# The Computer Aided Analysis of the Bus Accidents Oriented to the Numerical Simulation of the Injury of the Human Body

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*Abstract:* - While bus accidents tend to draw public concerns in China, much recent research has only focused on the analyses of car accidents due to relative high rates. However, the research dedicated itself to the scope of reconstructing and analyzing traffic accidents involving bus and quasi bus vehicle. Thus, the paper here is to represent a comprehensive method for the reconstruction of bus accidents, introducing analysis of human body injury as an auxiliary approach to verify the results of simulation in order to improve the accuracy of whole judgments, apart from using the technique of trajectory optimization as conventional reconstructions of car accidents, which ignore human body injury. According to clinical results and information collecting and concluding from the accident sites, the studies of body injury, which work as a kind of feedback in order to check and guide ordinary simulations, were carried out investigating the severity levels and dynamic response of human body under the given conditions calculated from common method. Within the method, the corresponding modifications of modeling, calculating and simulating need to be made, relating to the comparisons between predicted injury parameters and practical effects on victims. Through the demonstrations of the reconstructions and analyses of two real-life paradigms regarding bus accident, this paper indicates the general routing of the method for common cases. The research looks at applying two useful numerical reconstruction techniques, namely Multi-body body dynamics and trajectory optimization methods. With the help of two numerical modeling skills, preliminary results indicate that the combined reconstruction method can reflect the process of bus accident reasonably well. In comparison with conventional methods, the method provides more reliability as well as accuracy.

*Key-Words:* - bus accident; accident reconstruction; injury; occupant kinematics; trajectory optimization

## 1 Introduction

The Chinese road traffic has been in a severe condition. For instance, it is reported that the death toll caused by traffic accidents exceeded one hundred thousand persons each year successively from 2001 to 2004, with the fact that 2005 amounted to 9873 persons and 2006 still resulted to 89453 persons. Therefore, the situations of the Chinese road traffic need to be improved in many ways (e.g. making roads better, and developing vehicle technology). Nowadays, with the rapid development of the computer and software techniques, numerical simulation and reconstruction techniques that oriented to the analysis of the traffic accident have been widely applied and greatly concerned. However, these current techniques have mainly been focusing on how to strengthen the safety of small passenger cars, while ignoring the needs of accident reconstruction regarding bus, and the structural design of bus. In fact, road traffic accidents with respect to the buses become a common crash type in China. The number of cases and deaths caused by accidents of the bus has kept occupying a large proportion among all the traffic accidents. Besides, the number of deaths resulted from a single accident is also seen at a high level in China. According to the record data from the administration of Chinese traffic police, in 2006, the number of bus traffic accidents was 7421, which was equal to 11.6% of the total number of the vehicle-crashing accidents. Among others, the number of the significant traffic accidents, which resulted to over 10 deaths, even amounted to 26, leading to 396 people dead and 359 injured in all.

Obviously, the bus accident has rank itself among the leading cause of injury, death and disability of many people in a single traffic accident and in the meantime, this typical vehicle accidents are inclined to be eventful. Therefore, this kind of crash draws more and more concerns from the public and authorities at all levels. Impacts involving bus are selected as the accidents of interest in this present study, with the assistance of different computational resource.

The whole process of a vehicle accident can be divided into three phases: (1) Post impact - the usual starting point of the reconstruction which can be developed depending on the information obtained from the accident scene. (2) Impact - determination of the vehicle's impact speeds, directions and location, and so on. (3) Pre-impact - decision of speeds and trajectories. The main guideline of accident analysis is to find out the vehicle motion in collision phase according to the vehicle rest position in post-collision phase, and then the vehicle motion in pre-collision phase, based on collecting, recording, investigating and analyzing of the accident scene[1-3].

Vehicle collision analyses and accident reconstructions have become increasingly popular in recent years due to the expanding rate of civil litigation. Because of the deficiency of recording speed information, most of the focus of the vehicle crash reconstruction is on the determination of retrieving the pre-impact velocity.

In order to reconstruct the course of an accident, some methods have been studied and applied in different accident types. Occupant kinematics is important information for forensic experts, accident analyzers and engineers. Reconstructing occupant kinematics in a real-world accident usually requires a long simulation time. Therefore, multi-body method was developed as an effective approach to reduce the time cost of a simulation of the interactions between vehicle and occupants.

At present, there are mainly two common methods in the field of numerical reconstruction of the road traffic accident. The first one is depended on the tire skid marks, which can depict the movements of vehicle during the whole process of collision. The other is based on the vehicle's 2-D or 3-D deformation, which can be used as important information for concluding crash force, momentum, and then velocity according to the knowledge of material characteristic. Nevertheless, the analysis based on the human body injury has not received its deserved recognition in the identification of the traffic accident. As a matter of fact, the application with the characteristic of body injury can be very outstanding in dealing with the coach-involved traffic accident case. With the assistance of body injury, the vehicle speed can be analyzed more precisely due to this kind of auxiliary identification. In the following passage, two typical traffic accidents regarding bus were discussed separately. The vehicle speeds, which are calculated out in other ways, can get auxiliary verification by using the numerical analysis of the human body injury in the two typical cases.

Generally, there are several simulation methods presented in accident analyses, which can be grouped into two main types, dynamic methods and analytical methods. Engineers had tried to combine both methods together to simulate occupant motion inside vehicle. They applied analytic methods such as momentum-based method to simulate impact among vehicles, and used dynamic methods such as finite element method and multi-body dynamics method to calculate the interaction between environment (vehicle or road) and occupants. Usually, the accident reconstruction method based on the trajectory theory optimization reveals traffic accident through the momentum-based method to reduce the calculation time. The analytic method has a capability of reverse calculation, which is helpful to find optimum using simple impact model. On the other hand, the finite element method and the multi-body dynamics method could take advantage of both precise contact algorithm and detailed human model to calculate occupant injuries.

In order to realize the combination between trajectory optimization method and multi-body dynamics, it is assumed that equivalent impulse can replace actual impact and momentum exchange time can be determined by engineering estimation. However, errors caused by this estimation must be taken into account, and the feasibility of reconstruction by aforesaid method should be evaluated further.

## 2 Mathematical Model

The reconstruction of the accident involving human body kinematics and vehicle trajectories needs to combine three different methods: momentum-based method to simulate vehicle motion, multi-body dynamic method to evaluate the human body injuries, finite element method to obtain the deformation parameters at contact surfaces. In this kind of reconstruction, vehicle dynamics and human body injuries are virtually seen as interrelated factors, which can be used as a potential condition of constrain while interacting with each other.

Firstly, undetermined parameters of vehicle motions were predefined in the light of preliminary judgments in reference to investigations. Then the process of reconstructing vehicle collision through the simulation of vehicle trajectories was established. Some unknown parameters of interest, involving vehicle dynamics, were obtained through the momentum-based approach.

Secondly, the outputs from the simulation of the trajectory optimization, in the form of velocities, accelerations and orientations, are introduced as the inputs for calculating human body kinematics and injuries. 3D multi-body models were established to reflect the interactions between vehicles and victims. Then, the movements of human body dynamics were described according to the outputs of vehicle crash simulation with momentum-based method.

Finally, in order to verify the consistency between the simulation results and the accident facts, human body injuries and deformations of vehicle were reevaluated according to the legal medical reports and the recording materials. According to the simulation discrepancy with the practical effects, Modifications for undetermined parameters of vehicle motions, such as initial velocities, positions and orientations, were made. And the new conditions were introduced to the first step of vehicle trajectory optimization. The same process of calculations was carried out as aforesaid until desired results were received. The Undetermined parameters were solved as the iterative approach was accomplished.

## 2.1 Trajectories Optimization Method

Vehicle-vehicle impact model can be represented by momentum-based method. A normal-tangential coordinate system is established which originates at the impact center (Fig.1).

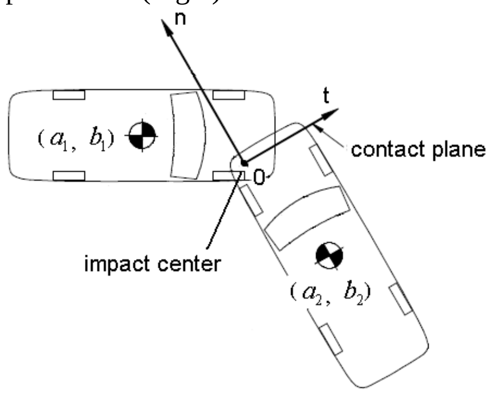



Fig.1 Impact configuration

The n axis is normal and the t-axis is tangential to the contact plane respectively. And the following assumptions are taken[4-6].

（1）Each vehicle has one mass and three degrees of freedom (two translations and one rotation).

（2）An exchange of the impact forces between vehicles happen within an infinite small time step at a single point.

（3）The motion of occupants inside vehicle can't affect vehicle kinematics.

Based on the law of conservation of momentum and the equation of linear and angular impulse momentum, the change of the relative velocity for both vehicles at the impact center can be calculated from pre-impact velocity and normal and tangential impulse.

In this study, the vehicle movement is analyzed with the software PC-Crash that is a common commercial tool to reconstruct vehicle-vehicle accident using momentum-based collision model. PC-Crash defines the restitution coefficient as ratio between restitution impulse and compression impulse. When the impulse is separated into two components, the normal and tangential impulse can be calculated from:

$$N = N_C(1+\varepsilon) \quad (1)$$

$$T = \mu N \quad (2)$$

In EQ (2), the equivalent friction coefficient $\mu$ can indicate the collision type. For example, equivalent friction coefficient is very low for the sliding impact in which impact force often results in severe rotation of vehicle and complex occupant kinematics.

Due to the fact that all data regarding the accidents were collected from the field, there is necessarily a degree of uncertainty regarding the precise conditions under which each accident took place. Without facility attached to the vehicle involved, it is impossible to know exactly the velocities of the bus during collision. The cases presented here have at best an eyewitness account of the accident, which is of course useful and necessary, but not scientifically rigorous. In many accident situations the approximate location where the vehicles collided can be found due to skid or scratch marks, shatter fields or several types of scuffs. If the vehicles have not been moved from their rest positions when the scene investigations were made, these positions and the movement directions are considered as reliable. If skid marks were found on the accident scene, intermediate positions of vehicle can be concluded on the post impact trajectories. Therefore, from the trajectories, valuable information can be collected from the field in terms of the impact position, rest positions and intermediate positions for accident situations.

For each vehicle, these parameters can be specified [4-6]:

$\boldsymbol{P}_{Stop}$ : Vehicle rest position (coordinates)

$\vec{\boldsymbol{d}}_{Stop}$ : Heading vector at rest position

$P_{impact}$ : Impact position and vehicle overlap

$\boldsymbol{P}_{Inter}, \vec{\boldsymbol{d}}_{Inter}$ : One or more intermediate positions (location and heading of the vehicles on the post impact trajectories)

Once these parameters have been specified for the real accident, the following quality function can be used to calculate the quality of the simulation results. This quality function defines the target of the optimization process. The assumption has been made, that the lower the difference between simulation results and real accident data is regarding these values, the closer the simulation is to the real case. This formula is based on the least mean squares, as the quality function tends to zero the best match between simulation and real accident data has been found, and a "simulation error" can be calculated.

$$Q = \sqrt{\frac{\sum_i (w_i \cdot x_i)^2}{\sum_i w_i^{\,2}}} \times 100\% \tag{3}$$

The term $\boldsymbol{x}_i$ of the quality function are defined by the differences between real accident data and simulation results. These factors are normalized and a weighting $\boldsymbol{w}_i$ for each parameter can be specified to gain more control over the optimization process. The quality function terms or error estimators $\boldsymbol{x}_i$ are defined for each car $\boldsymbol{i}$ as follows.

Positional errors (stop positions):

$$\boldsymbol{E}_{Positional_i} = \frac{\left\| \boldsymbol{P}_{StopSim_i} - \boldsymbol{P}_{Stop_i} \right\|}{\left\| \boldsymbol{P}_{Stop_i} - \boldsymbol{P}_{impact_i} \right\|} \tag{4}$$

Positional errors (intermediate positions):

$$\boldsymbol{E}_{PositionalInter_i} = \frac{\left\| \boldsymbol{P}_{InterSim_i} - \boldsymbol{P}_{Intre_i} \right\|}{\left\| \boldsymbol{P}_{Inter_i} - \boldsymbol{P}_{impact_i} \right\|} \tag{5}$$

Heading errors (stop positions):

$$\boldsymbol{E}_{Heading_i} = \frac{\mathbf{arccos}(\vec{\boldsymbol{d}}_{Stop_i} \cdot \vec{\boldsymbol{d}}_{StopSim_i})}{\boldsymbol{\pi}} \tag{6}$$

Heading errors (intermediate positions):

$$E_{HeadingInter_i} = \frac{\arccos(\vec{d}_{Inter_i} \cdot \vec{d}_{InterSim_i})}{\pi} \tag{7}$$

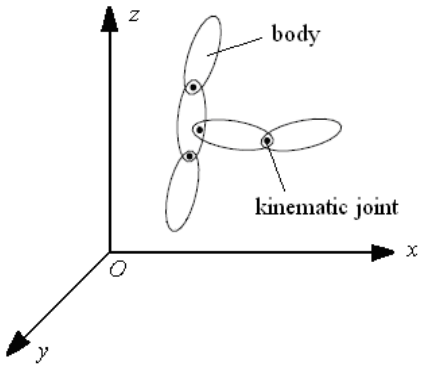
As for the optimization strategies, several different algorithms like the Coordinate approach by Gauss-Seidel, the Simplex method, the Gradient and Newton approach, Monte Carlo and Evolutionary methods deal with the problem of multidimensional optimization. Not all these methods are applicable, because some of these methods need derivatives of the target function to the input parameters. Thinking of the factors of robustness, numerical stability and high progress rates, the Evolutionary method, that is, the genetic algorithm is chosen.

In summary, the method of trajectory optimization, which depends on skid marks and scene of accident field, is actually achieved by using the aforesaid momentum-based technique.

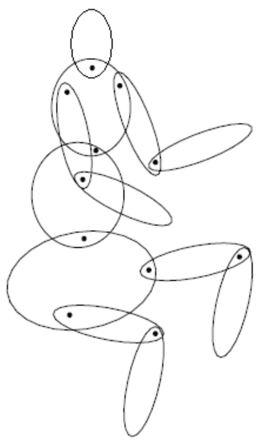
## 2.2 Injury Simulation

The multi-body dynamics method is introduced using MADYMO, one of the most advanced computational solutions in the world. The dynamics response of complex multi-body systems can be simulated. A multi-body system generally consists of rigid and flexible bodies joined together by kinematic joints (e.g., revolute or translational joints) or force elements (e.g., springs and dampers), and the presence of these kinematic joints is defined by means of global and local coordinate reference systems in such a model (Fig.2 (a)). It is sufficiently flexible to construct a multi-body model of human body or vehicle with various kinematic joints and discrete bodies of particular size and shape (Fig.2 (b)) [7].

While MADYMO (Mathematical Dynamic Model) MADYMO is the world-wide standard for occupant safety analysis and is routinely used by the automotive, aviation, and government industries, as well as academic institutions, for conducting research on injury biomechanics, our studies focus on its applications in vehicles, motorcycles and bicycles. This software uses numerical algorithms (e.g., modified Euler or Runge-Kutta) to predict the motion of systems of bodies connected by kinematic joints, based on initial conditions and the inertial properties of the bodies. Because MADYMO allows us to quantify diverse loading conditions to the body through the use of their family of validated crash test dummies and human models, such analyses were performed and the results were interpreted in an applied, scientific manor in our study. Furthermore, MADYMO has a database of human body models developed by TNO (Netherlands Organisation for Applied Science Research) and EEVC (European Experimental Vehicles Committee) include Hybrid III dummy and human models in this software, which is very suitable for reconstructing accidents involving humans. Besides, these human models are available to simulate human body injuries in various kinds of accidents.




(a)



(b)

Fig.2 The multi-body system of bodies connected by kinematic joints

The considerations of human kinematics in accident should be divided into two parts: vehicle-vehicle contacts and human involved contacts. In order to analyze human kinematics and its interaction with environment, 3D multi-body models of vehicle together with humans and the ground in the accidents should be established. These multi-body models are composed of ellipsoids and rigid bodies. The outer surfaces of vehicles and human bodies are described using planes, cylinders, elastic ellipsoids and facet surfaces. The ellipsoid-to-ellipsoid and ellipsoid-to-plane contact algorithms are used to calculate the interactions between human models and environments apart from those between vehicles and roads.

As shown in Fig. 3, the motion of vehicle can be defined by the location of origin and the orientation of the local CS (coordinate system) relative to the ground reference space CS by specifying the X, Y and Z components. A planar joint, of which describe the 2D motion of vehicle C.G. with 2 translational DOFs and the yaw motion with one rotational DOF, is used to connect these two CS together.

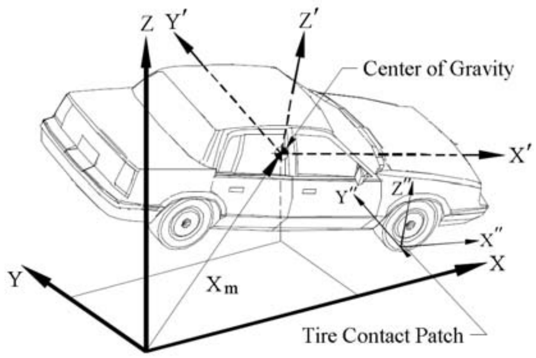



Fig.3 Two coordinate systems

Translational motion and yaw rotation acceleration derived from vehicle crash simulation are used as inputs for simulations of human kinematics. Because the aforementioned momentum-based method considers the exchange of the impact forces between vehicles occurring within an infinite small time, the inputs can't provide the time history signal in the impact phase. In order to re-create the equivalent acceleration instead of the actual acceleration, momentum exchange time is introduced to describe the width of the equivalent rectangular impulse signal. The equivalent acceleration is equal to the impulse divided by the momentum exchange time.

$$A_n = N/(m \cdot t) \tag{8}$$

$$A_t = T/(m \cdot t) \tag{9}$$

Generally, the total momentum exchange time in a real world collision is 40~80 ms. Therefore, it's necessary to prove the feasibility of the above simplification for forensic application [8-11].

## 3 Real-world Accident Application

A method of combining the trajectories optimization method and the multi-body dynamics method was presented to reconstruct human body kinematics. This method can be applied to answer the question what are the initial speeds and orientations of vehicles in the traffic accidents. In this paper, the kinematics of the dummies in the simulation was comparable with that in the real-world case in terms of resting positions, human body injuries, and impact locations.

The error resulting from momentum exchange time is unavoidable due to the limit of the coupling method. This study had tried to estimate the effect of momentum exchange time in a real-world accident reconstruction. The study showed the reliability of the conclusion could be validated within a reasonable range of momentum exchange time, which is very helpful for forensic application.

Comparing with legal medical report and other information, the feasibility of this conclusion was reasonably proved. Furthermore, by evaluating the integral simulation results of collision with respect to realities, the reliability of application with the coupling method was fully confirmed.

### 3.1 Brief Introduce and the Simulation Model of Case 1

A Volvo public bus was eastbound whizzing through an intersection on an April morning, when there was a young man, who had got strike by the vehicle, southbound trying to walk across the street just on the east of crosswalk , all of a sudden. The bus smashed into pedestrian at the surface of right front corner. And then the pedestrian was knocked down on the road and died at the scene. According to the scene investigation, it was on a dry and sunny morning, and asphalt was used for making the road surface. The rest positions of the pedestrian and the bus are shown in the post accident scene map, as shown in Fig. 4 and Fig. 5. Also, two long skid marks of front wheels were found on the road. No serious damage was found on the vehicle of accident except that the glass near the lower right corner of the windshield cracked, as shown in Fig.6.

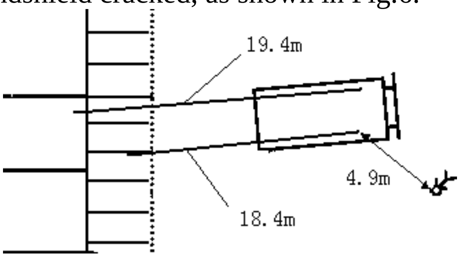



Fig.4 After-accident situation map

The victim was male, 20, 175 cm in height, about 70 kg in weight, which is almost like the 50th human model provided in software MADYMO. Detailed clinical examination of the victim revealed that the accident mainly resulted in impact over the right occipital region, hematomas on the left thorax and medial side of right femur and abrasions on the left side of the head. The fatal injury was brain contusion. Besides, there was no fracture in his extremities of limbs.

Fig.5 Accident scene

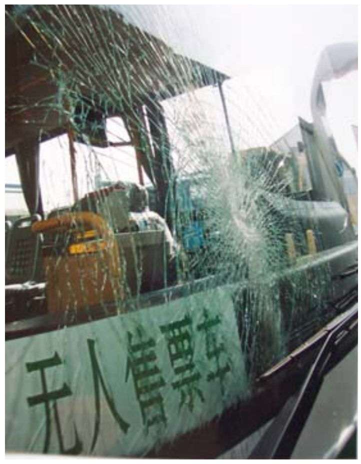



Fig.6 Vehicle damages

The above post accident data from investigations indicate that the left side of the pedestrian was struck by the right left corner of the bus. Then, his head hit the windscreen and the thorax contacted the front hood. Because pedestrian was always shot along the original direction of the vehicle and then turned toward ground in the flat-front vehicle accident, the contact with the ground is believed to be the cause of the bruises on victim right occiput.

In this case, the impact speed is an unknown primary parameter of interest. According to the accident data and the witness, the bus is estimated to launch an emergency brake just before the impact. There are some other initial conditions that can be obtained from the accident data, for example the orientation of the pedestrian, pedestrian walking speed, and pedestrian stance prior the impact. Therefore, the objective of the accident reconstruction is to find the optimum value of vehicle impact speed, which can help to reproduce the impact location and pedestrian injuries by multi-body simulation.

The reconstruction of the vehicle-pedestrian accident is performed with multi-body dynamic simulation software MADYMO. MB models of full crash field are developed for the case, including pedestrian, vehicle and ground. The vehicle model has only a translational DOF in the direction of straightforward motion. Its outer surfaces of vehicle front hoods are generated by rigid finite element mesh, which are fixed on a rigid body presenting the total mass of the vehicle. This rigid mesh can not only allow for relative quick computation but provide a detailed stiffness description of geometrically contact. The contact characteristics of the front of bus are estimated from public literatures.

The 50th TNO pedestrian model is used to simulate the victim in this case. Before simulation, in order to reproduce the injuries and the vehicle damage corresponding well with the scene data, the dummy is positioned for impact on the left side of his body. The dummy remains in a walking posture with the impacted section to the foremost position and the arms in a natural stance. Also, the pedestrian is given an initial velocity of 1m/s. A friction coefficient is applied to pedestrian-to-vehicle contact at 0.3 and pedestrian to ground contact at 0.7. The vehicle is assumed to have a deceleration of 0.7g when braking on the dry asphalt road.

## 3.2 Brief Introduce and the Simulation Model of Case 2

An IVECO bus was turning left on a suburb concrete road, on a dry and sunny morning in September. Because of the vision blockage resulted from road curve, the bus entered opposite lane and collided with a FAW heavy truck coming against it. The rest positions of both vehicles are shown in the after accident situation map. According to the skid marks, the truck drive had braked before impact. After the collision, the truck pushed the bus back for about 1.2m.

The expert examination of the vehicles after the accident showed that the two vehicles had collided head-on with each of their front left parts. The frontal coverage of the truck amounted to about 1.4m (total vehicle width 2.5 m). Longitudinal deformation of the front axis of the truck amounted to about 40cm. The IVECO bus was severely damaged over its entire front portion, more severely on the driver's side. Longitudinal deformation of the bus is about 4 m (total vehicle length 6 m).

In this case, there are one and twenty occupants in the truck and the bus, respectively. As result of the crash, one occupant in the truck and seven occupants in the bus died on the accident scene. None of the passengers on the bus was wearing a seatbelt except the driver.

According to the video monitor recording by the police, the truck's speed prior to the impact is about 52 km/h and its braking condition is known. So, the task of the reconstruction is to estimate the speed of the bus before impact.

Based on multi-body dynamic method, the combination of two scaled simulation model is applied to this case: vehicle-vehicle impact model and vehicle interior-occupant impact model. The outputs of the latter model, including occupant kinematics and injuries, are used to validate the results from the vehicle-vehicle impact model. Firstly, in vehicle-vehicle impact simulation, the movements of the two vehicles are analyzed in PC-Crash. Then, using MADYMO, the crash dynamics of vehicles from PC-Crash are used as inputs for occupant kinematics simulation.

The models of vehicle-vehicle impact simulation are available from vehicle database in PC-Crash. Its "stiffness based impact model" is used which provides linear stiffness function for calculating the contact forces between two vehicles. The outer geometry of the vehicles is presented by 3D DXF vehicle shape, which is very useful for calculating the location and direction of contact force.

The occupant sitting at the right-most seat of the second last row sustained the fracture of lumbar spine. Because the vehicle interior space around this seat is almost undamaged, the lumbar spine force of the above occupant is selected as the reference for validating the impact speed in occupant kinematics simulation. The MB model of the occupant and the vehicle interior are showed in Fig.7.

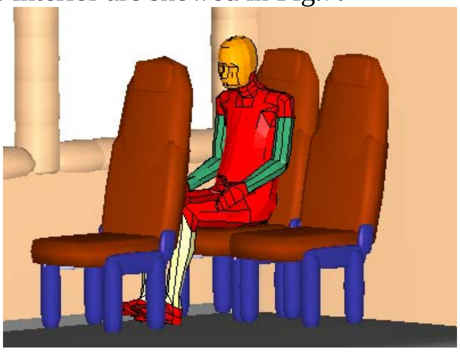


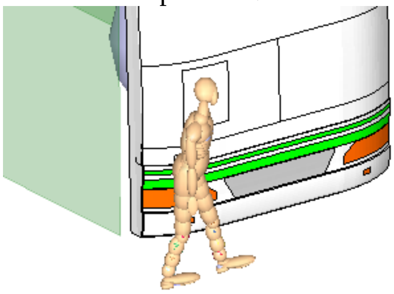
Fig.7 Occupant and vehicle interior model in MADYMO

The model of the vehicle interior is made of several ellipsoids, including the seats and the floor. A TNO 50th percentile facet occupant model is used. The outer surface of the facet occupant model is described by about 2000 triangular elements connecting about 1000 nodes defined as a null material. In this model, the vertebrae of lumbar, thoracic and cervical spine are generated by rigid bodies connected by free joints with lumped joint restraint model, of which the geometries are each described by a single ellipsoid. ELLIPSOID-FE contact is used to simulate vehicle interior-occupant interaction. The contact stiffness characteristics are referred to the relative research.

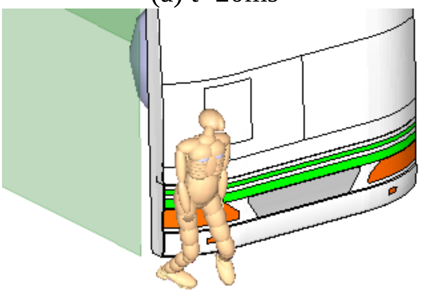
### 3.3 Injury Analysis of the Two Case

#### 3.3.1 Case 1

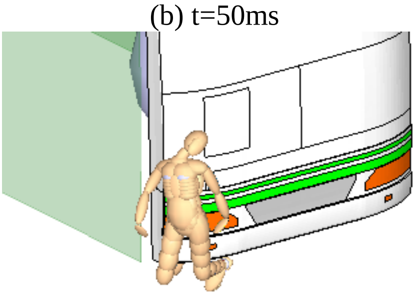
The impact velocity is calculated to be 29 km/h. Fig.8 shows that the reconstruction results correspond well with the accident data in terms of impact point and rest position.



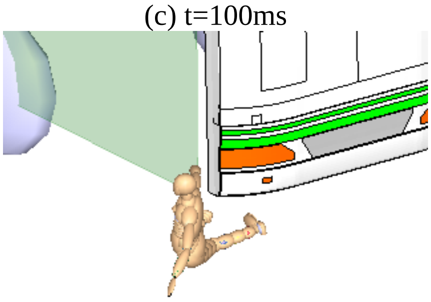
(a) t=20ms



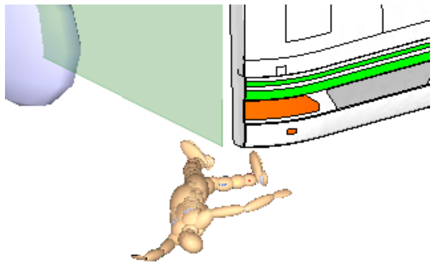
(b) t=50ms



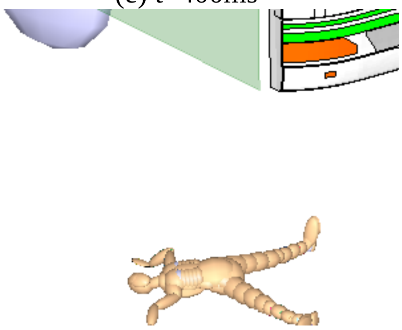
(c) t=100ms



(d) t=300ms



(e) t=400ms



(f) t=2000ms

Fig.8 Reconstruction results

Also, some pedestrian injury outcomes are listed in Table 1 and shown in Fig.9 and 10.

The injury criteria used in this case include HIC36, ASA20, max shear force and max lateral torque of right lower extremity.

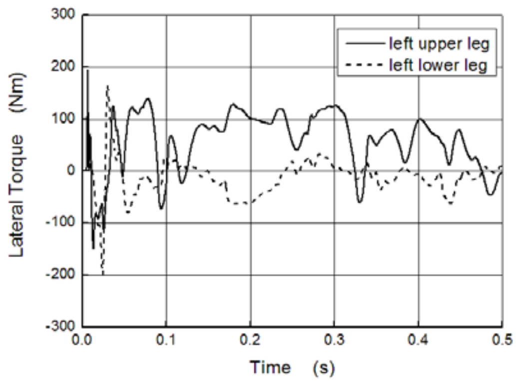



Fig.9 Lateral torque of left lower extremity

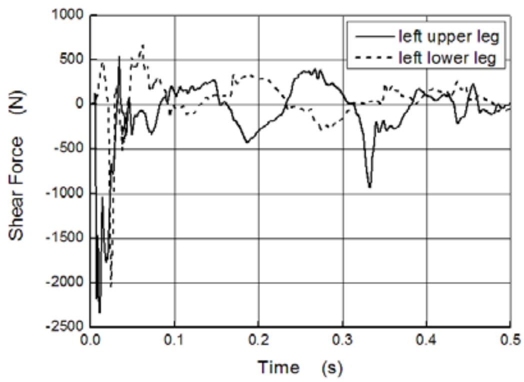



Fig.10 Shear force of left lower extremity

Table 1 Pedestrian injury analysis of Case 1

| Body region | Autopsy results | Injury criterion value | Tolerance level |
|---|---|---|---|
| Head | Fatal injury | HIC36＝3917 | 1680, 50％ prob. of AIS 3+ |
| Chest | No serious injury | VC=0.1m/s | 1m/s, 50％ prob. of AIS 3+ |
| | | ASA20=2.3g | 46g, 50％ prob. of AIS 3+ |
| Left upper leg | No fracture | max lateral torque 195Nm | 430Nm, 50％ prob. of fracture |
| | | max shear force 2340N | 6300N, 50％ prob. of fracture |
| Left lower leg | No fracture | max lateral torque 200Nm | 285Nm, 50％ prob. of fracture |
| | | max shear force 2040N | 4000N, 50％ prob. of fracture |

### 3.3.2 Case 2

With the above-mentioned known conditions, PC-Crash optimizes vehicle speed based on both vehicles' intermediate and rest positions and rotations. The impact velocity of the truck and the bus were calculated to be 25 and 50 km/h, respectively. The truck's velocity before braking is 62 km/h. The total trajectory of two vehicles is shown in Fig.11.

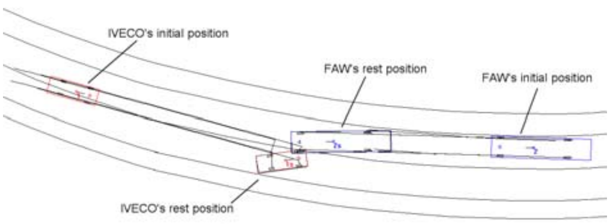
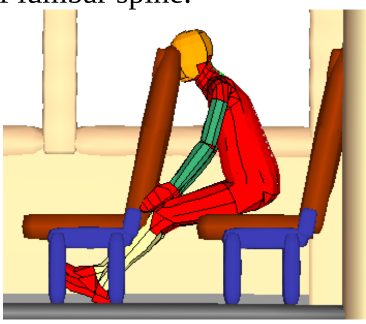
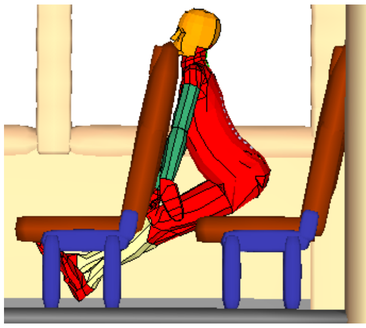



Fig.11 Calculated trajectory of the two vehicles

The linear acceleration and angular velocity of the bus C.G. are outputted for the next simulation. Then, the occupant kinematics is calculated as shown in Fig.12 and 13. According to these results, the lumbar spine mainly sustained compress force during the accident. The max axial force between the 2nd and 3rd lumbar vertebra (Fig.14) exceeds the tolerance level 2kN from some previous research. So, the simulation corresponds well with the fact that the occupant sustained the fracture of lumbar spine.



(a) t=50 ms



(b) t=100 ms

Fig.12 Movement of the occupant at 0, 50, 100 ms after impact

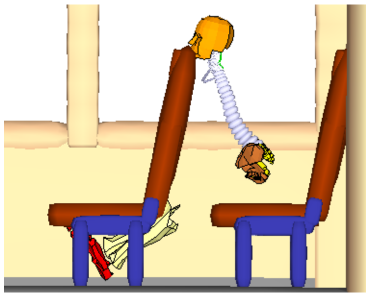


Fig.13 Status of the spines at 100 ms after impact

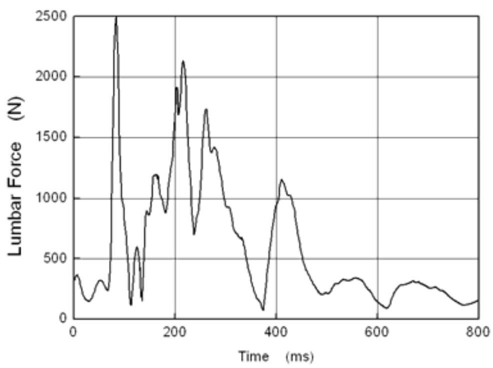



Fig.14 Axial Lumbar force during the accident

## 4 Conclusion

The analysis indicates that the selective application of multi-body dynamics simulations and the combination of using both multi-body dynamics modeling and trajectory optimization is an effective method for reconstructing real-life bus-involved traffic accidents. The results coincide well with the records provided by traffic police and the conclusions of investigations given by legal medical experts in the terms of vehicle skid length, estimated vehicle trajectory during crash, vehicle stop state after collision and parameters of body injuries.

The methods applied in the research, which integrate the trajectory optimization into multi-body dynamics analysis, prove to be efficient and effective in the reconstructions of bus accidents due to the reduction of time cost and more accurate simulation results corresponding to the practical situation of the accident scene. The results of the current study also show that the victim's injury parameters can be introduced to assist in verifying the multi-body dynamics and trajectory optimization as feedback.

Preliminary works shows that some improvements need to be made to these models in order to improve the accuracy of the simulations by substituting well-shaped finite element models of some parts of the interior ornaments for multi-body ones. The study presented in this paper can also be developed as a helpful approach in designing the interior decorations of vehicles for occupant safety in the future.

In summary, the real-life bus accident has been investigated in this study. And we successfully extend a collection of selective combined methods into the field of the road traffic accident involving bus impact in the research. Further more, the main disadvantage of using a single Multi-body dynamics analysis is that there perhaps exist varieties of possibilities that common single method can not distinguish one from another on the ground of the lack of condition limits of simulations. However, if evaluations of victim injury parameters and trajectory optimization can be incorporated into the original Multi-body dynamics analysis, the results of simulations will be more accurate and reliable.

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