CRASH SIMULATIONS OF THREE WHEELED SCOOTER TAXI (TST)

A. CHAWLA, S. MUKHERJEE, D. MOHAN, Jasvinder SINGH, Nadeem RIZVI
Transportation Research & Injury Prevention Programme
Indian Institute of Technology,
New Delhi. INDIA

ABSTRACT

This paper reports the rigid body based simulations for frontal impact of Three Wheeled Scooter Taxi (TST) with a rigid barrier and those of a TST with a pedestrian in different spatial configurations. The simulations have been carried out in MADYMO^{TM}. The paper describes the development of the TST model, assesses the scale of injuries to the driver, occupant and pedestrian during the occurrence of these impacts and analyses the crashworthiness of TST. It is observed that even with small changes in the TST there is significant improvement in the injury indices. We thus believe that there is a considerable scope of improvement of the crashwothiness of the TST.

INTRODUCTION

TST's plays a major role as para-transit modes in most Indian cities. However, the increasing concern of the general public and official agencies with road traffic crashes has focused attention on the safety characteristics of TSTs also. Most scientific studies on road traffic crashes and possible countermeasures originate mainly from a handful of nations in Western Europe, North America and Japan. As a result, a major proportion of the safety research effort has focused on the problems of the car occupant. Much less is known about the vulnerable road users (VRUs), who are not protected by a vehicle shell designed for crash worthiness according to international standards. This category of road users includes not only pedestrians and cyclists, but also motorized two-wheeler riders, occupants of three-wheeled scooter taxi's (TST), and cycle rickshaws, which are common in India.

According to data available with us the total number of road traffic deaths in Delhi was 1,768 in 2001, of which TSTs were involved in 2-3 percent of the cases and approximately 2% of the fatalities were occupants of these vehicles [1]. TSTs comprised two percent of the vehicle population in Delhi in 2001 and they were involved in approximately 12 pedestrian (total 907) and 8 bicycle (total 171) fatalities. The data on fatalities are not detailed enough to draw conclusions about safer designs for each type of vehicle. However, some trends can be observed. While the TSTs do not account for a high number of fatalities, these numbers are significant keeping in mind the fact that the number of TSTs is only about 2% of all the vehicles. Though buses, cars and trucks account for a major portion of the fatalities the popularity of the TST can be further enhanced if it is perceived to be a safer vehicle by the users.

This paper primarily helps in understanding the injury encountered by the pedestrian as well the occupants during crashes with the TSTs. [2-4] present some preliminary results on simulations done with the three wheeler. The current work is an extension of the results presented there.

METHODOLOGY

The MADYMO 5.1 3-D was used as to develop the crash simulation for the TST and the modified TST structure in impact with pedestrian and a rigid barrier.

The steps followed in the devlopment of these simulations are.

1. Modeling of the TST using dimensions measured from an on-the-road vehicle.
2. Simulations of frontal impact were developed; retardations pulse and contact interaction between the different bodies were identified and defined.
3. Simulations for pedestrian impact were developed.
4. Injury severity of different body parts for pedestrian as well as occupant is estimated through these simulations, after carrying out the analysis, certain design changes are suggested and incorporated in the simulation models.
5. The effect of these improvements obtained on the crashworthiness of these vehicles is studied.

The impact speed has been taken as 30kmph because the peek speed of these vehicles is about 50kmph. It is therefore believed that the impact speeds will be about 30kmph.

Modeling of the Three-Wheeler:

Modeling in MADYMO is done by representing rigid bodies by planes and ellipsoids, and with kinematical joints between these bodies. A total of 11 different bodies were identified. The floorboard is defined as the reference or the primary body, and rest of the bodies are attached to the floorboard as a chain. The exact geometry of the TST is defined by using planes and ellipsoids. 22 planes and 26 ellipsoids are used for modeling of the three-wheeler. The total mass of TST is 240 kg.

The two suspensions, front and rear are defined as two-Kelvin elements in parallel. In the front suspension system, one Kelvin element is been modeled as consisting of only an elastic spring while the other Kelvin element is modeled as consisting of the damper. In the rear suspension system, both the Kelvin elements have spring as well as damper characteristics.

Occupant and Pedestrian Model:

For frontal impact on the dummy, the occupants and the pedestrians have been modeled using the 50 percent Hybrid III Dummy. For the side impact simulations, a different dummy is used to account for increased bio-fidelity. The additional ellipsoids with increased semi-axes are attached to the left lower and upper leg in order to avoid that the ellipse-ellipse contact algorithm converges to an incorrect penetration in case the penetration is large.

Force Deflection Curves used for defining contact interface between TST and human dummy:

Force deflection properties of the components of the TST were obtained through static tests. On the basis of these components, input curves for Madymo were obtained. For each interaction between the TST ellipsoids / planes and the human body ellipsoids, force deflection curves were defined. During a crash various human body segments come into contact with TST components. Definitions of these interactions are modeled by assigning force deflection characteristics for the combined interaction between the TST component and the body part.

Contact Interactions:

The various contact interactions for the TST-pedestrian impact simulations and for the TST-rigid barrier with occupants' simulations were defined as follows:

a) Driver impact: Interactions were defined between the head and steering rod, windshield and windshield support rod; for the knee with dashboard, upper leg and for the lower legs with the dashboard.

b) Passenger impact: head with the driver backrest support, knee with the driver-passenger partition wall, tibia and the crossrod.

c) Pedestrian impact: head/chest with the windshield, abdomen with the TST front middle section, pelvis with the middle section and low front-shield, tibia with low front shield. For side impact simulations, similar interactions are defined with the left section of the TST.

SIMULATIONS DEVELOPED

Two types of simulations have been done for the TST:

1. Impact of pedestrian with TST: In this the impact of the TST with a stationary pedestrian has been studied.

2. Impact of TST (with occupants) with a rigid barrier: Here the impact of the TST with a rigid wall has been studied when there is a passenger and a driver inside the TST.

IMPACT OF THE PEDESTRIAN WITH THE TST

In these simulations, the scale of injuries over 4 different impact locations of the pedestrian is studied.

They are:

a.) Pedestrian front impact, in line with the TST-center
Here the pedestrian faces the direction of motion of the TST, in line with the TST center (Figure 1).

b.) Pedestrian front impact, offset wrt TST-center
Here the pedestrian is at the center offset of 42 cm from the mudguard (Figure 2)

c.) Pedestrian side impact, in line with the TST-center
Here the pedestrian faces sideways to the three-wheeler and is in direct line with the mudguard of the three-wheeler (Figure 3).

d.) <u>Pedestrian side impact, offset wrt TST-center</u>
Here the pedestrian dummy faces sideways and is at an offset of 42 cm from the mudguard of the three-wheeler (Figure 4).

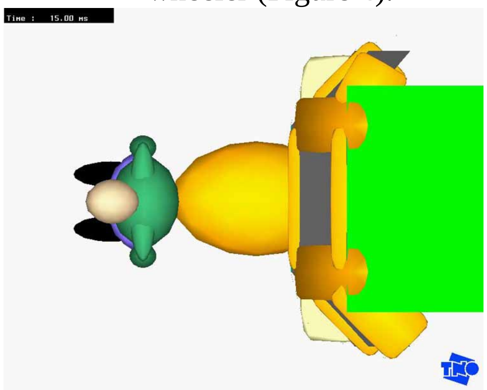


Figure 1 Configuration for the Pedestrian – TST frontal impact simulation (Case I)

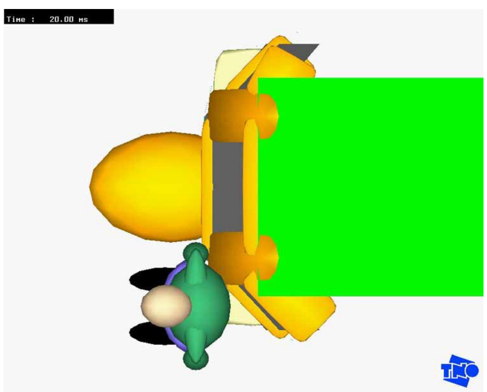


Figure 2 Configuration for the Pedestrian – TST frontal impact simulation with offset (Case II)

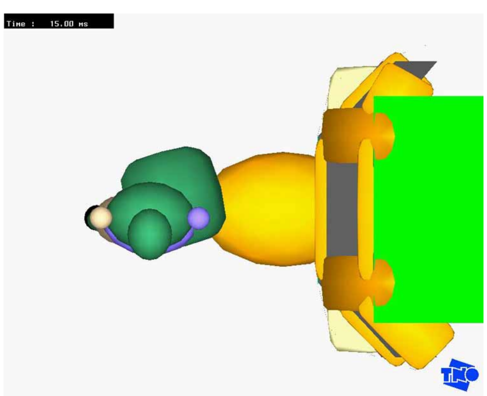


Figure 3 Configuration of Impact between TST and the pedestrian side. (Case III)

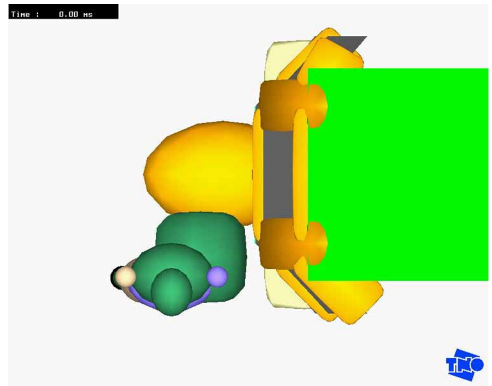


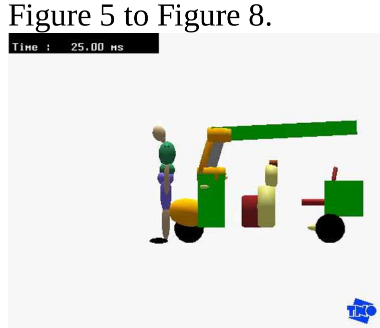
Figure 4 Configuration of an offset impact between TST and the pedestrian side. (Case IV)

Impact conditions in pedestrian simulations

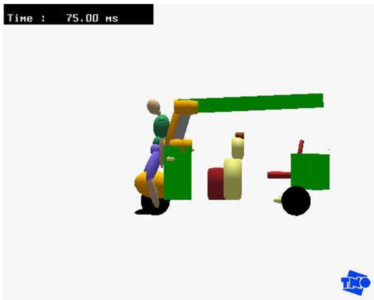
For each impact orientation, simulations were done for TST velocities of 10, 20 and 30 km/h. A uniform deceleration of 0.2 g is given to the TST at impact to simulate braking conditions. As stated earlier interactions have been defined for the different bodies that come into contact.

Simulations Results and Kinematics of pedestrian simulations

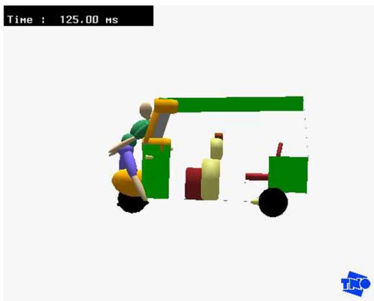
The kinematics obtained in the four pedestrian impact cases are shown from Figure 5 to Figure 8.



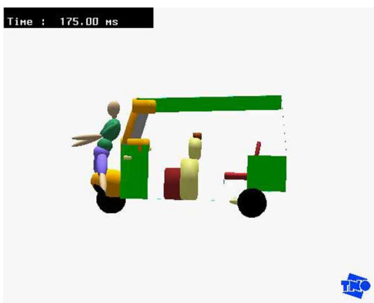
T = 25ms



T = 75ms



T = 125ms

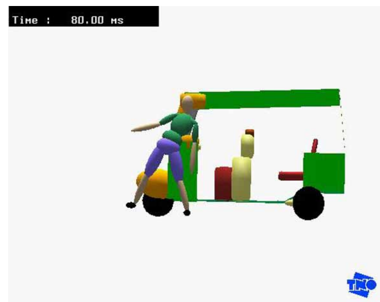


T = 175ms

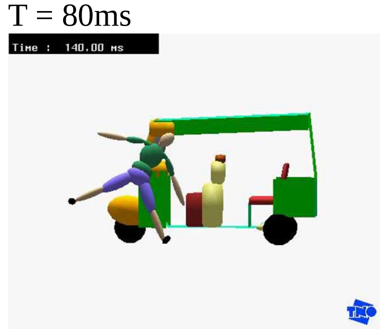
Figure 5 Kinematics for the Case I simulation

Figure 5 shows the kinematics of the pedestrian frontal impact with the TST. With the first impact of Tibia with mudguard, high forces are developed. At 75 ms the upper torso of pedestrian comes in contact with the windshield lower mount and the windshield. This contact remains till about 150 ms. At 125 ms the head comes in contact with the windshield. The head contact is established in the upper region of the windshield. As a result of these impacts, the pedestrian gains a velocity in the forward direction and from 175 ms onwards the pedestrian ceases to be in contact with the TST and moves forward till the end of the simulation.

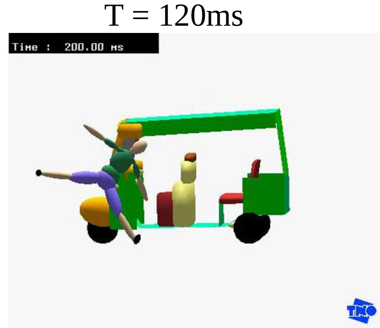
T = 20ms



T = 80ms



T = 120ms

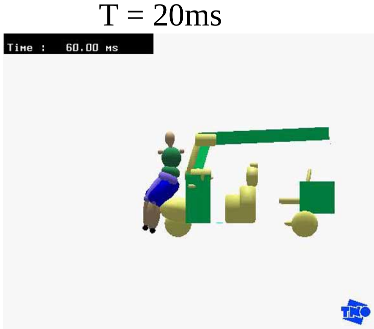


T = 200ms

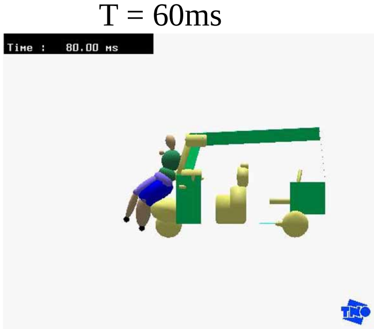
Figure 6 Kinematics for the Case II Siumulation

Figure 6 shows the kinematics of the pedestrian impact with the TST when a frontal pedestrian is positioned at an offset with respect to the TST. In this case the first impact takes place at 20 ms when the right hand of the pedestrian comes in contact with the front shield the TST. The right leg comes in contact a little before 40 ms and a forward impulse is given to the body the pedestrian where as the upper part of the dummy is stationary. The impact is also not symmetrical about the right and the left side of the dummy. This asymmetry introduces a rotation in the body, which was not present in the earlier case. As a result of this rotation, the impact in this case is more of a glancing type and no direct impact is seen for the head, and the forward velocity imparted to the dummy is also lower.

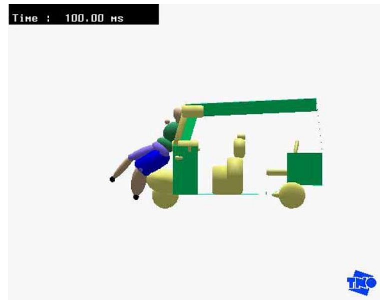
T = 20ms



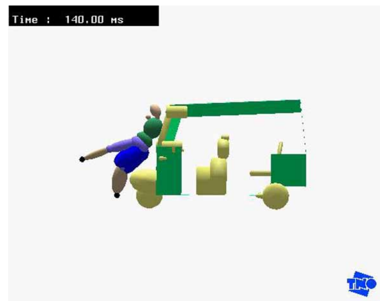
T = 60ms



T = 80ms



T = 100ms

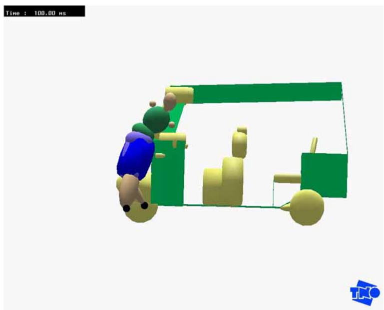


T = 140ms

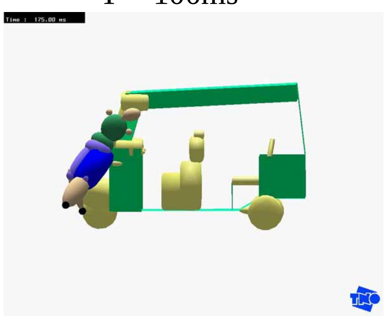
Figure 7 Kinematics for the Case III simulation

Figure 7 shows the kinematics when the pedestrian is positioned centrally in front of the TST, but is hit on his side (left). In this case, the first impact (20 msecs) takes place between the mudguard and the left leg of the pedestrian. As a result the legs get a forward and upward velocity and the pedestrian looses contact with the ground at 60 ms. The next impact takes place at 80 ms between the upper torso and the windshield lower mounting area. Subsequently, the head comes in contact with windscreen surface at about 100ms and remains in contact for about 20 msecs. During this time the pedestrian gains momentum and gets a forward velocity due to the impact between the dummy parts (the head, upper torso and the spine) and the windscreen surface and mounting. The dummy looses contact with the TST at about 140 msecs.

T = 25ms



T = 100ms



T = 175ms

Figure 8 Kinematics of the Case IV pedestrian simulation

Figure 8 shows the kinematics when the pedestrian is positioned with an offset in front of the TST, but is hit on his side (left). In the figure the individual positions are shown at 75msec intervals. In this case, the first Impact (25 msecs) takes place between the front shield and the left leg of the pedestrian. As a result the legs move in a direction normal to the inclined front shield of the TST. The impact is also not symmetrical about the right and the left side of the dummy. This asymmetry introduces a rotation in the body, which was not present in the earlier case. As a result of this rotation, the impact in this case also is more of a glancing type and no direct impact is seen for the head, and the forward velocity imparted to the dummy is also lower.

The acceleration curves for the head and upper torso and the force levels in the legs in these simulations are shown in Figure 9 to Figure 11 and the different injury indices for the pedestrian are tabulated in Table 1.

TST IMPACT (WITH OCCUPANTS) WITH RIGID BARRIER

In this simulation, a driver was seated on the front seat and an occupant in the rear seat. The crash of the TST into a rigid wall was simulated by giving an acceleration pulse to the occupants. The duration and the nature of the pulse was decided on the basis of duration recorded in a crash conducted by the manufacturer.

Simulations Results and Kinematics of rigid barrier simulations

The kinematics for this case is shown in Figure 12. Here, due to inertia, the driver and the passenger move forward. Knee of the driver hits the dashboard at T= 50ms. A second major impact takes place when the driver's head hits the windshield at T = 125ms. At around the same time the passenger's head impacts the driver seat. The next major impact occurs when knee of the passenger hits the cabin partition (the ellipse separating the occupant from the driver cabin) at T = 150ms. After this impact, the passenger bounces back and lifts up till the end of the simulation. The injury indices for this case are shown in Table 2.

		Front	Front Offset	Side	Side Offset
HIC		2149	282.6	2618	1016.2
Chest Deflection (m.)		6.40E-02	0.00E+00	3.92E-02	1.84E-02
Upper Torso					
	3 MS CONT (m/sec2)	328.5	136.4	317.5	164.3
	Max. Acceleration (m/sec2)	426	1.53E+02	4.61E+02	170.544
Lower Torso					
	3 MS CONT (m/sec2)	592.7	486.2	436.3	576.2
	Max. Acceleration (m/sec2)	612.8	4.97E+02	447.2	656.82
Lower Leg Forces					
	Right Leg (KN)	1.06	1.27	1.145	1.02
	Left Leg (KN)	0.925	8.47	1.289	7.55
Upper leg Forces					
	Right Leg (KN)	1.11	3.06	1.08	4.19
	Left Leg (KN)	0.982	0	7.849	4.19
TTI (Thoracic Trauma Index) (g)		59.74	27.6		

Table 1 Injury Index for the Pedestrian Impacts

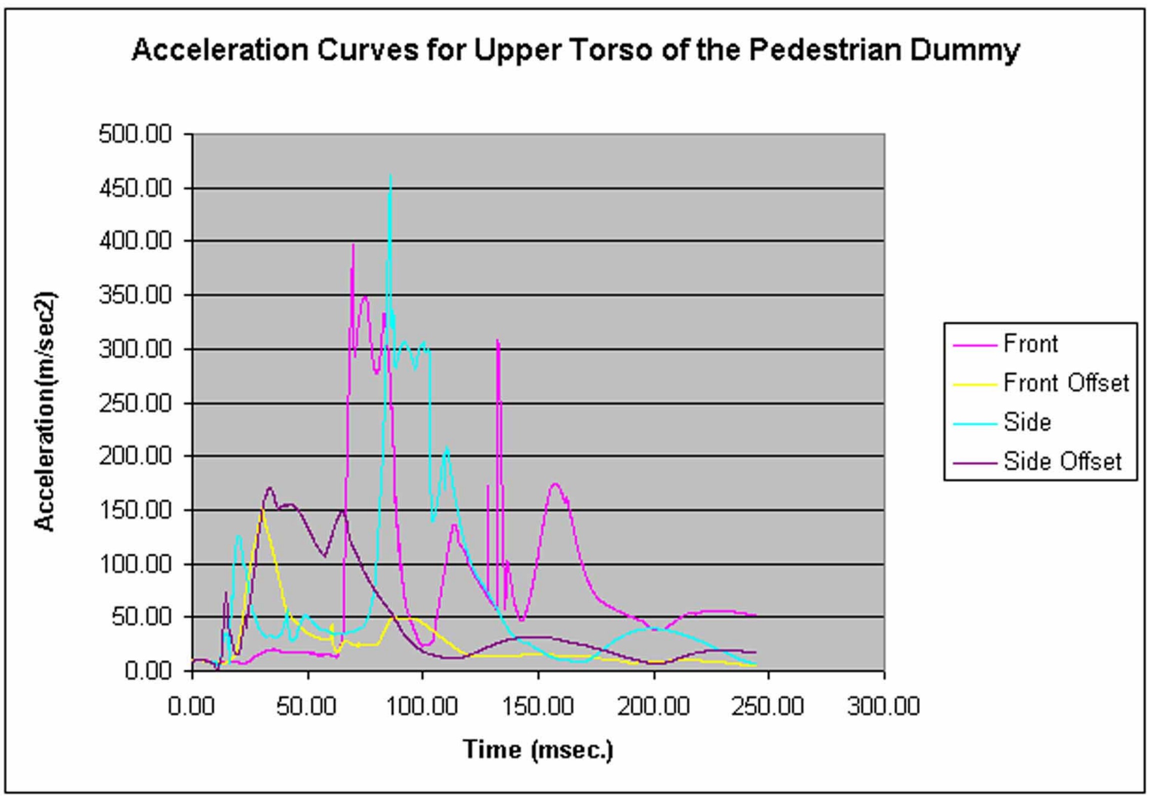


Figure 9 Acceleration curve for Upper Torso of the Pedestrian dummy for the four pedestrian impact simulations.

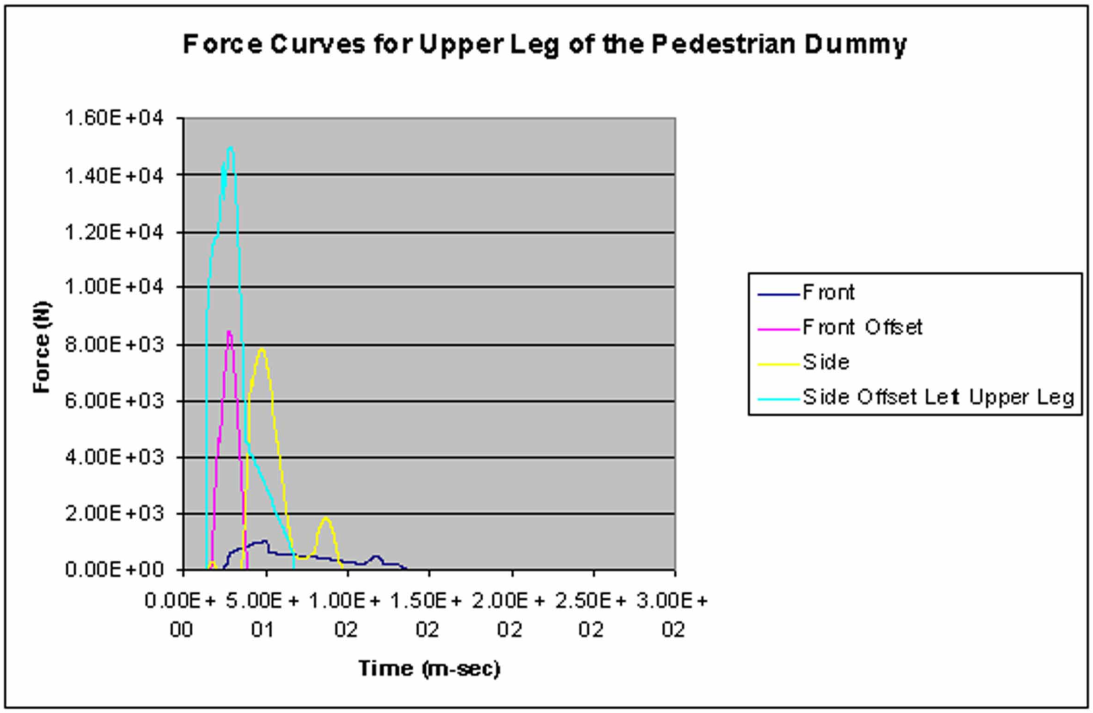


Figure 10 Acceleration curve for Upper Leg of the Pedestrian Dummy for the four pedestrian impact simulations.

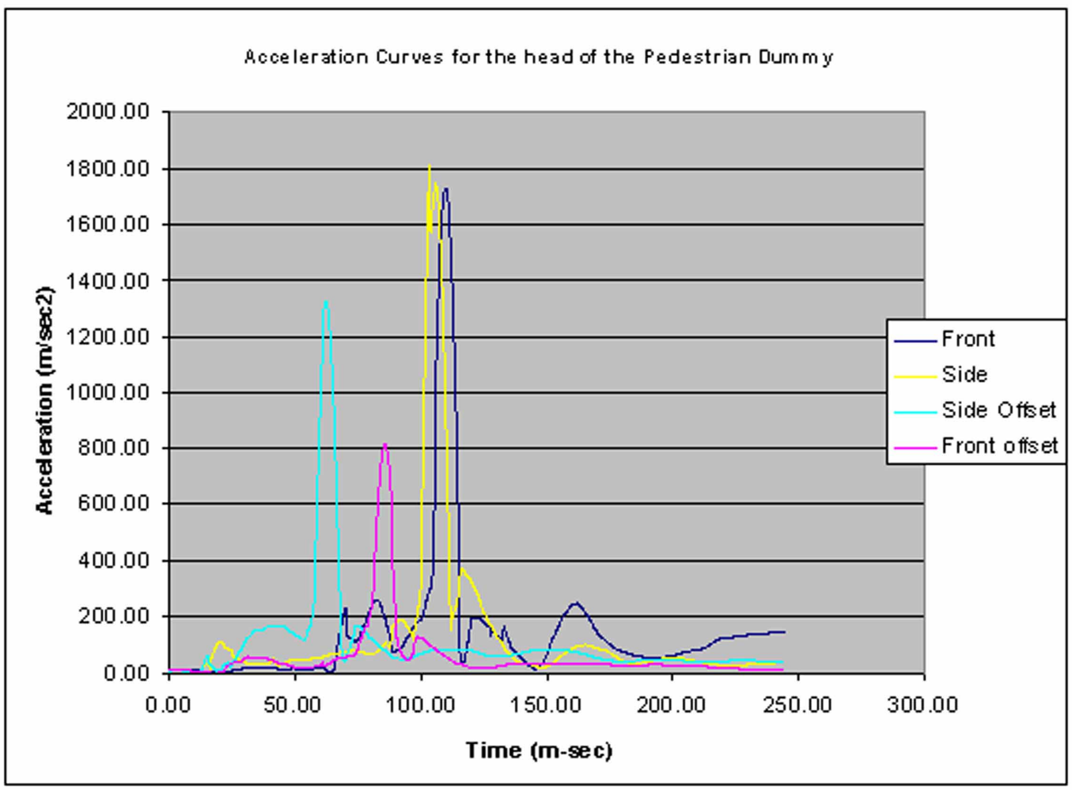
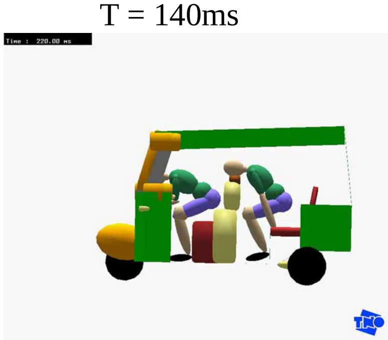


Figure 11 Acceleration curve for the Head of the Pedestrian dummy for the four pedestrian impact simulations.

T = 20ms

T = 80ms

T = 140ms



T = 200ms

Figure 12 Simulations for the TST impact into a rigid barrier at 30kmph.

SIMULATIONS OF THE MODIFIED TST

On observing the results of these simulations, following variations were incorporated in the design of the TST.

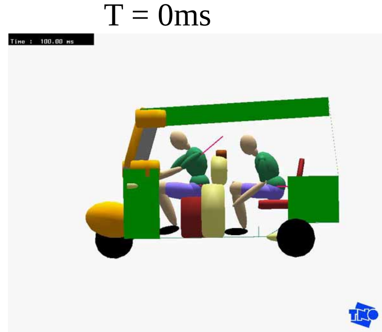
1.) Seat Belts for driver and Passenger
2.) Impacting surfaces such as Dashboard and driver seat back were covered with cushion.
3.) Passenger seats were made facing backwards.

The following sections describe the three simulations for the TST thus modified .

Seat belt for Driver and Passenger

In this simulations, a two-point lap belt is provided to the passenger while the driver is provided with a lap belt and a shoulder belt.

T = 0ms



T = 25ms

T = 75ms

T = 150ms

T = 250ms

Figure 13 Simulations for the rigid barrier impact at 30kmph with seatbelt for the passenger as well as for the driver

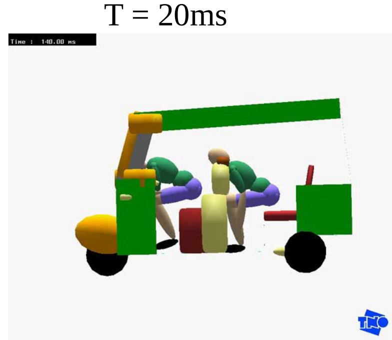
As a result of the belts, the driver and the occupant do not impact with any surface of the TST. The corresponding injury indices are thus lower. Only the neck forces for the passenger are observed to be high primarily due the high velocity obtained by the neck. Figure 13 shows the kinematics of the simulation. The injury indices for this case are shown in Table 2. As can be seen the acceleration levels for the head and the force levels for the legs show a marked decline as these parts no longer hit any hard portion of the TST. The upper torso forces, however, show a marked increase.

Padding on all Impacting surfaces

In this case, all the impacting surfaces were covered by soft padding and the corresponding contact interaction forces were accordingly softened. Figure 14 shows the kinematics for this case. While the kinematics is very similar, the forces obtained in the knee and head for driver and occupants reduces considerably as shown in Table 3.

T = 0ms

T = 20ms



T = 80ms

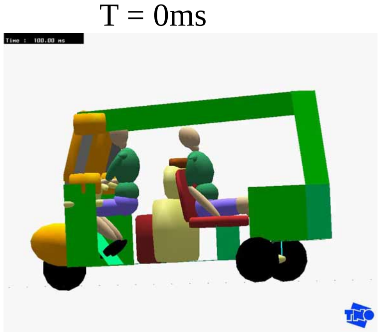
T = 140ms

T = 200ms

Figure 14 Kinematics of the simulations for the TST - rigid barrier impact with padding on impacting surfaces.

Passenger facing Backwards

T = 0ms



T = 75ms

T =150ms

T = 200 ms

Figure 15 Kinematics of the simulations for the TST - rigid barrier impact with passenger facing rearward.

In this simulation, the passenger is saved from hitting any surface of the TST. Hence the injury indices of the passenger are very low as shown in the Table 3

	30k	**Passenger lap belt + driver shoulder**	
		Value	**% improvement**
HIC			
Driver	1580.3	141.4	91.05
Passenger	1518.2	588.1	61.26
Peak Acceleration g's			
Driver			
Upper Torso	192.66	16.30	91.53
Upper Leg	24.66	15.69	36.36
Lower Leg	48.11	39.14	18.64
Head	138.63	28.84	79.19
Passenger			
Upper Torso	261.97	413.86	-57.98

Upper Leg	79.51	17.12	78.46
Lower Leg	78.08	57.69	26.11
Head	174.31	111.11	36.26
Peak Forces (KN)			
Driver			
Left Upper Leg	2.04	1.28	37.25
Left Lower Leg	1.52	0.41	73.22
Right Knee	1.58	0.31	80.32
Passenger			
Left Upper Leg	7.16		
Knee	7.09		

Table 2 Comparison of Injury Index with and with out seat belt for the Occupants

	The original Simulation	**Padding for the passenger at both head and knee**		**Passenger facing backwards**	
		Value	**% change**	**Value**	**% change**
HIC					
Driver	1580.30	1626.8	-2.94	451	71.46
Passenger	1518.20	1180.1	22.27	262.5	82.71
Peak Acceleration g's					
Driver					
Upper Torso	192.66	204.28	-6.03	183.49	4.76
Upper Leg	24.67	24.67	0	23.55	4.55
Lower Leg	48.11	48.11	0	47.71	0.85
Head	138.63	138.63	0	68.40	50.66
Passenger					
Upper Torso	261.98	269.11	-2.72	33.84	87.08
Upper Leg	79.51	57.70	27.44	34.86	56.15
Lower Leg	78.08	57.80	25.98	54.03	30.81
Head	174.31	140.67	19.3	14.21	91.85
Peak Forces (KN)					
Driver					
Upper Leg	2.04	2.04	0	1.87	8.33
Lower leg	1.52	1.46	3.95	1.42	6.58
Knee	1.58	1.53	3.16	1.38	12.66
Passenger					
Upper Leg	7.16	5.11	28.63	0	100
Lower Leg	7.01	5.13	26.82	0	100
Knee	7.09	5.13	27.64	0	100

Table 3 Tabulation of injury indices for the modified TST with those for the unmodified TST.

DISCUSSION AND CONCLUSIONS

As can be seen from the results shown in the previous sections, the TST can give serious injuries to its occupants when it is running at 30kmph and inpacts into a rigid barrier. However, this is primarily because the TST is an open vehicle and does not have any safety devices like seatbelts and airbags. With simple modifications like adding paddings or soft surfaces in the impacting region, there is a reasonable improvement in many cases. Adding seat belts improves the crashworthiness of the TSTs further. Infact, with the seatbelts it can be ensured that the driver and passenger head does not come into contact with any hard surface. This contributes significantly to the crashworthiness of these vehicles. Passenger safety can also be significantly increased by making rear facing passenger seats. In rear facing passenger seats the passenger does not hit any hard surface during a frontal crash.

This paper also describes simulations for pedestrian impacts. It can be seen that depending on the pedestrian orientation, the kinematics of the pedestrian changes. At impact speeds of 30kmph, the injury levels for the pedestrian are quite high. HIC values go upto as high as 2000. We are currently evaluating these simulations and will be suggesting changes to the design of the TST so as to make them safer under pedestrian impacts.

In this work we have demonstrated that the safety of the TST occupants at 30kmph impacts can be significantly improved by making small changes in its design. The current work is first step to study the safety of these vehicles. We feel that considerable work needs to be done in order to make the roads safer for VRUs in the developing countries. Since the TST is a common mode of public transport in India, we believe that this work is a step in that direction.

REFERENCES

References

[1] A. K. Ojha, Road Accidents in Delhi 2001, Accident Research Cell, Delhi Traffic Police, New Delhi, India., 2002.

[2] Chawla A., Mukherjee S. and Mohan D. Crash Worthness of Bajaj Three Wheeler. Bajaj Auto Ltd.. 2000. Indian Institute of Technology Delhi.

[3] Mohan D., Chawla A., Bhalla K.S., Kajzer J. and Bawa, *Impact modeling studies of a three wheeled scooter taxi*. In *Proceedings of the Annual Conference of the international Research Council on Biokinetics of Impacts*. 1995.

[4] Mohan D., Kajzer J., Bawa-Bhalla K.S., Chawla A. and Singh S., *Impact modelling studies for a three wheeled scooter taxi.* In *Proceedings of IRCOBI 1995.* 1995.