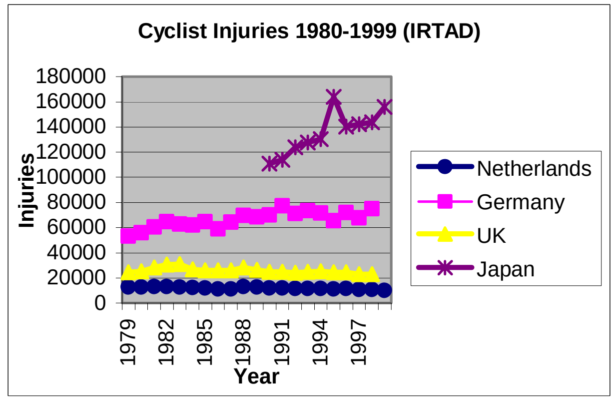


Figure 6 – Cyclist Injuries 1980-1999

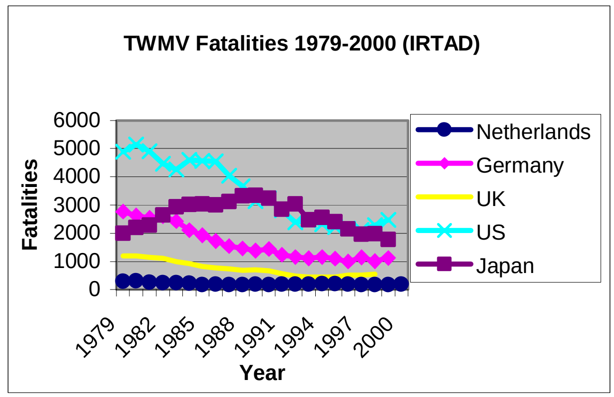


Figure 7 – TWMV Fatalities

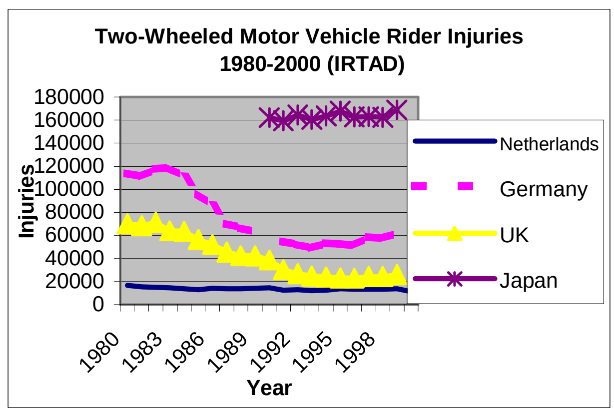


Figure 8 – TWMV Injuries

Injuries

In the pedestrian case, the trend is relatively flat in the West, and in fact there has been a slight increase in Japan over the last few years. Generally on average in Europe the trend is downwards.

The most interesting results of all these graphs is that for cyclist injury. It would appear that not only the total numbers of injuries are higher, but also the trend is flat at best and at worst (in the case of Japan) the rate of injuries is increasing dramatically. Clearly this is a worrying trend, and requires more investigation to discover the underlying reasons.

For powered two-wheelers, there is even more attention to address the lack of data, such that a European project called MAIDS (Motorcycle Accident In-Depth Study) is currently underway, and is already yielding some very useful data[11].

Although the lack of substantial information for two-wheeled accidents is a recognised problem that is being addressed in the west, the problem is more acute in developing countries. In particular, most developing countries use a large proportion of powered two-wheelers (motorbikes and mopeds) as well as bicycles as a major means of mass transportation. As their economies expand, and personal incomes increase, more of the population will move towards improved individual transport methods. By the time this occurs in large volumes, it is likely that traditional fossil-fuel driven vehicles may be superceded with new more environmentally-friendly powerplants. The future mix of vehicles will still have a high percentage of two-wheelers in the developing world, (e.g. in China there is an estimated 450 million bicycles in use).

TYPICAL CRASH TYPES FOR CYCLISTS

The basis for simulation has to be based on real-world accident scenarios. Some studies have been undertaken in some detail from Western countries to understand which orientations (in terms of cyclist to passenger car or truck), are the most common. The results of these are shown in Table 1in Appendix 1.

As can be seen junction-type crashes are the most common, according to these studies, however it can be noticed that there is a significant difference in the types of crashes experienced between motorcyclists and cyclists. In addition the data from DEKRA[12] suggests that greater than or equal to 57% of all accidents take place at speeds up to 40kph. On this basis it would seem reasonable to concentrate initially on CAE simulation of side collisions for cyclists.

A great deal more understanding has been gained from investigation of motorcycle crashes. This culminated in the ISO standard ISO13232[13] Although this is relevant for all two-wheelers, as can be seen from above, the reality for cyclists is different from those of mopeds and motorcycles. Many of the methods developed within the standard are still applicable to cyclists and will be used accordingly.

Draft Adaptation of ISO 13232 For Cyclists

It is for this reason that an adaptation to the ISO 13232 standard is proposed to examine bicycle to vehicle impacts, as can be seen in Appendix 2, Figure 10. This is still at a draft stage, as more detail needs to be addressed in terms of vehicle speeds, however taking the pedestrian studies as a template where the 'average' collision takes place at 40kph, this seems justifiable as an initial basis for research and will be refined in due course.

HUMANOID SIMULATION

The humanoid model used in the simulation has been developed by Cranfield Impact Centre under a Ford contract[14] specifically for use in determining the real-world effects of devices developed to improve pedestrian safety. It is an LS-DYNA model using elements from HYBRID III and EuroSID crash dummies, and heavily modified to give the best possible biofidelic performance (within reasonable run-times). The material models were adapted to as real-world a response as possible by using cadaver data from published papers by Ishikawa[15] et al.

In addition, the humanoid can be adapted into any size or ethnic group by manipulating the 50%-ile ‘reference model’ by changing the regression equations in the ‘GEBOD’ model[16]. For the purposes of this initial study, a male 50%-ile humanoid will be used as standard.

Most simulation of cyclist and motorcyclist accident scenarios have been developed using rigid-body methods (TNO’s MADYMO routine in particular). This is an effective method to give a parametric appraisal of the crash kinematics (particularly when dummies have been used in a physical crash test), however, when examining injury criteria, it has been shown that a more complex FE model will provide better biofidelic response in a complex crash case.

Results from the pedestrian use of the model have been very promising, and it is hoped that further development of this technique will yield a useful design tool for examining real-world crash scenarios when new deployable technologies become available. The next step on from this is to examine how two-wheeled crash events can be mitigated. It is hoped in both cases that suitable real-world accidents can be found that allow the model to be correlated.

Vehicle Model

This is a mid-size family car model, as developed by Howard[17], as part of the on-going development work on pedestrian safety. Clearly the effect of geometry on the crash event is a major factor in the results obtained, however it was chosen to keep to this vehicle, as this is a fully validated model for pedestrian collisions at 40kph and is equally applicable to the two-wheeler scenarios examined.

Individual components on the front of the vehicle are modelled in detail and have been correlated to individual impact tests aimed at pedestrian impact speeds (40kph). It should be noted that the remainder of the vehicle is modelled as a rigid item to reduce processing time and model complexity.

An *INITIAL_VELOCITY card is used to provide the 40kph vehicle speed, however a *RIGID_BODY_MOTION card attached to the rigid part at the rear of the vehicle provides a 1G deceleration to simulate heavy braking.

Bicycle Model

Adaptation of the model began by creating the basic geometry of a using a mountain bike that is generally representative of those seen on the roads in the UK. The geometry is based on a commercially-available mountain bike, as shown in Figure 9.

The model was created with revolute joints in the stock, and pedals. Materials cards in the DYNA keyword file were used that replicate the materials used in construction. Rigid elements were used in the fork support bracket, and the pedals. The tyres and rims were modelled using a generic steel card (since the rims have the largest effect on the structure), and the spokes were modelled using springs.

Impact tests on bicycle frames are planned in order to correlate the model, however, experience has been used to apply the correct material cards to the structure in the first instance.

Adaptation of the humanoid

For the initial set of simulation runs, a 50th percentile male humanoid was taken as a basis for the study. By using an anthropomorphic mannequin, an assessment of the correct joint angles was taken in the position shown in Figure 9. The orientation of the humanoid on the bicycle was adapted to suit a reasonable riding position.

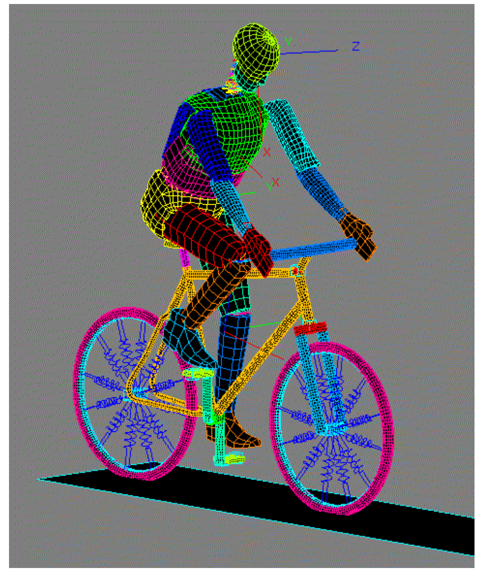


Figure 9. Adapted Humanoid and Bicycle FE Model.

A *LOAD_BODY_Z card is used in the input deck to allow the humanoid to "settle" into the required position on the bike. The time it takes for this to occur is around 10ms, and therefore the distance between the vehicle and the first impact point (leg to bumper) is then calculated according to the speed at impact (i.e. 40kph is equivalent to 111mm). The combined bike and humanoid model is then placed at the correct distance according to the speed of the vehicle.

Initial Results

Over the next few months, it will be possible to examine the main accident scenarios involving pedal cycles and cars, using the combined LS-DYNA models, as shown. For the purposes of this paper, a single *preliminary* scenario will be shown for clarity.

Figure 11 in Appendix 3 is a side crash at 40kph onto the front of the vehicle, with the cyclist stationary in front of the vehicle.

The overall kinematic performance is reasonable when compared to the cadaver tests undertaken by Janssen et al[5], however more development is needed to improve both the bicycle and the humanoid. In particular, the rigid foot on the humanoid deforms the bicycle frame unrealistically, which may lead to a slightly different kinematic effect and therefore influence the results. More details need to be gathered from real-life incidents to see if the deformation of the bicycle or the vehicle is accurate.

In more detail, the model shows the right leg being trapped within the structure of the bicycle frame and the rest of the body impacting the windscreen / bonnet. The head strikes in the upper centre of the windscreen.

CONCLUSIONS

The global trend of accident data seems to point towards the developing world taking an ever-greater share of the cost both in physical and financial terms for road traffic accidents. Indeed as more vehicle types become limited in inner-cities in the West (particularly Europe), it is highly likely that there will be a higher proportion of cyclists on the roads in highly-motorised countries as well.

The role of two wheeled riders in highly-motorised and developing transport systems needs more detailed analysis. Even with future segregation of cyclists from motorised vehicles, crossing points and junctions will always prove to be a problem. The underlying data is still patchy and although it is improving, there is still a lack of detailed information (which, for instance, the motorcycling community is addressing through the MAIDS project), other than studies in the Netherlands.

As computer processing power improves each year it is possible to make more detailed models that run in a reasonable time. Through correlation of these models it should be possible to get improved design solutions for safety devices both on vehicles and also worn by the rider.

Research needs to be aimed at cyclists specifically, in order to account for the different circumstances that occur in an impact compared to pedestrians. It is hoped that this work will provide a basis for future work within the scope of the author's PhD – particularly for children and investigation of the effect of cycle helmets.

REFERENCES

(1) C.J.L. Murray & A.D. Lopez - "The Global Burden of Disease: A Comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020" Harvard University Press.

(2) G.W. Trinca, I. Johnson, B. Campbell, F. Haight, P. Knight, M. MacKay, J. McLean, and E. Petrucelli, - "Reducing traffic injury – a global challenge" A.H. Massima & Co, Melbourne, 1988.

(3) G. Jacobs, A. Aeron-Thomas, A. Astrop, - "Estimating Global Road Fatalities" – Transport Research Laboratory Report TRL445 (2000)

(4) A. Akiyama and M. Okamoto, Honda R&D Ltd, and N. Rangarajan GESAC Inc – "Development and Application of the New Pedestrian Dummy" – ESV Conference 2001 – Paper 463.

(5) J. Newman, J.W. Zellner, and K.D. Wiley - "A Motorcyclist Anthropomorphic Test Device MATD", Proceedings IRCOBI Conference, Berlin, September 1991.

(6) E.G. Janssen, and J. Wismans – "Evaluation of vehicle-cyclist impacts through dummy and human cadaver tests." The 11th Technical Conference on Experimental Safety Vehicles, 12th-15th May 1987, Washington D.C. USA.

(7) European Commission:- DG-III "Draft proposal for a European Parliament and Council Directive relating to the protection of pedestrians and other vulnerable road users in the event of a collision with a motor vehicle", EC Document reference III/5021/96 EN, 1996, Brussels

(8) EEVC WG17 Report "Improved test methods to evaluate pedestrian protection afforded by passenger cars", European Enhanced Vehicle-Safety Committee, March 1999, http://www.eevc.org/publicdocs/WG17_Improved_test_methods.pdf

(9) OECD – IRTAD Database 1997

(10) R. Sferco, W. Koch, 'IMPAIR Study –In-depth Medical Pedestrian Accident Investigation & Reconstruction', Poly-Trauma Trauma-Forschung, Greifswald, Jun 29-30 2001

(11) H.G. Mooi TNO Automotive & F. Galliano, ACEM – ESV Conference 2001 Paper 236.

(12) H. Osendorfer and S. Rauscher, BMW AG – " The Development of a New Class of Two-Wheeler" – ESV Conference 2001 Paper 01-S8-0-475.

(13) ISO 13232, Motorcycles – Test and analysis procedures for Research evaluation of Rider Crash.

(14) M.S. Howard, A.V. Thomas, W. Koch, R. Hardy, J. Watson – "Validation & Application of a Finite Element Pedestrian Model for Use in Pedestrian Accident Scenarios." IRCOBI Conference 2000.

(15) H.J. Ishikawa, J. Kaiser and G. Schroeder: "Computer simulation of impact response of the Human Body in car-pedestrian

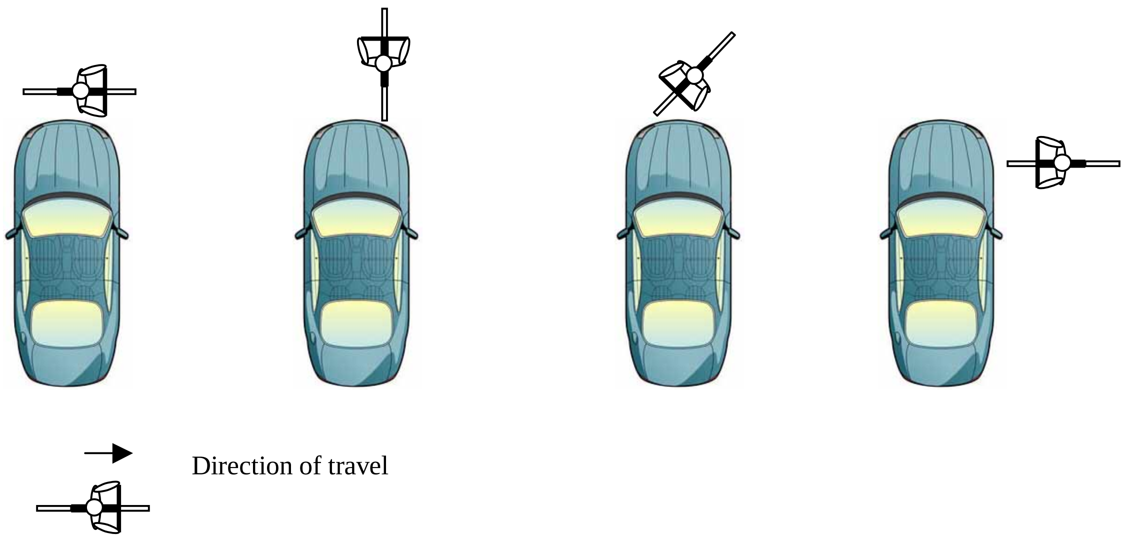
accidents", 37th Stapp Car Crash Conference, Proc P-261, Society of Automotive Engineers Inc, 1993.
(16) H. Cheng, L. Obergefell, and A.Rizer – " A Generator Body (GEBOD) Manual", AL/CF-TR-1991-0051, Air Force Materiel Command, Wright-Patterson Air Force Base, Ohio, 1991.
(17) M.S. Howard, J.W. Watson and R.N. Hardy (1998) – "The Simulation of Real-World Car to Pedestrian Accidents using a Pedestrian Humanoid Finite Element Model", International Journal of Crashworthiness, Vol3 No4, Woodhead Publishing Ltd, 1998.

APPENDIX 1

Table 1. Rider impact orientation

Source	**Front Collision**	**Side Collision**	**Side Swipe Collision**	**Rear Collision**	**Falling Down**	**Others**
For Motorcycles						
BMW[12]	42%	4%	18%	2%	10%	24%
For Cyclists						
DEKRA	20%	59%	-	21%	-	-

APPENDIX 2



Config	1	2	3	4
$\mathbf{V_{OV}}$	40kph	40 kph	40 kph	0 kph
$\mathbf{V_{PB}}$	0kph	0 kph	15 kph	20 kph

V_{OV} = Velocity of other vehicle
V_{PB} = Velocity of pedal bicycle

Figure 10 – Draft proposal for the adaptation of ISO 13232 for cyclists

APPENDIX 3

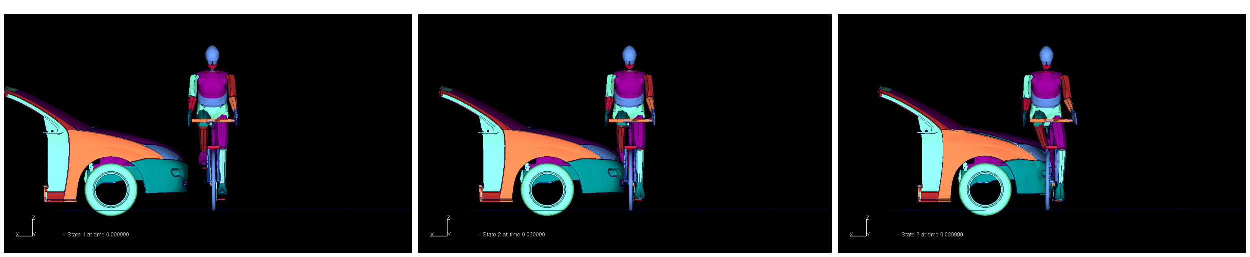


Figure 11 – Side view of car to bicycle accident at 40kph.