FE Simulation Studies of a Three-Wheeled Scooter Taxi

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In India alone, there are around 500,000 accidents each year, resulting in deaths of around 60,000 people. This data is fairly representative of most of the LMC's (less motorized countries). Analysis of the crash data shows buses and trucks to be the main culprits. However, a significant number of fatalities result from TSTs (Three-Wheeler Scooter Taxis). These, though accounting for only 3.5% of the vehicles on road, result in up to 5% of the reported fatalities [TRD, 1993 & DP, 1994]. TST, being unique to the Indian sub-continent, not much study has been carried out regarding their crash worthiness on the roads, or their pedestrian friendliness.

TSTs, apart from buses, are the main mode of public transport for most of the urban middle class population in the Indian-subcontinent. Crashworthiness studies and tests have traditionally been carried out for cars, etc. Previous studies regarding TSTs have mainly concerned with analyzing the dynamic characteristics of the TST with the aim to ascertain the comfort level of the passengers [Ramji and Goel, 2001]. An earlier work by [Mohan etal, 1995 and 1996] has used rigid body modeling to study the safety of the pedestrian in accidents involving the TST. The aim of the current study is to develop FE models of the crash of the TSTs and study the safety of the occupants, namely the passengers and importantly, the driver.

Methodology

ESI Systems® PAM-CRASH 2001.1™ software was used to carry out the crash simulations. Preliminary studies have been based on two basic setups. The first setup consists of the TST model, without the front mudguard being impacted against a rigid modeled wall. In a second set of studies, the front mudguard is being modeled and then a similar frontal rigid-wall impact simulation carried out. The aim being to visualize the effect of the mudguard on the dynamic behavior of the TST during the impact. It is strongly suspected that the mudguard plays a dominant role in determining the impact forces being transmitted to the occupants and that it acts somewhat as the impact bars in cars and other similar LMVs.

The modeling of the model has been carried out using the I-DEAS™ software. Geometric data has been collected by taking measurements of a vehicle on the road. Individual component models were validated against quasistatic test data for the same.

The force-deflection curves for many components were obtained experimentally. These include the front shield, the partitioning panel between the driver cabin and the passenger area, the cross members, the seat base below the driver, the windshield and the windshield support. The impactors used for loading of individual parts are different to simulate the actual loading conditions. For instance, the cabin partition impactor is a 175mm flat circular disk, while a 150mm hemispherical impactor has been used for the windshield. Appropriate material properties have been supplied to achieve close match between the physical tests and the simulation results.

Other detail like friction value for road-tyre interaction has been obtained from literature. Velocity data has been used keeping in view the average speed on the roads. These velocities tend to be in the range of 20-30 kmph. Hence, the simulations have been done at 30kmph. Acceleration field of *g* has been added to simulate gravity.

Before carrying out the crash-simulations, free-run simulations of the TST carrying the driver were carried out to validate the mass distribution by measuring ground reactions. The suspension springs were pre-compressed as per these reactions before using the TST model in the simulations.

TST model

In PAM-CRASH the TST model consists of individual FE meshes corresponding to the parts present in the physical TST. These parts have been individually meshed using I-DEAS as explained before. Force deflection characteristics have been obtained from quasi static-loading tests. In principle, there are three basic types of TSTs currently plying on Indian roads. These are the FE (Front Engine) model, the petrol based RE model and finally, the newest addition, the CNG RE model. The FE model confirms to the petrol based RE model. There are significant differences in the last two models, namely the petrol based and the CNG models. These differences include a mass difference of more than 25% and also difference in the location and mounting of the engine block. The current model might require significant changes to conform to the newer CNG model.

As mentioned before, the effect of the front mudguard appears to be critical. Thus the simulations carried out have two basic models, one without the front mudguard and the other comprising a front mudguard. This is being done specially because some models of TSTs have a frontwheel guard that rotates with the steering column, and the mudgaurd then does not play a significant role in absorbing the energy. At his stage the model without the mudguard is ready. The modeling of the front mudguard is being done in stages. Initially a crude model of the mudguard was included. Once it was firmly established that the mudguard is critical, the accurate model of the mudguard is now being developed. Figure 1 shows the TST model developed

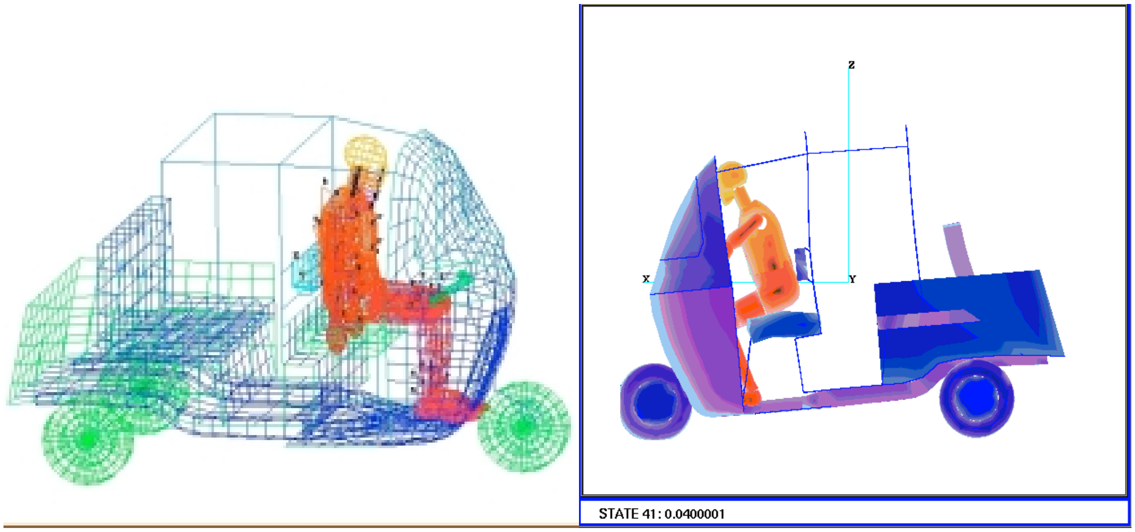

Figure 1: FE model of the TST with the driver: (a) position before impact; (b) positions 40msecs after impact with front rigid wall

After meshing the individual parts, interactions have been defined between them. These interactions are defined between the surfaces of different parts and control the transmission of forces and moments between individual members. Kinematic joints have been defined for the front and rear suspensions, and the axles carrying the wheels. These K-joints are used to simulate real life bearings and spherical joints. PAM-CRASH also allows definition of welded joints and spot welds which have been used to define the contact between the cross members in the front portion of the TST. Contact interfaces have been created for the defining the interaction between the dummy and various parts of the auto like the windshield, the front portion, driver seat, etc. Contact interfaces are also used to define the interaction between the impacting surfaces, i.e. the front shield and the front tire with the impacting rigid wall, and similarly, that between the road and the tires.

Simulation of the wall crash

The objective of the current work is to validate the developed model against experimental crash test data. An actual crash test has been carried out by the manufacturer by allowing a TST running at 30 kmph to impact against a wall. We are therefore modeling the crash of the TST into an infinite and perfectly rigid wall. In the simulation the road as well as the wall have been modeled as rigid, planar walls of infinite mass. The dummy used for the driver is a 50% Hybrid III male dummy available in the PAM-CRASH dummy database.

Figure 2 below shows the kinematics of the crash of the TST model (without the driver) into the wall. The individual snapshots are at 10msec intervals. Figure 2b, shows all the 10msec snapshots superimposed on one another to give a feel of the deformations observed in this case. Subsequently the dummy model was inserted in these simulations for the driver. The Figure 3 shows the kinematics for the driver.

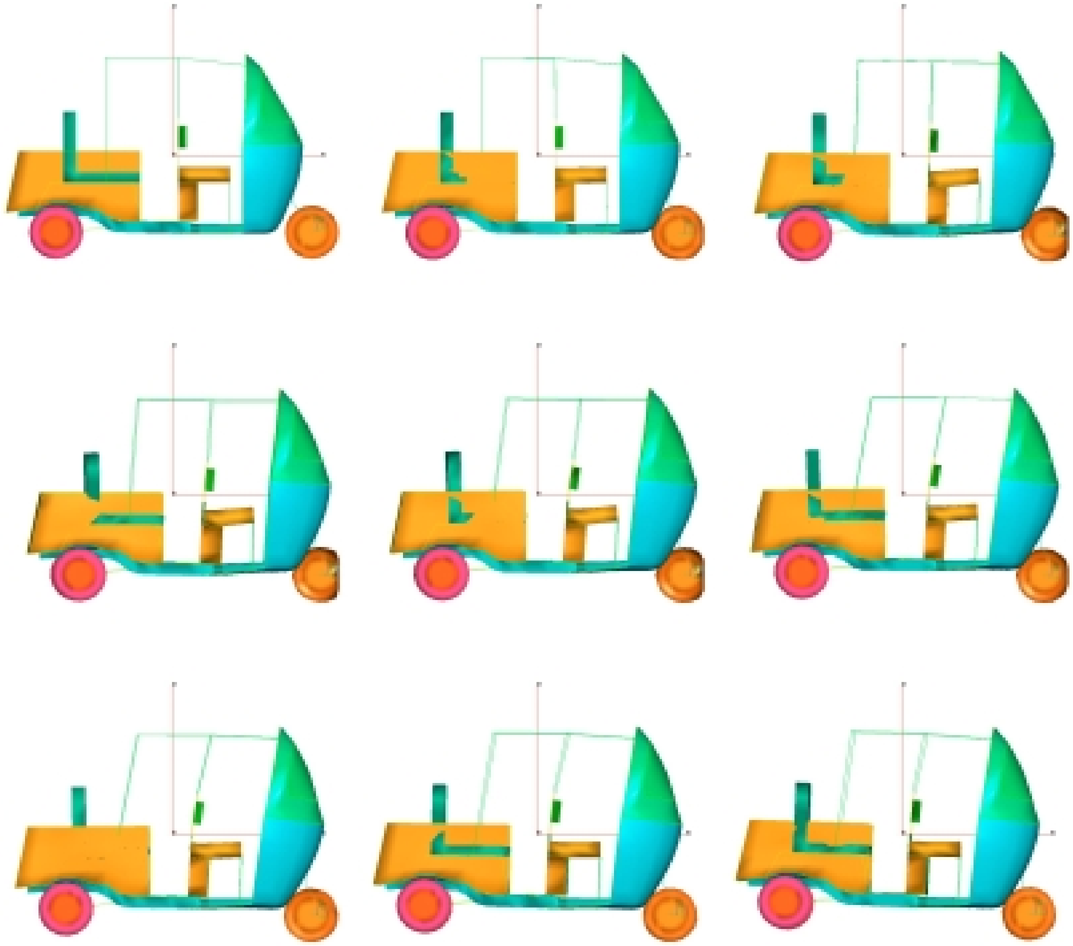

Figure 2: The kinematics of the TST – wall crash.

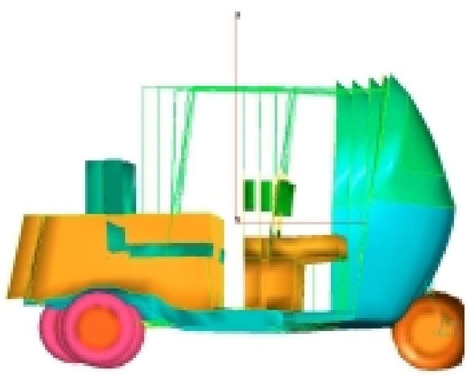

Figure 2b: The kinematics of the TST – wall crash with the 10msec snapshots superimposed on one another.

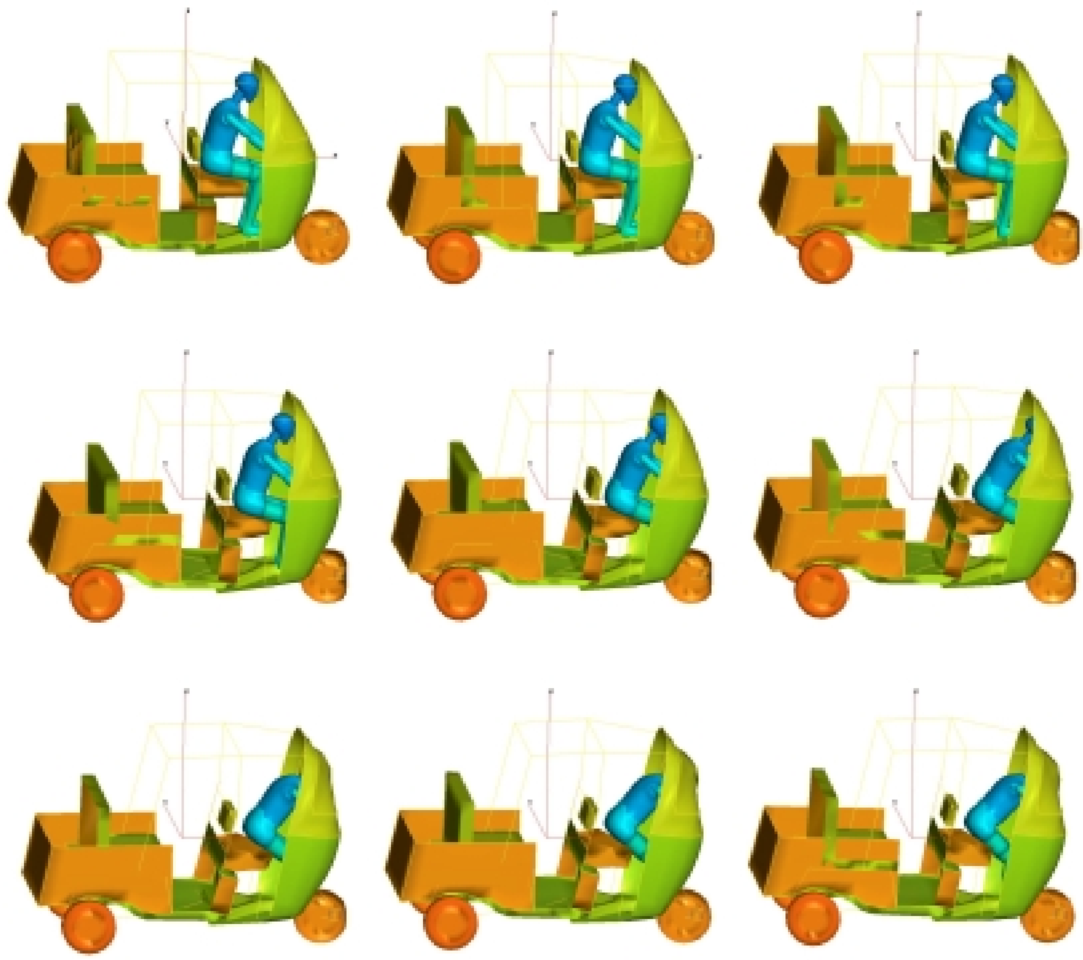

Figure 3: The kinematics of the TST – wall crash with the driver.

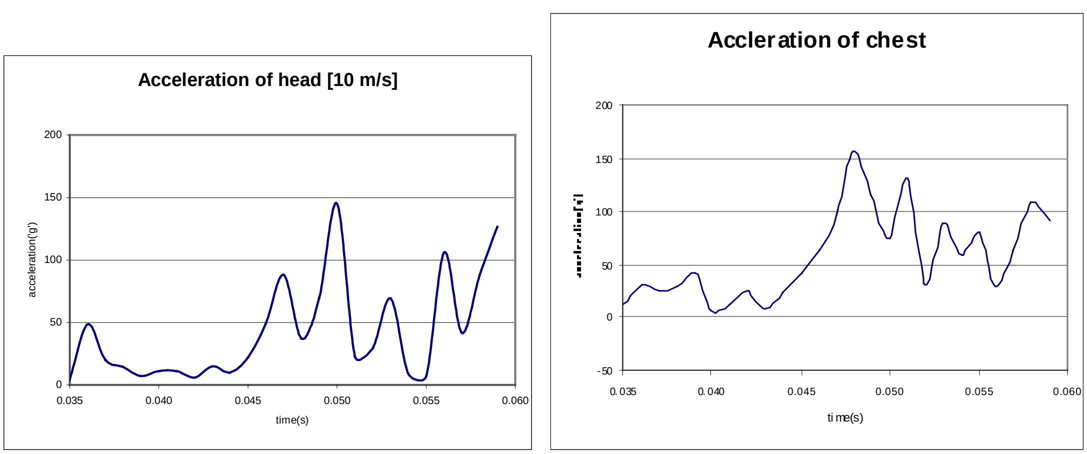

Fig. 4. Acceleration during impact: (a) driver head ; (b) driver chest

Discussion

The simulations have been carried out at impact velocities of 30kmph. The accelerations experienced by the head nodes and chest nodes of the driver dummy during impact is shown above in Figure 4. It is important to note that in the unmodified TST accelerations are around 150g which is clearly very dangerous. Also the HIC value for the head comes out to be around 1200. This value is higher than the acceptable limit of 1000.

The deformations of the front shield have also been observed. We have also done some preliminary simulations with the mudguard. The results show that the mudguard affects the dynamics of the impact. In the absence of a mudguard, there is a significant shearing of the front shield and the contact between the knee-joint and the front shield is delayed. This knee contact with the front shield is suspected to be a major source of injury. It has been shown by [Gehre et al.] that the lower extremities play a crucial role in determining the safety features in a three-wheeler. The prime reason being that the knee-joint in a three-wheeler is much closer to the impacting surface and thus more susceptible to injury than say, in a car. In the presence of front mudguard, there is no shearing action and hence the deformations in the shield are greater. The mudguard in this case plays an important by absorbing a significant amount of energy in the process of getting crushed. We are making more detailed models of the mudguard to study and wuantify this phenomenon.

It is also observed from the initial studies that upon impacting against the windshield, the head tends to bend backwards and, as a result the neck is subjected to elongation. Further studies would help in quantifying the severity of neck injuries in this mode vis-à-vis the injury to head.

The above findings lead us to believe that in the present form the TST is very dangerous for the occupants, esp. the driver. However, we believe that with small and low-cost changes the vehicle can be made much more safe for the driver. These changes could include appropriate padding / cushions at the impacting surfaces and addition of a lap-belt for the driver. Further studies will quantify the effect of these modifications on the behavior of the TST.

The current model is in early stages of validation. The current model being validated will also be available for studies of TST crashes at different configurations. In the absence of specific standards for crash testing of TSTs, it will be very beneficial to have a pre-validated model and to compare the results of crash-simulations carried out in different configurations, e.g. frontal impacts, sideways impacts, glancing impacts, etc. These would help in preparing a comprehensive data-sheet about the crash worthiness of the TST.

The current study shows that FE simulations are a very powerful method for carrying out tests to determine the crash worthiness of vehicles being used in Asian countries. It is even more important in cases where standards as well as extensive testing data is not available. In LMCs, the amount of capital available to carry out such tests is very limited and the manufacturers themselves are hesitant to carry out such expensive tests. Thus FE simulations can present a viable alternative to physical tests involving huge costs.

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