TRIPP BULLETIN
VOL 13 NO.2 MONSOON 2016
TRANSPORTATION RESEARCH & INJURY PREVENTION PROGRAMME
INDIAN INSTITUTE OF TECHNOLOGY DELHI

Ph.D. Scholars *Current*

Naturalistic driving behaviour study
Scholar: Abhaya Jha

Study of the effect of geometric design features on capacity of hill roads
Scholar: Achyut Das

Transport, gender and climate change
Scholar: Akshima Tejaz Ghate

Context aware technology and systems
Scholar: Alok Nikhil Jha

Multi objective optimization in construction project management
Scholar: Amit Chandra

Urban landuse and transport modeling
Scholar: Amit Sharma

Accident reconstruction based study on motorcycle crashes
Scholar: Amrit Lal

Design and optimization of air ventilation system for improved heat transfer characteristics in helmet
Scholar: Bhagwat Singh Shishodia

Bus transit route network - aspects of design, optimization
Scholar: Bhamidipati Siri Aparna

Railway track pedestrian safety
Scholar: Darbamulla Saibaba

Methodology for low carbon mobility plan for indian cities
Scholar: Deepty Jain

Safety issues in project management
Scholar: Dilip A Patel

Modelling and risk assessment of heterogeneous traffic
Scholar: Gaurav Pandey

Methodology for design of vehicle front of an urban car for safety of vulnerable road users
Scholar: Hariharan S

Analysis of travel behaviour and impact of demand management interventions on non-captive bus users
Scholar: Hemant Kumar suman

Establishing relationship between elements of highway engineering on crashes on national highways in India
Scholar: H.M. Naqvi

Issues in human body FE modelling
Scholar: Kanhaiya Lal Mishra

Human body model (thorax modelling and its validation)
Scholar: Khyati Verma

Pedestrian and crowd modelling
Scholar: Lakshmi Devi Vanumu

Urban freight modelling
Scholar: Leeza Malik

Private participation in metro rail projects in India: challenges and way forward
Scholar: Mukund Kumar Sinha

Ph.D. Scholars *Continued*

Road safety risk assessments of modern toll plazas and standardization of its geometric design
Scholar: Navdeep Kumar Asija

Urban freight studies
Scholar: Nilanjana De Bakshi

Thorax model building and validation – diaphragm and aorta
Scholar: Piyush Gaur

Pavement materials
Scholar: Priyansh Singh

Finite element human body modelling direction
Scholar: P Devendra Kumar

Effect of traffic characteristics on vehicle emissions
Scholar: P.V. Pradeep Kumar

Human body finite element modelling
Scholar: Rajesh Kumar

Measuring public health effects of urban transportation in Delhi
Scholar: Rahul Goel

Mode choice initiators in public transport demand modelling
Scholar: Sandeep Gandhi

Finite element human body modelling direction
Scholar: Sanyam Sharma

Vehicle and crew scheduling optimisation of city bus systems
Scholar: S B Ravi Gadepalli

Estimation of perceived and actual risk faced by pedestrians: case study delhi, india
Scholar: Shalini Rankavat

Service level benchmarks for urban transport systems
Scholar: S.K. Lohia

A methodology for simultaneous route network design and frequency setting problem in small and medium sized cities
Scholar: S.M. Hassan Mahdavi M.

Framework to determine the level of service of urban bus systems - Case study: Delhi
Scholar: Sneha Lakhotia

Impact of traffic control measures on speed and driver behavior in highway work zones
Scholar: Sumeet Gupta

Human body modelling requirements for vulnerable road users
Scholar: Wondwosen Ayelework Lakew

Ph.D. Scholars *Completed*

Methodology for design of vehicle front of an urban car for safety of vulnerable road users
Scholar: Hariharan S Subramanian

Characterization of long bones bending under impact
Scholar: Mike W.J. Arun

The **Transportation Research and Injury Prevention Programme (TRIPP)** at the Indian Institute of Technology Delhi, is an interdisciplinary programme focussing on the reduction of adverse health effects of road transport. TRIPP attempts to integrate all issues concerned with transportation in order to promote safety, cleaner air, and energy conservation. Faculty members are involved in planning safer urban and inter-city transportation systems, and developing designs for vehicles, safety equipment and infrastructure for the future. Activities include applied research projects, special courses and workshops, and supervision of student projects at postgraduate and undergraduate levels. Projects are done in collaboration with associated departments and centres at IIT Delhi, government departments, industry and international agencies.

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LEGISLATION, ENFORCEMENT AND EDUCATION FOR TRAFFIC SAFETY: A BRIEF REVIEW OF THE CURRENT STATE OF KNOWLEDGE

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This paper briefly reviews the current state of knowledge with respect to the use of legislation, enforcement and education to promote traffic safety. Legislation can be a very strong policy instrument to promote traffic safety. Examples are given of major changes in road user behaviour and accidents associated with the introduction of new legislation. These examples also show that the effects of new laws may erode over time. To sustain the effects of legislation in the long term effective enforcement is needed. Factors that influence the effects of enforcement are discussed and accident modification functions associated with enforcement are presented. Challenges in maintaining a high level of enforcement in the long run are discussed. Finally, the possibilities of motivating road users to adopt safer behaviour by means of education are discussed. It is concluded that some educational measures may improve safety, but that not all educational measures are likely to do so. Characteristics of the more effective educational measures are discussed.

This paper is intended to give a brief overview of the current state-of-the-art with respect to the effects of legislation, enforcement and education as road safety policy instruments. Key questions addressed in the review include:

What types of road user behaviour are regulated by means of legislation, what types of behaviour remain unregulated?

What can we learn from the history of road safety legislation with respect to changing road user behaviour and reducing the number of accidents and injuries?

How do legislation, enforcement and sanctions interact in bringing about changes in road user behaviour and in traffic injury?

Why are laws never one hundred percent effective in solving a problem and what can be done to make them one hundred percent effective?

What are the effects of educating road users? Why have most educational measures had limited success and how can they be made more effective in improving road safety?

The review starts by discussing legislation and continues by discussing enforcement. Education is discussed at the end of the review.

Until the energy crisis in 1973, quite a few European countries did not have speed limits at all, at least not in rural areas. Today, few people believe that this could really be the case, but it was. There was a free choice of speed. In many countries, until about 1970, there was also a free choice about whether to drink and drive. Well, strictly speaking, drinking-and-driving was not allowed, but the legislation made effective enforcement almost impossible. In the first place, the police could normally only stop a driver if they suspected him of drinking and driving. If there was nothing peculiar about driving behaviour, there was no legitimate reason for suspicion. In the second place, the police had to prove that the driver was impaired. This involved various assessments of behaviour that were often contestable in court. The police might say, for example, that the driver could not walk a straight line. The driver would protest, and unless there was other evidence, it was word-against-word and a driver with a good attorney might get acquitted. Today, this sounds like a tale from the past, as indeed it is. Nowadays, the freedom of road users to make their own choices has been circumscribed and many motorised countries have legislation that lays down:

•Permitted driving speeds. There are speed limits everywhere, except on German motorways.

•Use of protective devices. Wearing seat belts is required in very many countries. Using motorcycle helmets is still voluntary in some places (see below).

•Drinking-and-driving. All highly motorised countries have per se laws, i.e. laws stating that a driver is regarded as drunk if blood alcohol concentration exceeds a certain value (0.05 percent is the most common).

•Use of daytime running lights. Some countries require motor vehicles to use headlights at all times.

Over time, legislation has expanded and included more and more aspects of road user behaviour. Since the expansion of legislation can be regarded as curtailing freedom, it is important to determine if legislation does accomplish its stated objective of improving road safety. Below, a few examples are reviewed in order to answer this question.

1.Introducing a law can lead to a large improvement in road safety.

2.If the law is repealed, a large part of the safety improvement may be lost.

Laws do therefore not necessarily lead to learning or to changes in behaviour that are sustained permanently. As soon as motorcyclists were allowed to take off their helmets, many did so, although both scientific and anecdotal evidence should have convinced motorcyclists that wearing helmets improve their chances of surviving an accident or getting less seriously injured.

the law requiring seat belts to be worn in Norway. The law was passed in 1975. However, until October 1979, those who violated the law were not punished in any way. All the police could do was to give drivers and passengers a friendly reminder of the law. Figure 3 shows seat belt wearing among car drivers in Norway from 1973 to 2013.

When the law passed, there was an increase in seat belt wearing. But then, in the next year, seat belt wearing remained unchanged at about 60 % in rural areas and about 30 % in urban areas. In 1979, a fixed penalty of NOK 200 (1 NOK = 0.12 US Dollars in July 2015) for not wearing seat belts was introduced. Wearing then soared to almost 90 % in rural areas and around 70 % in urban areas.

For a law to be effective, there must be a sanction for violating the law. Without a sanction, the law cannot be enforced.

For a sanction of violations of a law to be effective, it must be possible to apply the sanction whenever the law is violated. Sanctioning should not depend on having violated a different law.

1.The effects of enforcement are transient. When enforcement ceases, its effects disappear quickly.

Road users adapt their behaviour to even minor changes in enforcement. This is shown in data collected in a recent Norwegian study (Elvik and Amundsen 2014). The study collected data for ten years on speed enforcement. During these ten years, examples could be found both of increases in enforcement and reductions of it. Using annual change in the rate of speeding (kilometres driven while speeding as a percentage of all kilometres driven) as dependent variable, 54 data points were identified by combining years (9 annual changes), urban or rural area (2 values) and three levels of speeding (3 values). These data points are shown in Figure 7. Although the data are somewhat noisy, there is still a tendency for speeding to go up as enforcement is reduced and go down as enforcement is increased. Figure 8 shows the relationship more clearly. It is based on a review of a large number of studies of speed enforcement for the purpose of developing accident modification functions describing the effects of enforcement (Elvik 2015A).

2.The current level of enforcement maintains the current level of safety.

3.When enforcement is reduced, violations and the number of accidents increase.

4.When enforcement is increased, violations and the number of accidents are reduced.

5.Road users react to even small changes in the level of enforcement.

6.There are greater changes in behaviour and accidents when the risk of apprehension is high than when it is low. This explains why speed cameras are more effective than traditional police enforcement

The advantage of speed cameras is that they can be operated continuously. The disadvantage is that the effects are very local. It is possible to connect several speed cameras with one another, in the form of section control. The cameras would then calculate the mean speed of driving over a certain distance of road. Section control may thus enlarge the area where speed cameras have an effect. However, section control is not feasible or practical everywhere. If the road has many junctions, there will be many cars entering and leaving the road and thus passing only one of the speed cameras. Installing and operating cameras is expensive. Section control would therefore be most effective on roads with a high traffic volume.

It is therefore difficult to believe that section control by means of speed cameras could ever be used on more than a small fraction of all roads in a country. Until vehicle technology monitoring and possibly regulating speed (ISA-systems; Intelligent Speed Adaptation) becomes more widely used, traditional enforcement performed by police officers will be the most important form of enforcement. This leads on to the final lessons regarding enforcement. These lessons concern the interaction between road users and the police in determining the level of enforcement.

7.Enforcement will never be one hundred percent effective, in the sense of eliminating violations.

8.The police always apply a certain tolerance margin when doing enforcement. This means that a certain level of minor violations is tolerated.

9.If violations go down, the police will tend to reduce enforcement.

Education is a very broad concept and includes many measures taken to enhance the knowledge and skills of road users. It is therefore not possible in this paper to review all studies that have evaluated the role and effects of education in improving road safety.

One of the road safety problems that has proven difficult to solve in all highly motorised countries is the high accident rate of young drivers, in particular male drivers. Elvik (2010) discusses why this problem has proven difficult to solve and offers the following remarks on it:

"It has long been the hope of educators that novice drivers can learn not just the skills needed for safe driving, but also acquire an understanding that these skills develop slowly and have not been fully learnt by the time a driver is licensed. However, teaching young people not simply to acquire certain skills, but also to correctly assess the limits of their skills is an almost impossible task. It is, so to speak, impossible to teach people that they do not know anything, or that what they know is only a very small part of what they need to know. Gregersen (1996) reported a very interesting experiment that shows this. He compared two groups of novice drivers. One group had been given skills training to make the driver as skilled as possible in braking and performing an evasive manoeuvre. The other group had been instructed that this task was very difficult and that they could not necessarily be expected to perform it successfully. The two groups then performed an evasive manoeuvre on a test track. Actually, the group that had been taught to master the skill and who erroneously believed that they did in fact master the skill, did a little worse on the task than the group who had been taught to have more modest expectations about their own performance.

Novice drivers regularly overestimate their competence. A recent study shows that 30-40 % of young drivers in Finland and the Netherlands rated their competence as better than driving licence examiners did (Mynttinen et al. 2009). Those who overestimated their competence (rated their competence higher than the rating given by the licence examiner) failed the driving test more often than those who slightly underestimated their competence. Overestimating driving skills is hazardous, as it can make the driver accept a higher level of risk than he or she would if skills were understood more correctly.

As far as deliberate risk taking is concerned, Evans (2006) proposes the hypothesis that it can be caused by hormonal factors, in particular the high level of testosterone in young males. While introducing biological explanations of social phenomena is controversial and not always taken seriously, the data presented by Evans at the very least indicate that his hypothesis is plausible, although these data do not confirm it. Support for the hypothesis that testosterone levels influence risk taking comes from a study of financial risk taking and career choice, although in that study the largest effect of testosterone was found among women (Sapienza, Zingales and Maestripieri 2009; both sexes produce both male and female sexual hormones, but in different mixtures)."

The Handbook of Road Safety Measures (Elvik et al. 2009) summarises many studies that have evaluated the safety effects of basic driver training. Although the results of these studies vary, on the average no effect on safety has been found. It would obviously be unscientific and overly pessimistic to suggest that a successful way of teaching young people to drive more safely can never be found. It does, however, seem to be a challenge.

1.Training novice drivers advanced skills that are rarely practised in traffic may generate overconfidence that increases the number of accidents.

2.Imposing restrictions on novice drivers, which prevent them from driving in difficult conditions is associated with a reduction of the number of accidents.

3.Lowering the age for driver training, permitting novice drivers to drive more kilometres before getting licensed may reduce the number of accidents.

4.If there is motivation, education can be highly effective in producing safe behaviour.

5.The source of motivation may vary, but would often be that a person experiences an immediate personal benefit in learning the safe behaviour.

It is clear that legislation, enforcement and education can all contribute importantly to improving road safety. Yet, it is also clear that these policy instruments may not always be as effective as their proponents are hoping for.

Laws can be repealed if they do not have popular support. Laws requiring motorcyclists to wear helmets survived only for a few years in many states in the United States. The national maximum speed limit of 55 miles per hour, introduced as an energy conserving measure in 1974, survived until 1987. States were then allowed to raise speed limits to 65 miles per hour. In 1995, the national speed limit was abolished entirely and states could set any speed limit they wanted, including no speed limit at all. There is therefore no guarantee that even highly effective legislation can be sustained in the long term.

It is important that laws regulate important risk factors, not risk factors that make small contributions to accidents or injuries. Current legislation is not entirely consistent with such a principle.

Legislation is never one hundred percent effective. In all societies, there are individuals who are more or less delinquent, who live their lives more or less as criminals and who are difficult to influence.

Legislation will not be very effective without enforcement. Enforcement is effective, but only when and where it takes place. As soon as enforcement ceases, violations tend to increase. Current enforcement technology, in particular speed cameras, are highly effective but cannot entirely replace enforcement performed by police officers.

Educating road users to behave more safely is difficult, a lot more difficult than regulating their behaviour by means of laws and their enforcement. Laws and enforcement are often viewed as repressive policy instruments. They are negative. They tell people what they should or should not do. They command rather than encourage.

Proponents of education have therefore long argued that laws and enforcement reflect an impoverished view of human nature, that these policy instruments do not recognise the positive capabilities of humans to learn, help each other, love each other and excel in sports and academic performance. Would it not be better to educate road users, to use positive policy instruments that foster human development, proponents of education ask.

Modern road traffic is an advanced system in which you cannot travel safely without being, in a wide sense of that term, highly educated. However, this does not mean that road traffic offers great opportunities for education, in the form of formal instructions or lectures delivered in classroom style. In the first place, the system is remarkably self-instructing and forgiving. It normally allows a margin for error and thereby for learning all by yourself. To put it elliptically: Safe driving can certainly be learnt, but it cannot be taught. It is all about learning by doing, learning by trial and error, learning by imitation, learning from mistakes, etc. – all of which a driver can do entirely on his or her own. The technical skills needed to drive a car are easy to learn. Any teenager can learn it in a few hours. The danger is that when the technical operation of a car has been learnt, the driver may erroneously think that he or she can drive.

In the second place, road users are remarkably reliable in behaving in ways that prevent accidents. Given the very many opportunities there are for accidents to happen, extremely few of these opportunities result in an accident. There is, in other words, little room for improvement. There is little to learn. Most road users know everything they need to know to travel safely.

This does not mean that human factors do not contribute importantly to accidents. They obviously do. The driver is the problem. The solution is therefore to abolish the driver, not try to reform him, which is in most cases a hopeless project. Self-driving cars are rapidly being developed and hold great promise for improving road safety.

Excerpts from a chapter in a forthcoming TRIPP publication: The Safe Way : State of the Art Lectures on Road Safety

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VOL 13 NO.2 MONSOON 2016

M.Tech. Projects

Completed

Characteristics of freight vehicles in delhi and trip attraction model for vehicle coming from outside Delhi
Student: Ashwani Kumar
Trip generation model for mixed land use development
Student: Hitesh Kumar Meena
Level of service estimation for in-vehicle travel in buses-Case study of Delhi
Student: Jatin Bhutani
Meta-analysis of crash modification factors in road safety on highways
Student: Rajat Gupta
Handling missing data issues while predicting pavement temperature
Student: Snehlata
Impact of socio psychological variables on public transportation mode choice: case study metro
Student: Snehalata Thakur
Use of angle of repose as an indicator of mix-ture properties
Student: Varun

NEWS

The mortality impact of bicycle paths and lanes related to physical activity, air pollution exposure and road safety

We have estimated the health benefits of bicycle lanes and pathes, assuming a scenario with 0.5 km/km2 of new bicycle lanes and paths (about an equal share of both facilities) in hypothetical Dutch city with a population of 100,000. Modelling the currently available research on mortality related to time spent cycling, air pollution risks and cycling safety, suggested that bicycle lanes and paths are associated with health beneits, primarily due to increased cycling (and consequent physical activity). However, the impact on time spent cycling is also subject to the greatest uncertainty due to a lack of causal evidence. Only few high-quality quasi-experimental research (with a before-after design) is available. Reduced exposure to the risks tof air polluion and road safety may have additional health benefits among all cyclists. However, their effect size is relatively small. A lower base level of cycling - under the assumptions of this paper - does not substantially change these conclusions.

A major strength of this study is the quantitative comparison of different health aspects associated with bicycle infrastructure. However, the study has a number of weaknesses. The mobility effects are still uncertain. There are only a few high quality before-after studies and those that are available are mainly from countries with lower base levels of cycling. We therefore recommend to evaluate a variety of bicycle infrastructure facilities in areas representing a wide range of base levels of cycling participation. This will assist in developing improved estimates of causal relationship between bicycle infrastructure and cycling. Although only true experiments (with random assignment of participants to an experimental and control group) enable testing causal hypotheses, evaluations using a quasi-experimental design can substantially improve internal validity compared with correlational research. Information about intervention characteristics needed to inform ex-ante evaluations is often lacking and the debate about how to operationalize different degrees of intervention exposure is ongoing. This information is needed to describe dose-response relationships. Increasing the evidence base of the impact of bicycle infrastructure on mobility is important to improve the quality of health impact assessments. Evaluations should include modal choice, duration, and route choice because these are needed for health impact assessment of bicycle infrastructure.

Our study only included health benefits that concerned cyclists. There are additional benefits for other road users who are less exposed to air pollution and road safety risks, as well as people living along busy roads who are less exposed to air pollution and noise. These impacts are likely to be smaller than the health benefits of increased physical activity due to cycling, but including them would more accurately estimate the expected total health benefits of bicycle infrastructure.

This study was restricted to mortality because the evidence for mortality is more conclusive than for morbidity. This raises the question of whether a health impact assessment including morbidity would yield different results. A commonly used measure for the total disease burden is the number of Disability Adjusted Life Years (DALYs) which combines the years of life lost (mortality) and years of life lived with disability (morbidity). Some 60% of the total number of DALYs related to physical inactivity in the Netherlands has been estimated to result from morbidity. The risks of air pollution are primarily related to cardiovascular and respiratory diseases, of which about half of the disease burden results from morbidity. The road safety effects of bicycle lanes and paths is limited to bicycle-motor vehicle crashes of which between 50% and 60% of the disease burden is related to morbidity. Non-motor vehicle crashes are excluded. These results suggest that it is important to include morbidity to assess the absolute size of the health benefits of bicycle infrastructure. The shares of morbidity in the disease burdens of the three health aspects included in our study do not strongly differ. This means that the relative sizes are unlikely to change to a large degree if we would include the whole disease burden. However, more research on the morbidity impact of more people cycling, and those who already cycle cycling longer, as well as air pollution risks would be needed to draw firm conclusions.

Paul Schepers, Elliot Fishman, Rob Beelen, Eva Heinen, Wim Wijnen, John Parkin (2015). Journal of Transport & Health, 2, 460-473.

Establishment funds have been received from
Ministry of Industry, Government of India
Asian Institute of Transport Development
Tata Motors, India
Volvo Research and Educational Foundations (VREF), Sweden

Endowments for perpetual Chairs
CONFER, India: TRIPP Chair for Transportation Planning
Ford Motor Co., USA: Ford Chair for Biomechanics and Transportation Safety
Ministry of Urban Development India: MoUD Chair for Urban Transport & Traffic Planning
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VOL 13 NO.2 MONSOON 2016
TRANSPORTATION RESEARCH & INJURY PREVENTION PROGRAMME
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Excerpts from a Ph.D. Dissertation : A TRIPP BULLETIN INSERT

Title: Characterization of Long Bones Bending Under Impact

Scholar: Mike Winifred Jimbry Arun

Supervisors: Sudipto Mukheerjee and Anoop Chawla

Department: Department of Mechanical Engineering

In the past four to five decades road traffic injuries remain an important cause of death, injury, and disability. Over 1.2 million people die annually in road crashes all around the world. This figure is equivalent to 3242 people getting killed per day worldwide. Additionally, between 20 and 50 million people suffer non-fatal injuries (WHO 2005). The alarming fact is that this epidemic of road traffic crashes is steadily increasing in low-income countries (LIC) and middle-income countries (MIC) despite the decreasing fatality rates in high-income countries (HIC).

In 2004 World Health Organization (WHO) estimated that the road traffic crashes are the ninth leading reason for death worldwide. Also WHO predicted road traffic crashes would be the fifth leading cause of death worldwide in 2030, if no major actions are taken. Road traffic crashes can be reduced possibly by two ways. First, through appropriate road and transport planning in which the interaction between pedestrian and vehicle, and between vehicle and other roadside structures can be avoided. Secondly by making the vehicle safe for both occupants and pedestrians. The aim of this work is an effort to support the second course of action.

A fracture mechanism in long bones under three point bending impact loading condition is proposed. The proposed mechanism is consistent with results from FE simulation, experimentally conducted as part of this work and published literature. The following conclusions can be drawn:

1. High magnitude compressive stresses are present locally in the vicinity of the impact section, even in the segment of the bone that is nominally tensile in quasi-static loading. As the bone has high strength in fail in compression; shear failure occurs.

2. Shear failure is indicated by the presence of shear lines in the impacted specimens and is predicted by FE simulations.

3. A possible mechanism for oblique fractures obtained for some loading and boundary condition is shear failure.

Physically realistic impact bending response and failure characteristics of long bones continues to remain as one of the major shortcomings in the human body FE model. The first objective of the present thesis is to characterize the long bone response through measurement of force-time response of human long bones at varying strain rates. The second objective is to generate accurate subject-specific long bone volumetric meshes, which captures both geometry and density distribution accurately. The third objective is to identify material models suitable to represent the long bone response under impact bending in explicit FE simulation. This objective includes the formulation of a user material code, which simulates the rate-dependency of elastic modulus of bones as existing ones do not suffice. The fourth objective is to back compute the unknown material parameters using Genetic Algorithm as the optimization tool. The final objective is to analyze and validate the fracture causing mechanisms in long bones, which are subjected to impact bending loading.

Experiments involving three-point bending under central impact loading using a drop tower setup have been conducted to characterize long bones as part of this work. Three different drop heights were used to induce different loading rates to investigate rate-dependency in the dynamic response of bones. Fracture event post impact was recorded by using high-speed video cameras. Quantifiable differences in elastic modulus, and fracture behavior have been observed by varying the strain rates.

Subject-specific volumetric meshes have been generated from CT data that is appropriate for simulation at time steps in the order of 10-6 in the explicit formulation. Assigning material sets and mapping density differentially using HU as a parameter captured the heterogeneity in material distribution in bones.

Based on the experimental observations, and published information; an extended linear Drucker-Prager model has been used to simulate the yielding behavior of bones. A damage model has been used to capture the failure mechanism of long bones under impact three-point bending. Due to the unavailability of a predefined element definition in Abacus for this, user defined element type has been used to code the rate dependency in bones.

A constrained Genetic Algorithm was used to back calculate the parameters that track the variation of elastic modulus with HU. This has been done to reduce the error between the responses from the FE simulations and the observed response in the lead up to fracture.

Case studies through simulations reproduce phenomenon observed from experiments conducted by us and reported earlier in literature.

A subject-specific FE femur model to replicate experiments performed by Kress et al. (1995) was developed and simulated using dilatational cut-off stress. Results showed that the fracture types obtained from simulations matched in four cases out of six cases. Tweaking the failure criteria within 10% is shown to match the other two cases.

It was concluded that critical dilatational cut-off stress failure criteria could be a better predictor of crack progression as compared to strain based failure criteria. In spite of being a better fracture predictor, the material model did not predict the force response of the long bone. In the experiments by Kress et al. (1995), only the peak forces values were reported. To validate a proposed material model, it might be appropriate to correlate the entire response history between experiments and simulations. Therefore, the need to conduct fresh experiments was felt.

A possible fracture causing mechanism for long bones was proposed. Due to the presence of high magnitude contact induced compressive stresses in the nominally tensile side during bending, and as bone has a large compression limit; shear failure occurs. Shear failure is physically indicated by the presence of shear lines in the impacted specimens and is predicted by FE simulations.

Important outcomes of the current study are highlighted. Bending tests were used successfully to characterize whole human bones under impact. Drucker-Prager (D-P) plastic model performed better than the Von-Mises model, as D-P model captured the yielding of bone accurately. A progressive damage model was preferred over a simple strain based failure model. Genetic Algorithms have been used successfully in optimizing the unknown material parameters. The current study showed the prominence of experimental observations and FE simulations to investigate failure mechanisms in bones.

By using the proposed method, fracture types observed in the field were reproduced in most of the cases, including those, which were not predicted by earlier models. In addition to the fracture types, the force responses were also predicted with a Pearson's correlation co-efficient greater than 0.8. Hence a single FE material model was derived that can predict both force response as well as fracture types over a wide range of strain rates.

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Excerpts from a Ph.D. Dissertation : A TRIPP BULLETIN INSERT

Title: Methodology for Design of Vehicle Front of an Urban Car for Safety of Vulnerable Road Users

Scholar: Hariharan S Subramanian

Supervisors: Anoop Chawla and Sudipto Mukherjee

Department: Department of Mechanical Engineering

To contribute to VRU safety by designing safer vehicles, this work addresses the research question, "Is there a front-end shape of urban cars that causes minimal injury threat to pedestrians in a given urban population?"

Estimation of the effect of crash injury to the body of a pedestrian has been quantified by a unitary scale as Injury Cost (IC). The IC measure was extended to quantify potential injury to a pedestrian population with anthropometric variation using frequency of occurrence reported in crash data and anthropometric data of population in a particular geographical area to a weighted IC (WIC). With a measure for threat to a population formulated, parameter driven CAE based techniques were used to run simulation of crashes to set up an optimization problem. Vehicle front shape was divided into 14 parameters and single objective optimization problem formulated for reduction of WIC. A reverse Monte Carlo technique based evaluation of pre-crash variables based on post-crash data available was developed to address issues of sparsity of reconstructed pedestrian crash data. The optimization studies yielded at least one conventionally "feasible" shape other than existing vehicle shapes with significantly better crash performance. A methodology to search for least threat to pedestrian population within desired constraints and data variations was hence demonstrated in this work.

Vulnerable Road Users (VRU) is the term that represents the collection of road users with lesser or no protection on roads; e.g. the pedestrians, bicyclists and motorcyclists. Trends on traffic crashes for India (Mohan, 2010) indicate that the pedestrian fatalities for Indian roads have higher crash fatalities in urban areas. Reports compiled by the WHO (World Health Organisation, 2009, 2013) indicate that the traffic injuries are to be ranked within the top 10 health hazards in the world. In the view of WHO, road traffic injuries are a health problem. (Haddon, 1980) formulated road traffic injuries as a public health problem and created a matrix based approach to address safety as part of a holistic traffic safety policy. Haddon's matrix based approach was adopted by (Norton et al., 2006) to discuss VRU safety with the role of various factors leading to crash, during crash and immediately post-crash scenarios.

During a vehicle-VRU crash, there is a significant difference in kinetic energy involved which varies directly with mass of the body and square of relative speed of the vehicle to VRU. The kinetic energy of vehicle is roughly 1000 times higher than that of VRU. From a safety perspective, hence, the VRU remains at the receiving end of the mentioned energy from vehicle. For reducing the impact of higher energy transfer to VRU, safety features in the form of energy absorbers are planned around the vehicle front shape at critical areas. These safety features are broadly divided into passive features, which act independent of a trigger; and active features, which act based on a trigger.

The vehicle front shape design has changed from flat front vehicles of the early 1900s to the shape which is seen on roads today, possessing smooth profiles. The role of shape on VRU safety was discussed with specific detail by Cavallero et al., (1983). The work discussed an approach to vehicle design parameters based on crash-test against 50 cadavers. Since the study, the vehicle shape has been modified to have smoother edges. Vehicle outer surface construction materials-based research is also in progress to improve the energy-absorption during a crash with VRUs.

With crash related studies indicating specific vehicle design features to have a strong influence on the incidences of VRU and occupant injuries, vehicle crash tests were developed to protect vehicle occupants in the earlier stages. Subsequently pedestrian safety tests were also introduced. These crash tests involved staging of a vehicle crash to a counterpart to measure the safety in terms of defined injury measures based on engineering parameters like displacement, velocity, acceleration and force. Insurance companies' associations also came up with a set of tests based on these regulatory tests to assess the potential monetary risk involved with a particular car apart from separate tests for assessing reliability of a vehicle or vehicle component. Consumer safety associations and ISO have also developed their own safety test protocols to assess "safety". These tests are collectively referred to as rating tests. New Car Assessment Programs (NCAP) tests provide a star rating for car based on the results obtained for a series of tests in the protocol.

The energy involved during such frontal crashes remains in the order of Mega Joules. For better occupant protection, which is measured as the amount of intrusion into the passenger cabin, the vehicle structures need to be made stiffer to have minimal intrusion values. In a VRU-vehicle crash scenario, the kinetic energy would be proportional to the mass of VRU and the relative speed between the two, whose order of energy involved is significantly lesser. Hence, a car designed to be safe for occupants in a frontal crash test, will pose a more severe threat to VRU in a vehicle-VRU crash. The VRU-vehicle crash scenario would necessitate more energy absorbers at lower energy levels than the levels involved in frontal crash tests.

The design for minimal aerodynamic drag and aesthetics significantly vary the vehicle structural members' location and material composition. With this challenge, the significance to find an optimal shape assumes more significance. As observed in most crashes, the severity of injury to VRU remains influenced by external factors in combinations with vehicle and VRU factors.

The present work is aimed at searching for an optimal vehicle front profile with minimal threat to a pedestrian population represented by 5 different multibody pedestrian models in MADYMO solver from a parametric vehicle front modelled using ellipsoids.

The present study is to focus on finding a vehicle front profile which can cause minimal threat to a pedestrian population. The vehicle front profile was parameterized into Bumper (lower and actual), Bonnet leading edge, Bonnet, Cowl and Windscreen. Such a vehicle model was simulated in a crash with pedestrian models from TNO (TNO and TassB.V., 2012) in 5 different anthropometric sizes. The crash scenario was modelled in MADYMOTM and the inputs to Sensitivity study in OptiSlangTM were the XML input files for MADYMO solver. MADYMO output files in PEAK format were read using file reading operations of MATLAB and conditionally processed to Weighted Injury Cost (WIC) values (Sankarasubramanian et al., 2013). The sensitivity study output was expected to provide an idea of the relative importance of variables on the outputs. With knowledge of high priority parameters, an optimization would be made to find out minimum threat profile within the range of car profiles chosen based on geometry of existing in-production cars. Vehicle to pedestrian crash was planned in a multibody simulation using MADYMO solver. A lateral crash to pedestrian in walking position was considered. The hands are considered close to the body to avoid change in kinematics due to upper extremities. The size of vehicle is indicative and does not represent in exact scale for any specific car. Force-deflection characteristics for vehicle front components were obtained from (Martinez et al., 2007). Orange level of force deflection curves was used for all components. Vehicle initial speed was assumed 40 kmph with a hard braking of 4.7g based on autonomous braking inputs from (Matsui et al., 2011) before crash with pedestrian models. The expected crash speed was around 27 kmph.