IMPACT MODELING STUDIES FOR A THREE-WHEELED SCOOTER TAXI

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ABSTRACT

Three-wheeled scooter taxis (TSTs) are being used in many Asian countries and besides buses are the main mode of public transport for the urban middle class population. The TST chassis is made by the manufacturer and the body is fabricated by local body-makers. The vehicle is not subject to any crash safety specifications.

This work is the first attempt to study the crash characteristics of TSTs using a crash simulation computer software (MADYMO) with the objective of developing practical guidelines to make the vehicle safer in collisions with other motorized road users and pedestrians. Impact modeling was done for the standard and modified TST occupied by a driver and one passenger at impact velocities of 10 - 30 km/h crashing with a pedestrian and a bus front.

The results show that the passenger and the driver of the standard TST can sustain high HICs, face/head contact forces and tibia/knee contact forces in crashes with buses at velocities 20 km/h and greater. The magnitude of these parameters can be reduced slightly by small changes in the design of the interior and padding of critical surfaces. To increase the safety of the TST significantly major modifications need to be incorporated in the design of TSTs and bus fronts. Pedestrian impact simulations indicate that it may be possible to reduce the impact forces by changing the shape of the front of the TST.

The results indicate that it should be possible to improve the crash safety properties of vehicles indigenously designed in Asian and African countries by the use of crash simulation models like MADYMO. This procedure is relatively inexpensive and can provide the first approximations for design of safer vehicles.

EVERY YEAR, ABOUT HALF a million people are killed and thirty-five million injured in road traffic accidents worldwide (Evans, 1991). Huge economic losses and serious consequences result from these traffic accidents. This is obviously a serious public health problem all across the world. 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 research and safety efforts have been 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. This category of road users includes not only pedestrians and cyclists, but also motorized two-wheeler (MTW) riders, occupants of three-wheeled scooter taxis (TST), and cycle rickshaws, which are common in Asian countries.

Table 1.
Proportion of road users killed by various modes of transport as a % of all fatalities.

City, Nation/Year	Pedestrians	Bicyclists	MTW	Motorized four wheelers	Others (incl. TST)
Delhi, India (1994)	42	14	27	12*	5
Thailand (1987)	47	6	36	12	-
Bandung, Indonesia (1990)	33	7	42	15	3
Colombo, Sri Lanka (1991)	38	8	34	14	6
Malaysia (1992)	16	7	51	18	9
Japan (1992)	27	10	20	42	1
The Netherlands (1990)	10	22	12	55	-
Norway (1990)	16	5	12	64	3
Australia(1990)	18	4	11	65	2
U.S.A. (1992)	14	2	6	76	2

* Of this, car occupants are represented in 4% of fatalities.

Table 1 summarizes the proportion of road user fatalities by various modes of transport. The data presented in this table is based on available national statistics or on unpublished statistics available with the authors. Except in Western Europe and North America, VRUs comprise as much as 80% of the road traffic fatalities.

Though the majority of road crash victims are VRUs, a disproportionately high share of research funds, time and energy have been spent on making the car occupant safer in the past four decades. It is only recently that a little more attention is being given to the safety of VRUs. These efforts will not have any major impact, unless we understand clearly the special needs and problems of different categories of the VRUs in road accidents.

In India, official statistics for road accidents are available for 1992 (TRD, 1993) and these show that there were 308,087 recorded accidents in which 57,217 persons were killed. The number of recorded accidents is a gross underestimate but the number killed would be closer to the actual number. This is because a large number of non-fatal crashes are not reported to the police but it is difficult to hide cases where someone gets killed.

Detailed crash analysis data are not available from most cities in India. We have done an analysis of police reported traffic fatalities in New Delhi for the year 1994. The results of this analysis are presented in Figure 1. These data can give a good idea of the specific issues regarding road safety in India and other LMCs. Figure 1b shows the distribution of all the fatalities by road user type in New Delhi during 1994 and pedestrian/bicyclist fatalities by the impacting vehicle (c, d).

The data on fatalities as available in the statistics here is not sufficient to draw conclusions about safe design of each type of vehicle. However, some trends can be observed. While the TSTs do not account for a high number of fatalities (they account for only 5% of the pedestrian deaths and about 3% of bicyclists being killed), these numbers are significant keeping in view the fact that the number of TSTs is only about 3.4% of all the vehicles. Thus 3.4% of the vehicles account for about 3-5% of the pedestrian and bicyclist fatalities. While the buses, cars and trucks account for a major portion of the fatalities, it was felt that the fatality rate for TSTs was not small either, keeping in view the fact that only 3.4% of the vehicles on the roads are TSTs.

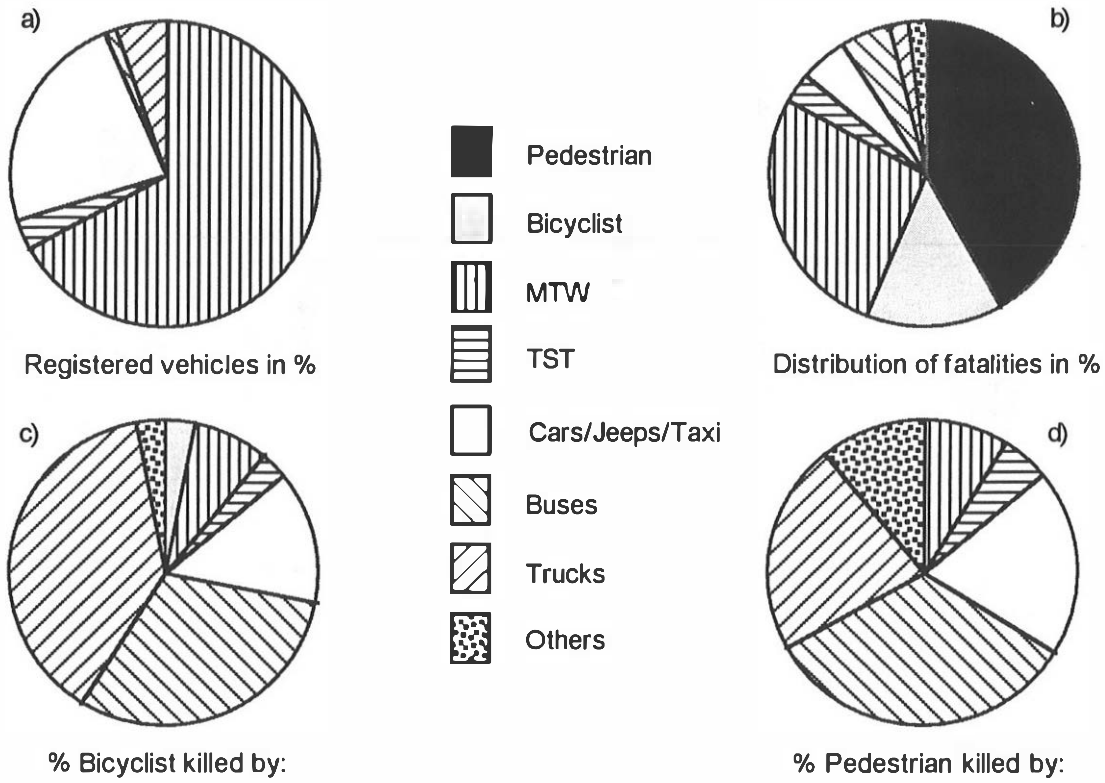


Figure 1. Percentage of registered vehicles; distribution of all fatalities and distribution of bicyclist/pedestrian fatalities in New Delhi in 1994 by road user type. MTW = Motorized two-wheelers, TST = Three-wheeler scooter taxi.

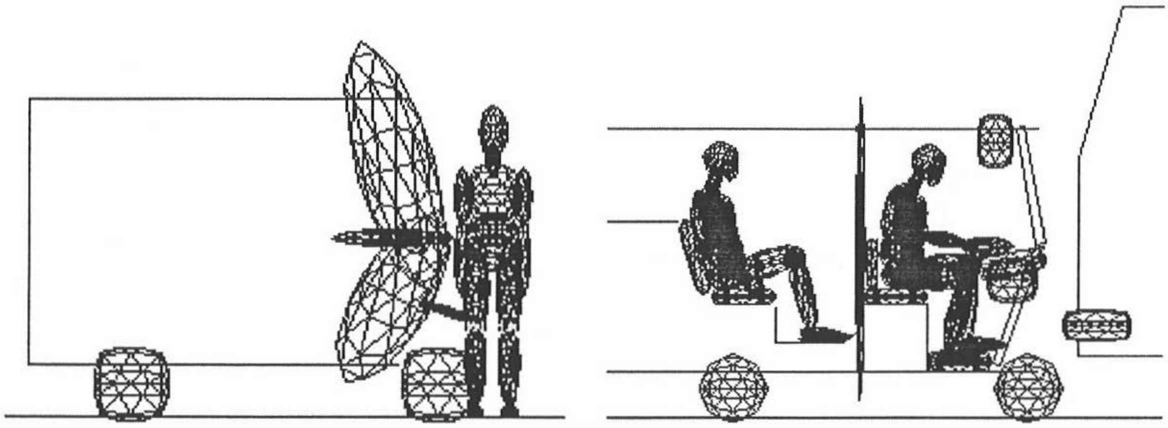
The TSTs are being used in many Asian countries and, besides buses, are the main mode of public transport for the urban middle class population. This has provided the basic motivation for the research. We are not aware of any previous attempt to look into the safe design of these vehicles.

METHODOLOGY

The MADYMO 5.1 3-D Crash Victim Simulation software (TNO 1994 a,b) was used to evaluate the crash properties of the TST and the modified TST structure in accidents with buses and pedestrians. Mathematical models have good repeatability and enable assessment of the influence of the modifications made to a vehicle.

Two setups were used in this study. The first one represents a pedestrian dummy impacted from the side by a TST front, as shown in Figure 2-a. The second one represents a TST with one driver and one passenger in frontal impact with a bus front (Figure 2-b). In the TST-pedestrian simulations the model can be divided into two separate systems: one for the pedestrian dummy and one for the TST. In the TST-bus simulations, the model can be divided into three separate systems: one each for the TST, driver dummy and passenger dummy, respectively. The bus is a part of the inertial space.

The force-deflection properties of the front of the TST, the petrol tank in front of the driver, and the partition panel between the passenger compartment and the driver seat were tested separately. Each component was fixed horizontally on a rigid surface and then subjected to compression loads by a flat metallic surface of 100 mm diameter at quasi-static loading rates. The force-deflection properties were obtained for three locations on the front panel of the TST, for two locations on the partition panel, and for one location on the petrol tank. The values so obtained were approximated by multi linear force-deflection curves for use in the model.



(a) (b)

Figure 2. The simulation set-up: (a) TST-pedestrian impact; (b) TST-bus impact

In general the stiffness of the structure of TST is much lower than the stiffness of buses (Figure 3). The TST will be subjected to large deformations at impact with a stiff bus front.

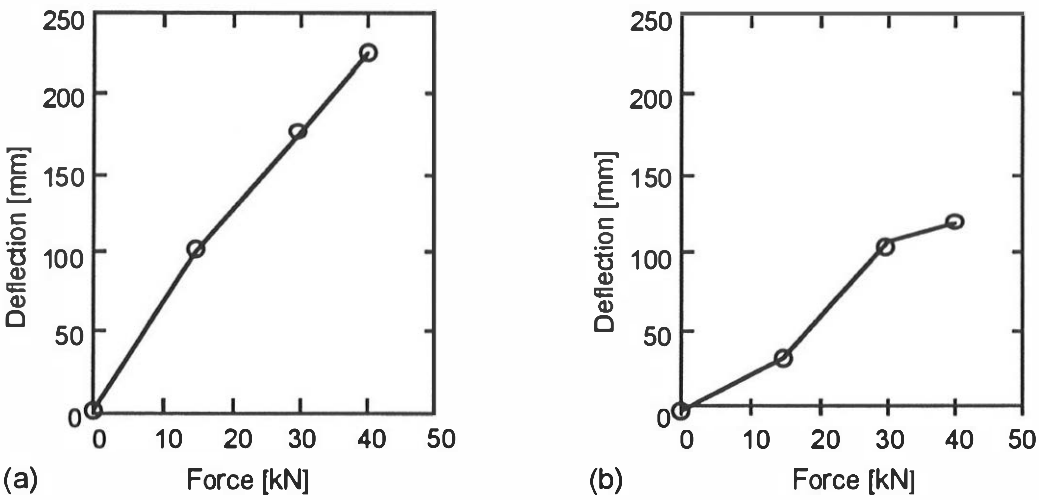


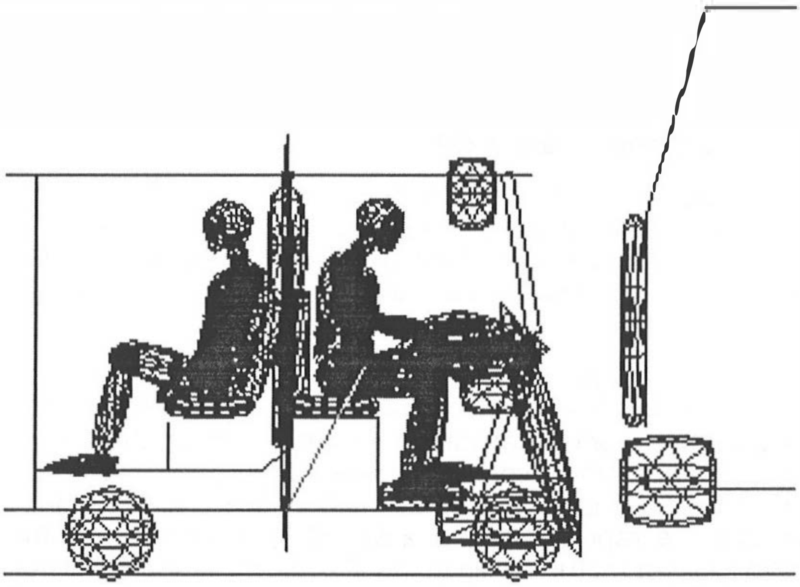
Figure 3. Force-deflection characteristics: (a) the TST front; (b) the bus front

Details of impact velocities are not exactly known but traffic surveys in New Delhi indicate that TST speeds vary between 15-38 km/h with an average speed 22 (SD 6) km/h. In urban traffic, the average speed of buses is somewhat lower than those for the TST. Based on these observations, a relative impact velocities of 10, 15, 20, 25 and 30 km/h were chosen for the TST-pedestrian and TST-bus impact simulation. A deceleration field of 0.5 g is assumed to simulate braking of the TST.

Five simulations were performed with TST-pedestrian and TST-bus setup respectively. Based on the results from these simulations, padding on the critical surfaces of vehicles were designed and new simulations were done. Finally, in the last series, the TST design was changed and the bus front was also modified. The simulations of TST-pedestrian and TST-bus impacts were repeated. The following data from both series of simulations were compared and analyzed: the kinematics of the pedestrian, driver and passenger, the HIC of driver and passenger, the head/chest acceleration, impact forces to abdomen, pelvis, tension of knee ligaments of pedestrian and the contact forces between head/face, chest, pelvis, tibia, knee of passenger/driver and TST structures.

THE TST MODEL - In MADYMO the TST has been modeled as a separate one-body system. The geometry of the system was based on Chandna and Sharma (1994). The information about mass and center of gravity of TST was obtained from the manufacturer. Force deflection characteristics in static loading of various surfaces of the TST were determined in laboratory experiments at IIT Delhi. Some estimations were made to describe the dynamic properties of the TST structures.

Planes and ellipsoids are connected to this system to represent interior and exterior surfaces of the TST. The main structures represented by planes are: roof, windshield, low front, floor, driver-passenger partition wall; and by ellipsoids: windshield, low front, dashboard, steering bar, rear view mirror support (rear view mirror occupies a space of 150x1000 mm across the top section of the windshield), passenger and driver seats, driver backrest, crossrod. The TST mass is 350 kg.



(a) (b)

Figure 4. TST with major modifications (a), and modified bus (b).

Three types of TST were used in simulations: the original TST, TST with modified impact surfaces and TST with major modifications. When the TST with modified impact surfaces was simulated, a padding material with characteristics adjusted to deform 75% at force level of 4 kN was represented by additional ellipsoids in the contact areas for head and femur impact (driver, passenger impact) with the dashboard, steering bar, mirror support, driver-passenger partition wall, driver backrest and abdomen (pedestrian impact) with mid-section of the frontal surface. The thickness of the padding material is 100 mm. TST with major modifications (Figure 4-a) has a new design of the front and was additionally equipped with reverse seats for the passenger, a lap-belt for the driver and the floor was much stiffer than the low front in original TST.

THE BUS MODEL - The stationary bus was used in MADYMO simulation. The bus was attached to the inertial space. Five planes and one ellipsoid are used to represent the shape of bus front. The geometrical description is adjusted to a typical bus front from Delhi, India. Four finite planes are used for the grill, windshield, top-hood, respectively. The bumper is represented by an ellipsoid.

The modified bus front was simulated by an ellipsoid added in the front of the bus. This ellipsoid was defined to model the padding on the front of the bus. The thickness of the padding material is 160 mm. The simulated padding material has a force plateau on the level of 5 kN and maximal compression of 75%. The additional ellipsoids below the ordinary bumper was added to provide contact with modified floor of the TST (Figure 4-b).

THE PEDESTRIAN MODEL - The same pedestrian model (Figure 2-a) was used in all simulations with TST. For MADYMO simulation, the geometry, mass, moment of inertia and center of gravity of all segments of the human body model were generated by the GEBOD program (Baughman, 1983). GEBOD uses a set of 32 body measurements to determine size of body segments and the location of joints connecting these. Three groups of regression equations stored within GEBOD were used to obtain values for the required 32 body measurements. The model generated by GEBOD was for 165 cm man with body mass of 65 kg. This body size is found to be representative for an Indian.

The MADYMO pedestrian model is based on one developed and validated by Ishikawa et al. (1993) and combined with the knee joint model proposed by Yang and Kajzer (1992). This knee model was used to investigate tensions in ligament structures of the first impacted lower extremity. The pedestrian model is also a three-body system connected by Kelvin elements that represent the knee structures. The model consists of fifteen segments connected by fourteen joints. The geometry, the characteristics of the body segments, and the mechanical properties of the joints are based on available anthropometrical and biomechanical data.

The parameters used to describe the aggressivity of TST against pedestrian were: head lateral acceleration, chest acceleration, abdomen and pelvis impact forces. The following tolerance limits were used for the analysis of pedestrian impacts: head lateral acceleration 150 g, chest acceleration at centrum of gravity 60 g, pelvis impact force 10 kN.

All the relevant elements of the knee, which are mainly responsible for the transfer of forces acting on the knee joint, were taken into account in the knee model. For simplification purposes, some anatomical structures, such as the menisci, are not included. The mathematical knee model consists of skeletal parts, ligaments and the capsule. The skeletal parts of the knee joint, are represented by ellipsoid and plane elements. The soft tissue structures are represented by a set of spring elements: the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL) and lateral collateral ligament (LCL) by one spring each, the medial collateral ligament (MCL) by two springs. The posterior part of the capsule is also represented by two springs.

Table 2

Correlation of the ligament strain with severity classification of the ligament injuries

Ligament strain	AIS code
≥20%	3
>15% and <20%	3 -*
12 - 15%	2
<12%	0 - 1

** "-" behind the AIS code indicates that there is a slightly less serious injury than the number itself defines.*

The correlation of ligament strain calculated in computer simulation to the Abbreviated Injury Scale (AIS) severity classification of the ligament injuries was used as shown in Table 2 (AAAM 1990). This correlation made it possible to compare the injury risk to the knee region in simulated TST -pedestrian crashes. For the relative elongation of knee ligaments a tolerance limits of 15% was used.

THE DRIVER AND OCCUPANT MODEL - In the simulations of TST-bus and TST-pedestrian crashes (Figure 2-a, b) the same model was used for driver and occupant. A 50 percentile model of HYBRID III male dummy was chosen for simulation. This model has been slightly modified due to low velocity of impact. To obtain better biofidelity of the model at low speed crashes the stiffness of joints has been reduced by about 50% (Ishikawa et al. 1993).

The parameters used to describe the severity of TST-bus crashes were for driver and passenger: HIC, face/head impact force and knee impact force; for passenger additionally tibia impact force. The following tolerance limits were used at the analysis of driver/occupant impact: HIC 1000, face impact force 2.5 kN, head impact force 8 kN and tibia/knee impact force 4 kN.

CONTACT INTERACTIONS - The various contact interactions for the TST-pedestrian impact simulation and for the TST-bus were defined. The interactions analyzed in the study were for:

a) driver impact: face/head with steering bar and mirror support, knee with dashboard;
b) passenger impact: face/head with driver backrest, knee with driver-passenger partition wall, tibia with crossrod;
c) pedestrian impact: head/chest with windshield, abdomen with TST front middle section, pelvis with TST front middle section and low front, tibia with low front.

RESULTS

UNMODIFIED TST-BUS IMPACT - Table 3 summarizes the results of the simulations for the original TST-bus impact. These simulations were carried out at impact velocities of 10, 15, 20, 25 and 30 km/h. The forces between different parts of the TST and the bus, and between the TST and the passenger/driver dummy systems have been tabulated. The HIC values of the passenger and the driver and acceleration of the pedestrian head/chest are also presented.

Table 3

Results: simulation of the TST - bus impact and TST - pedestrian impact (standard design).

Standard TST with bus	Velocity [km/h]				
Parameter	10	15	20	25	30
Force: bus - TST windshield [kN]	1.7	2.6	4.3	12.6	23.1
Force: bus - TST middle front [kN]	12.2	21.3	28.6	32.8	35.2
Force: bus - TST low front [kN]	7.6	15.6	21.9	28.5	35.1
Force: TST dashboard - driver knee [kN]	1.3	2.5	2.8	3.2	3.4
Force: TST steering bar - driver face [kN]	-	1.6	3.2	4.1	4.7
Force: TST rear view mirror supp. - driver head [kN]	2.2	6.2	12.7	17.2	17.8
HIC driver	20	131	800	2303	2822
Force: TST middle crossrod - passenger tibia [kN]	<1	3.8	4.5	7.0	-
Force: TST driver/pass partition wall-pass. knee [kN]	3.5	7.3	8.7	13.3	15.8
Force: TST driver backrest - pass. head/face [kN]	-	6.0	8.2	12.3	11.3
HIC passenger	-	967	985	2893	1685

In the TST-bus impact the middle front of the TST experiences the maximum forces as it is stiffer than the windshield and the low front. The simulation showed that at speeds of 25 km/h the total deformation in the TST is about 20 cm. At 30 km/h the deformation was more than 30 cm. This is of concern as the driver is directly exposed to serve injuries in the contact with intruding bus structures (Appendix e-f).

In the driver TST-interior impact it is observed that the driver knee hits the dashboard and the driver face/head hits the rear view mirror support and then the steering bar. As a result the knee is subject to forces of about 2-4 kN. At 30 km/h impact velocity this increases to 3.4 kN and can cause injury to the knee.

The face/head of the driver is subject to large forces, decelerations, and HIC values. At 20 km/h the face experiences forces of 12.7 kN and HIC of 800. Even at 15 km/h the face forces are 6.2 kN. These values are even higher at impact velocity of 30 km/h with consequences of severe face or head injuries. In addition to these the kinematics of the impact shows that on hitting the rear view mirror support the driver neck is exposed to a serious hyperextention that can be a cause of neck injuries.

In the TST-bus impact the passenger's knees hit the cross rods and the mid partition wall between the passenger compartment and the driver cabin, and his head/face hits the backrest of the driver seat. As a result the passenger knee experiences forces of 7.3 kN at impact velocities as low as 15 km/h. At this speed the head/face experiences peak forces of about 6 kN and HIC values of 967.

These results clearly show that the TST is not safe for either the driver or for the passenger even at speeds so low as 15 km/h. Consequently minor modification to the TST were investigated in order to try and make the TST safer for both the driver as well as the passenger.

UNMODIFIED TST-PEDESTRIAN IMPACT - In the current study the impact of the TST with a pedestrian was modeled at impact velocities of 10, 15, 20, 25 and 30 km/h. It was observed (Table 4) that the pedestrian head accelerations were not critical as the TST body is very soft. However the abdomen forces at 20 km/h and above were of concern. The forces were about 3.9 kN at 20 km/h while the forces at the pelvis were lower. This led us to believe that the front of the TST has not been designed keeping the height of the average adult pedestrian into account (Appendix a-b).

Table 4
Results: simulation of the TST - pedestrian impact (standard design).

Standard TST with pedestrian	Velocity [km/h]				
Parameter	10	15	20	25	30
Acceleration: pedestrian head [g]	3	37	60	70	81
Acceleration: pedestrian chest [g]	8	18	26	38	60
Force: TST front - pedestrian abdomen [kN]	0.8	3.1	3.9	5.3	6.6
Force: TST front - pedestrian pelvis [kN]	-	1.1	1.9	2.9	3.7
Force: Pedestrian femur - tibia condyle [kN]	0.5	0.9	2.0	8.9	5.1
Elongation: pedestrian ACL [%]	<1	3	3	5	5
Elongation: pedestrian PCL [%]	2	2	4	6	4
Elongation: pedestrian MCL [%]	7	10	13	15	16
Elongation: pedestrian LCL [%]	3	7	9	10	10

The relative elongation in the ACL, PCL, MCL, and LCL are also presented (Table 4). Except for the MCL these are found to be well within limits.

TST WITH MODIFIED IMPACT SURFACES AND BUS IMPACT - For this set of simulations, padding was added on the TST partition wall and the TST crossrod. This has been done to decrease the impact forces on the passenger knee which was found to hit the crossrod and partition wall. In simulations with original TST, the driver head was hitting the rear view mirror support and the steering bar. These structures were also padded so as to decrease the injury to the driver. The simulations were carried out at critical speeds of 20 and 25 km/h. The results are presented in Table 5.

After these modifications, the total deformation of the TST remained unaltered but the forces on the passenger knee dropped to acceptable levels at 20 km/h. The head/face forces for both the driver and the passenger came down considerably. At 20 km/h these values were found to be 2.5 and 5.3 kN (12.7 and 8.2 kN earlier) and the HIC values 512 and 904 (800 and 985 earlier) for the driver and the passenger, respectively. However, at 25 km/h these values are still very high, i.e. HIC for the passenger is 2963 and the forces on the head/face are 8.1 kN.

Table 5

Results: simulation of the TST with modified impact surfaces - bus impact; and TST with major modifications - modified bus impact.

Parameter	TST with modified impact surfaces Velocity [km/h]		TST with major modifications Velocity [km/h]	
	20	25	25	30
Force: bus - TST windshield [kN]	4.3	12.6	16.0	20.0
Force: bus - TST middle front [kN]	28.6	32.8	20.5	23.3
Force: bus - TST low front [kN]	21.9	28.5	45.7	57.5
Force: TST dashboard - driver knee [kN]	2.8	3.2	2.8	3.2
Force: TST steering bar - driver face [kN]	1.8	2.9	2.1	1.5
Force: TST rear view mirror supp-driver head [kN]	2.5	3.7	3.1	3.2
HIC driver	512	2289	841	2111
Force: TST middle crossrod - pass. tibia [kN]	4.5	7.0	-	-
Force: TST driver/pass. partition -pass. knee [kN]	4.9	6.3	-	-
Force: TST driver backrest - pass. face/head [kN]	5.3	8.1	-	-
HIC passenger	904	2963	545	788

It appears that when the extensive intrusion of the bus into the TST remains unaltered it is not possible to improve the safety of the driver and passenger at impact velocities greater than 20 km/h.

In order to improve these values further it was felt that major modifications need to be made on the TST. The seating arrangement for the passengers in the TST was then modified so that the passengers were facing backwards. This was done so as to eliminate head impact with hard structures. A lap-belt was introduced for the driver and the floor structure was made stiffer.

Table 6

Results: simulation of the TST with modified impact surfaces - pedestrian impact; and TST with major modifications - pedestrian impact.

Parameter	TST with modified impact surfaces Velocity [km/h]		TST with major modifications Velocity [km/h]	
	20	25	25	30
Acceleration: pedestrian head [g]	42	59	47	57
Acceleration: pedestrian chest [g]	23	38	24	38
Force: TST front - pedestrian abdomen [kN]	3.4	3.9	4.3	5.9
Force: TST front - pedestrian pelvis [kN]	2.8	3.5	1.3	2.2
Force: Pedestrian femur - tibia condyle [kN]	0.1	0.1	1.5	2.6
Elongation: pedestrian ACL [%]	4	4	7	7
Elongation: pedestrian PCL [%]	6	6	5	5
Elongation: pedestrian MCL [%]	13	14	6	6
Elongation: pedestrian LCL [%]	2	4	12	12

TST WITH MODIFIED IMPACT SURFACES AND PEDESTRIAN IMPACT - In the unmodified TST and pedestrian impact it was felt that the abdomen forces were very high while the forces at the pelvis were relatively low. The front of the TST was therefore modified so as to decrease the abdominal forces even if the forces on the pelvis were higher. Accordingly the simulations at 25 and 30 km/h indicate (Table 6) that the abdominal forces have come down to 3.4 and 3.9 kN (3.9 and 5.3 kN earlier) while the pelvic forces have gone up to 2.8 and 3.5 kN (from 1.9 and 2.9 kN). This is desirable as the pelvis can withstand higher forces than abdomen.

TST WITH MAJOR MODIFICATIONS AND MODIFIED BUS IMPACT - For this set of simulations, major modifications were made to the TST as shown in Figure 4. The TST front as well as the bus front have also been modified. The impact between the TST (with major modifications) and the modified buss was modeled at 25 and 30 km/h.

After these modifications the peak contact forces (Table 5) between the TST and driver knee, face and head have decreased and the HIC for the driver has also decreased to 811 at a speed of 25 km/h. At 30 km/h HIC is still very high (2111 for the driver). However, the passenger is now relatively safe even at speeds of 30 km/h. This is because he is now facing backwards and does not have an impact with any hard surface (Appendix g-h). The HIC for the passenger is now 545 and 788 at 25 and 30 km/h respectively. Thus, as a result of these modifications the passengers become safe even at a speed of 30 km/h while the driver can be considered to be safe at a speeds up to 25 km/h but not at 30 km/h.

TST WITH MAJOR MODIFICATIONS AND PEDESTRIAN IMPACT - The impact between the TST (with major modifications) and the pedestrian was modeled at 25 and 30 km/h. The results are summarized in Table 6. At 25 km/h while the head accelerations of the pedestrian have come down the abdominal forces show a marginal increase (from 3.9 to 4.3 kN). This indicates that the TST front needs fine tuning to bring down the abdominal forces. All the other values seem to be within acceptable limits.

CONCLUSIONS

From the results discussed above it can be concluded that the existing TST is not safe for either the driver or the passenger or the pedestrian even at low impact velocities of about 15-20 km/h. There is a lot of scope in changing its design to make it more safe. Minor modifications like adding padding at suitable locations and altering the front of the TST can make a significant difference to safety of the occupants as well as the pedestrians. These modifications make the TST safe up to about 20 km/h.

Changes of the design of the TST, like changing the orientation of the passengers and introducing stiff floor structures combined with increasing of the compatibility of bus front can make it safer for the passenger at speeds of 25-30 km/h. However, in order to make it safe for the driver at higher speeds ranged from about 30 km/h more modifications in the design of the TST would be needed. These could be in the form of chest seat belts for the driver, or other structural changes in the TST.

In the crash situations where the TST and bus are involved it is not sufficient to modify only the TST, even the bus front should be optimized for crashes with TSTs. Bus fronts will have to be modified in the future to make them more compatible with cars and vulnerable road users because buses are involved in 30-40% of the fatal crashes with these road users. A bus front which is compatible with cars and more forgiving for pedestrians and bicyclists is also likely to be more compatible with TSTs. Therefore, in planning for the future it is reasonable to investigate what bus front properties will be more compatible with TSTs.

The current study shows that computer models like MADYMO can be very useful in understanding the limitations of various design changes for enhancement of safety of indigenously designed vehicles in Asian countries. The crash simulation results provide first approximations for safety countermeasures appropriate for TSTs. Some of these measures like cushioning impact surfaces, can be implemented without much risk of adverse effects. However, major modifications can only be made after more analyses have been carried out using more detailed TST dynamic crash properties and impact simulations under a host of different conditions.

A large number of locally designed vehicles are used in Asia. Almost none of them have been designed using impact safety guidelines and do not satisfy any safety standards. Computer simulation models like MADYMO can be very useful in making these vehicles safer without heavy capital expenditure.

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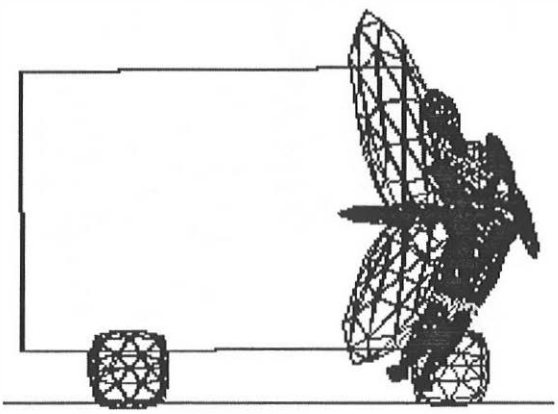
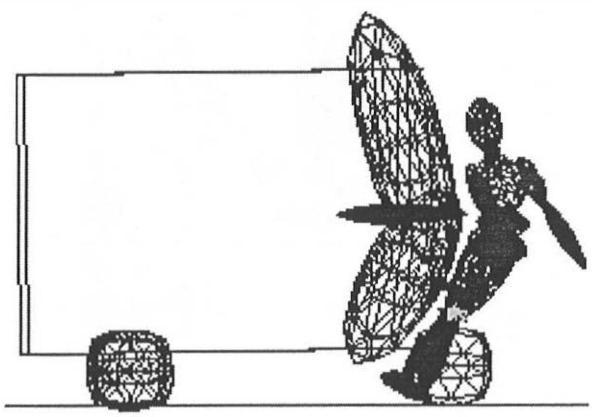
APPENDIX

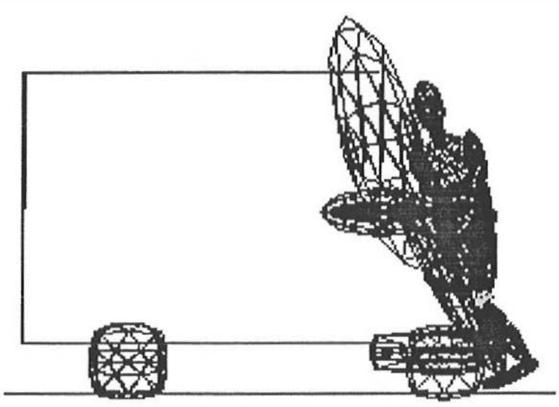
Kinematics of the TST-pedestrian impact (a, b) and TST with major modifications-pedestrian impact (c, d). Relative velocity 25 km/h.



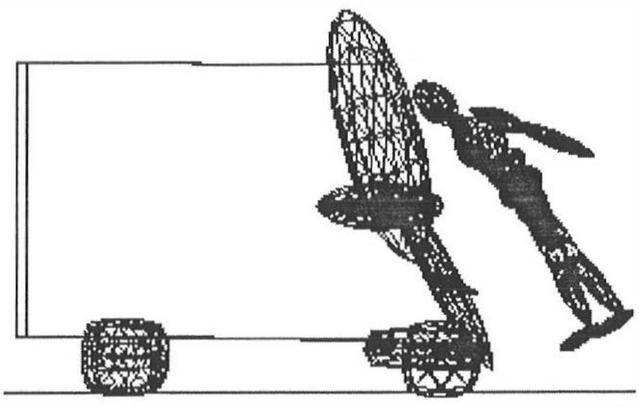
a) t= 10 ms



b) t=40 ms

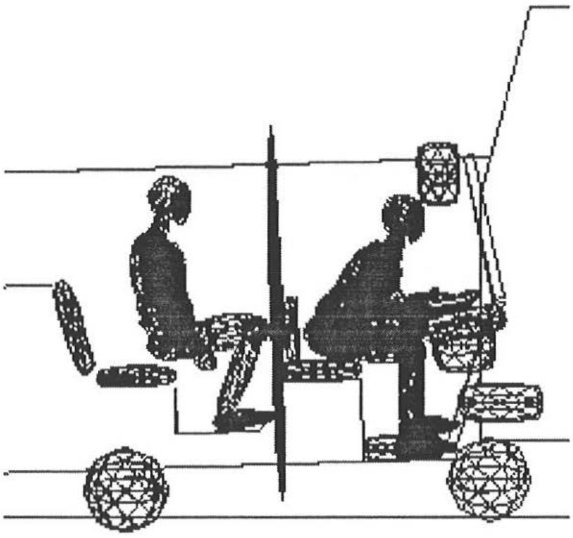


c) t= 25 ms

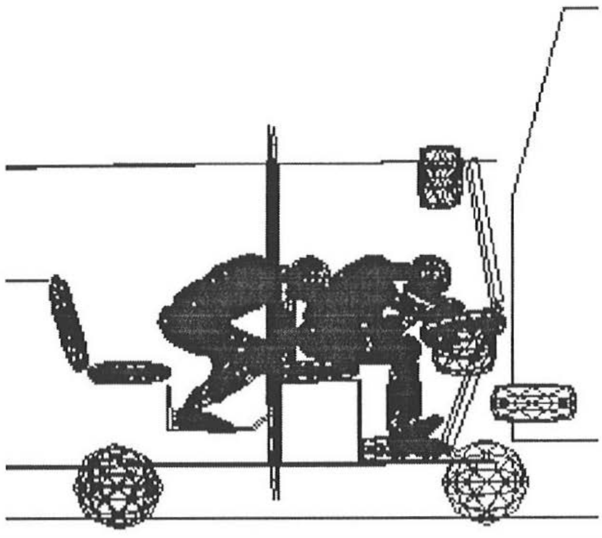


d) t=70 ms

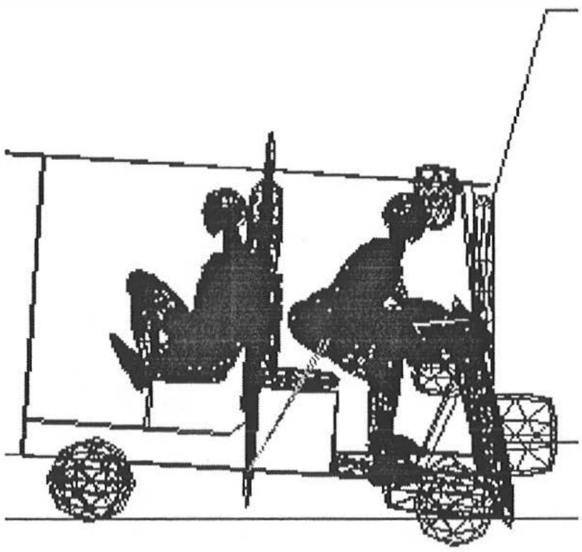
Kinematics of the TST-bus impact (e, f) and TST with major modifications-modified bus impact (g, h). Relative velocity 25 km/h.



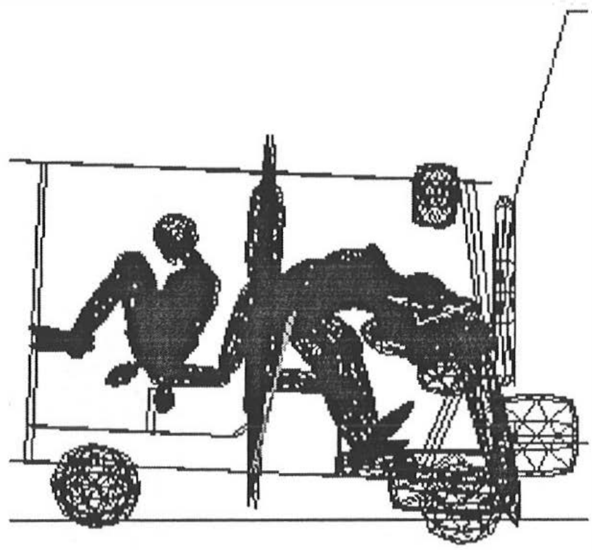
e) t= 60 ms



f) t=150 ms



g) t= 30 ms



h) t=100 ms