

# Crash Reconstruction of Mixed-Vehicle Collision Using PC-Crash

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## Abstract

Road traffic crashes are a leading cause of injury and property damage worldwide, which has disclosed the need of taking systematic and precise reconstruction techniques. This paper presents the simulation of real-world road crash between a minitruck and a motorcycle using PC-Crash Software. The reconstruction followed a structured four stage workflow, i.e. the reconstruction of the accident scene, Vehicle modeling, crash simulation, and iterative validation. Calibrated simulations established pre-impact speeds of 34 km/h for the minitruck and 18 km/h for the motorcycle, with post-impact rest positions and vehicle orientations showing strong correspondence with physical scene evidence. Most significant dynamic parameters such as head acceleration, contact force and energies were obtained to describe the severity of collisions. The motorcycle was modeled as a complete multibody system including the biomechanical aspects of the rider, which allowed to simulate the realistic behavior of a human body during the impact event. The results show that PC-Crash can be very appropriate in reconstruction of mixed-vehicle collisions within the context of low- and middle-income countries like Nepal, where crash databases are not centralized, and field evidence is represented by police documentation.

*Keywords:* Crash Reconstruction, PC-Crash, Vehicle Dynamics, Road Safety

## 1. Introduction

Traffic safety is a major concern in the present global context. Road crashes are one of the most important factors of injury, death and property damage, impacting millions of lives globally. As per WHO (2023), road traffic crashes claimed the lives of 1.19 million people in 2021, equivalent to 15 deaths per 100,000 population. Low- and middle-income countries account for the deaths of most people in road traffic collisions (about 92%), largely because of inadequate road safety infrastructure and the enforcement of traffic laws. In 2024, Nepal registered 242,441 vehicles, with motorcycles alone accounting for 80.9% of total registrations due to their affordability and suitability for the country's challenging terrain (Department of Transport Management, GoN, 2025). Nearly 160,000 road traffic crashes occurred in Nepal from 2015 to 2024, killing 23,900 people and leaving 50,000 seriously injured (Ghimire et al., 2025; Nepal Traffic Police, 2024) - an average of seven deaths and 83 injuries each day. Estimated economic impact is 1.5 - 2% of GDP, more than national health expenditure for 2021. With these trends, it is now essential to use systematic crash analysis and computational simulation tools like PC-Crash to gain insight into collision patterns, severity of injuries, and to identify targeted safety interventions.

Crash reconstruction is an essential element of road safety research, which offers systematic and technical basis to the study of collision mechanics, identifying contributing factors, and informing both engineering interventions and policy decisions. In high-risk traffic environments for two wheelers such as Nepal, reliable reconstruction methodologies are critical for understanding crash occurrences and designing targeted safety interventions. Conventional analytical or field-based reconstructions are constrained by missing scene evidence, measurement errors, and the lack of capability to test alternative collision hypotheses. These restrictions are especially acute in mixed-vehicle collisions where significant disparities in mass, geometry, and structural stiffness can generate complex pre- and post-impact dynamics that are difficult to resolve through manual calculation alone. These restrictions lead to the necessity of the development of sophisticated simulation tools that can provide detailed, repeatable and physically reliable analysis.

PC-Crash, developed by Dr. Steffan Datentechnik GmbH (DSD), is a complex vehicle dynamics and crash reconstruction software designed to meet the need for more accurate computational analysis of road traffic crashes (Steffan & Moser, 2011). The software incorporates multi-body dynamics and the impulse-based collision model of Kudlich and Slibar which calculates the momentum exchange between vehicles based on pre-impact kinematic conditions and vehicle geometry, along with a parameter set of restitution coefficients and friction parameters (Moser et al., 1999). The application of PC-Crash for research, forensic investigations, and educational uses may be suitable, due to its ability to show crash sequences and to simulate the input of measured field data and the analysis of different variations of scenarios.

Considerable studies have utilized PC-Crash to test different types of collisions proving its applicability in both vehicle-vehicle and vehicle-vulnerable road user studies. Zhang et al.(2014) developed a systematic approach for PC-Crash to simulate vehicle to vehicle interactions and they found that the pre-impact velocity and stiffness coefficients of the collision model of Kudlich (1966) and Slibar (1966) can be iterated to replicate post-impact vehicle kinematics with reasonable accuracy. Zou and Zhang (2013) explained the uncertainty in the simulation outputs, Kong-kang (2008) validated the applicability of PC-Crash as a quantitative crash reconstruction tool by showing its capability to reproduce pedestrian throw distance and impact dynamics in the case of vehicle-pedestrian collisions, provided that input parameters are carefully set. Zou et al. (2010) extended this study by identifying statistical regularities in vehicle-pedestrian collision simulations, and then Zou et al. (2011) compared pedestrian trajectory modeling in PC-Crash with physical evidence, further demonstrating the reliability of PC-Crash as a forensic reconstruction tool. Studies involving motorcycles have also progressed. Zhao et al. (2022) used PC-Crash to reconstruct cyclist and electric bicycles crashes explaining how multibody models were able to produce physically representative injury estimates. Similarly, wang (2019) used detailed human body models to study injury responses of riders on motorcycles and the injury patterns among motorcycles and e-bike riders have been studied through national accident databases and PC-Crash simulation

Although this wide range of applications is available, the available literature is based on either the targeted types of impacts, such as mostly side impacts, or on a single type of vehicle and little has been done on the data constrained phenomena of the low- and middle-income states including Nepal. The field of mixed-vehicle crashes between light commercial vehicles and motorcycles is a relatively under-researched area of the crash reconstruction field, especially when lacking a centralized crash database and instrumental recording devices for crash investigations.

## **2. Crash Case Introduction**

The crash occurred in the morning of 2022 on Kathmandu Ring Road between a fully loaded minitruck and a motorcycle with a rider and a pillion passenger. A fully loaded minitruck was moving along the road, tried to overtake slow moving vehicle by moving into the right lane when it collided with a two-wheeler causing considerable structural of damages to both vehicles. Both two-wheeler occupants sustained severe injuries while the minitruck driver sustained no injuries. Reconstruction was limited to secondary documentary evidence sources, with official police reports used to set up the PC-Crash simulation including the vehicle specifications, damage patterns, rest positions, skid mark geometry and scene measurements as boundary conditions and validation benchmarks. Measurements and photographic records of the scenes were done by the authorized police officers totally; the researchers did not conduct any measurements independently in the field. The case is noteworthy in that it involves a common but under-studied collision type in Nepal, and that it proves forensically credible reconstruction is possible in a very evidence-limited setting, with important implications for road safety practice where instrumental crash recording is underdeveloped.

## **3. Methodology**

### **3.1 Data collection**

In the lack of a centralized crash database in Nepal, data were collected to support this study using official police records. These sources provided essential information, including type of crash, time of occurrence, vehicle identifications, rider details, helmet usage, injury descriptions. Where available, supplementary data on road geometry, vehicle deformation and collision points were included. Missing vehicle specifications were sourced from verified manufacturer documentation and official technical databases. All scene documents were conducted

by the officials; the researchers performed no independent field surveys. The collected data were reviewed for internal consistency and completeness prior to use, ensuring the dataset was sufficient to support a credible reconstruction.

### 3.2 Vehicle modeling

The information in the official records about the vehicles was compared to the PC-Crash database and in the case, it had no exact models, similar vehicles were adjusted with parameters like mass, dimensions, and wheelbase altered in such a way that they reflected the actual car dynamics as in the Figure 1 a. The diversity of vehicle library at PC-Crash could simulate the physical characteristics and behavior of motion so that collision re-creation would be accurate and visually realistic. Similarly multibody human vehicle model was integrated into PC-Crash environment to realistically model the occupant motion and response throughout the crash incident. The model comprised rigid body segments representing major anatomical regions, connected by articulated joints that permit flexion and movement consistent with human biomechanics (Moser et al., 1999) as shown in Figure 1 b. Each segment was assigned mass, dimensions, and a center of gravity based on standard anthropometric values; the total model represented a typical adult of 70 kg and 170 cm, consistent with available records.

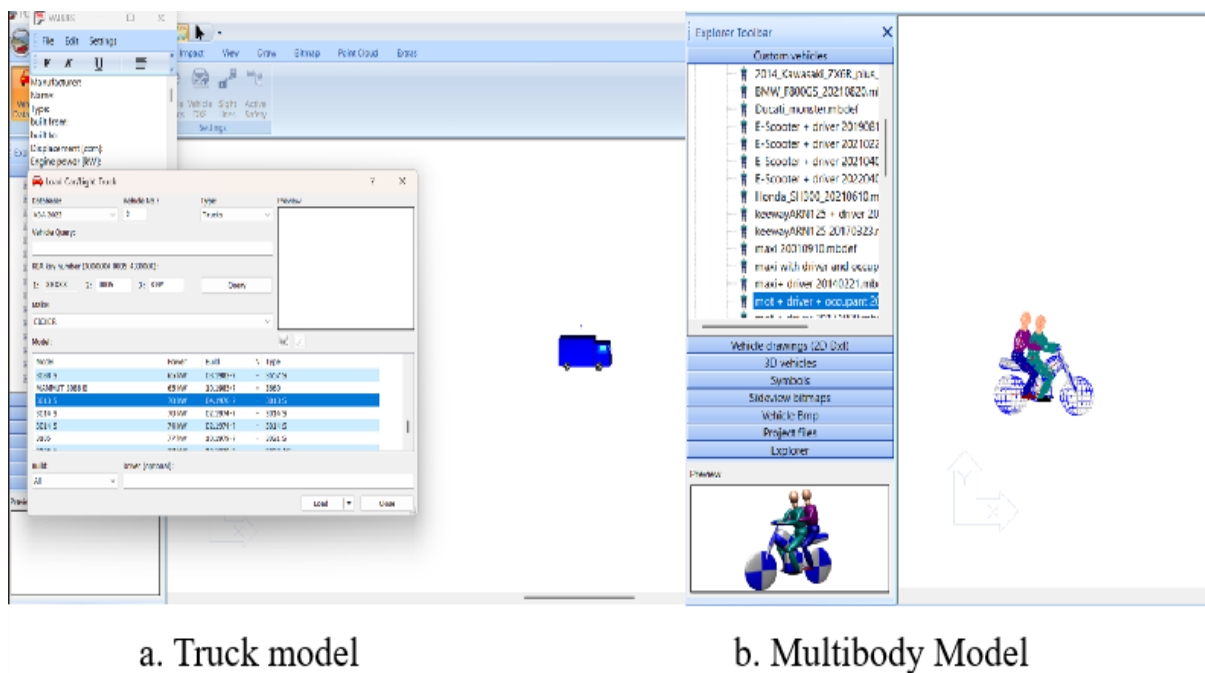


Figure 1 Vehicle model selection from database

### 3.3 Vehicle setup and data

The motorcycle and minitruck were modeled in PC-Crash using DSD database vehicles that best matched the requirements available in the official records. Critical parameters of vehicle dynamics, such as curb weight, center of gravity, ABS setup, wheelbase, and axle geometry were tuned to produce realistic motion behavior, without altering standard geometry or suspension inputs. The minitruck was then suspended more rigidly and engine power and torque values were added to reflect the pre-impact acceleration of the mini truck. Linear tire models defined tire properties, such as type, dimensions and spacing, to provide computationally stable and reliable braking performance as shown in Figure 2

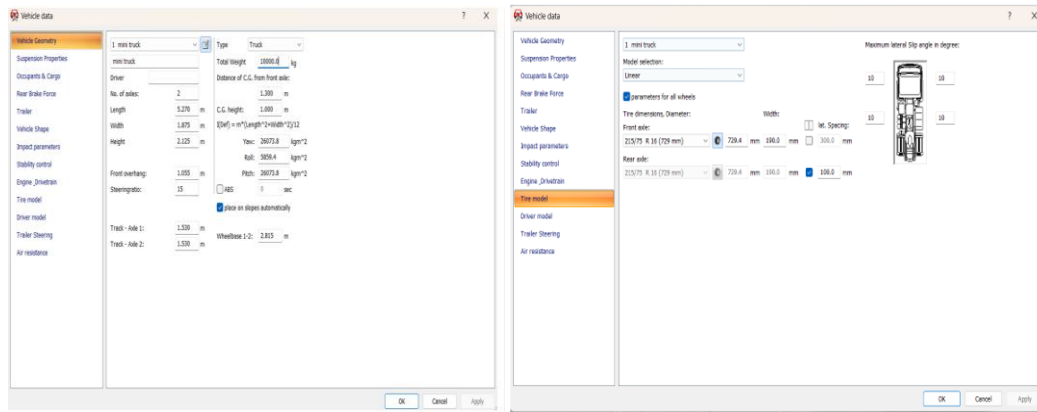


Figure 2: Vehicle parameter input box

### 3.4 Dynamics modeling

In PC-Crash, the collision event occurred by means of a single and permanently evolving simulation that blended the pre-impact and post-impact vehicle motions. The realistic driver dynamics were included by specifying the sequential control inputs of acceleration, braking and steering during the entire event and thus provided an overall picture of vehicle behavior during the initial approach to the final rest positions.

In the absence of verifiable instrumental speed data, an iterative calibration strategy was adopted. Simulations were initialized at an initial velocity of 35 km/h as a conservative baseline and iteratively refined, converging on pre-impact speeds of 34 km/h for the truck and 18 km/h for the motorcycle. Input parameters were systematically refined across successive runs until the simulated vehicle final positions, motion trajectories, and deformation patterns converged with the physical evidence documented at the crash scene. Figure 3 shows the dynamic control inputs, comprising acceleration of the truck, lane change steering, and braking control and the motorcycle emergency response, which were tuned iteratively to reproduce realistic driver reaction behavior consistent with the documented scenario.

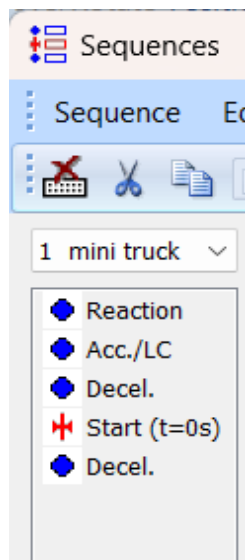


Figure 3: Impact motion sequence box

Lane-change maneuver of the minitruck was determined as a crucial aspect that affected the reconstruction accuracy. Longitudinal acceleration was set to  $1.0 \text{ m/s}^2$  and a rightward lane change was performed within 3.25 s (Figure 4). Motion steering was simulated by 3.8 m lateral movement, which is equivalent to the largest lateral acceleration of  $4.0 \text{ m/s}^2$  and a steering angular velocity of  $5.0 \text{ deg/s}$ , representing a desperate move. The braking parameters chosen with the data of the RTA crash database were used in order to provide realistic braking deceleration and wheel-specific braking response, avoiding tire lockup or failure.

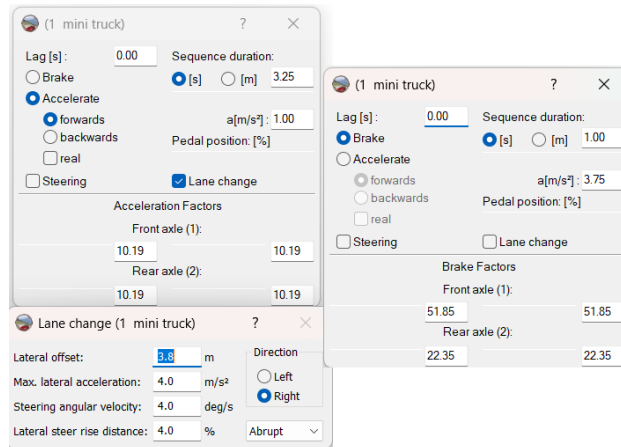


Figure 4: Pre-impact sequence box

### 3.5 Impact

At the impact phase, the motorcycle multibody system and truck model were placed at the identified POI to simulate the crash event. Initial contact conditions were assigned based on pre-impact speeds of 35 km/h for both vehicles. A coefficient of restitution of  $e = 0.1$  and friction coefficient of  $\mu = 0.6$  (S. Wang et al., 2014) were applied to reflect typical road and contact surface conditions, consistent with PC-Crash standard values for this class of collision.

The simulation was run iteratively, with post-impact velocities and final rest positions compared against documented physical evidence after each simulation. Iterations continued until simulated post-impact kinematics and final rest orientations converged with the recorded scene evidence. The motorcycle was modeled as a complete multibody system with integrated rider biomechanics, allowing for a physically representative response of the human body during and following the impact. The POI location determined from this process is illustrated in Figure 5.

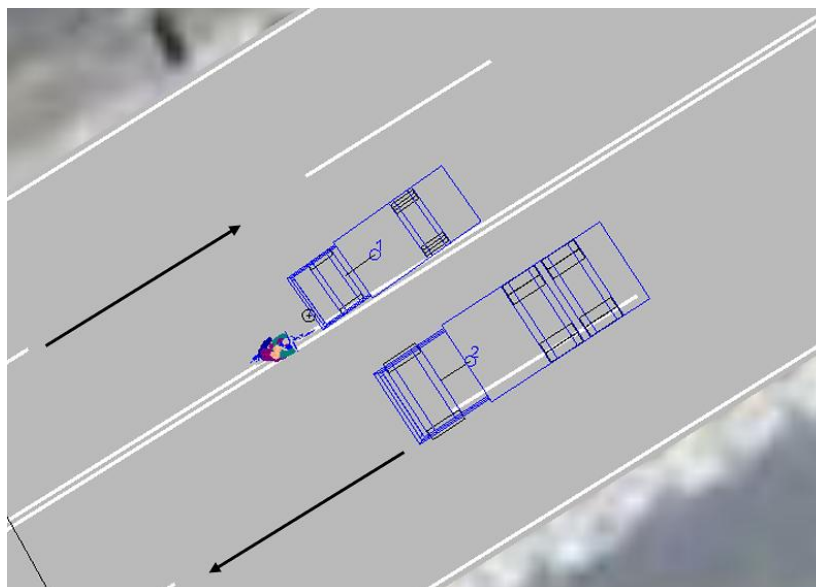


Figure 5: location of impact point

### 3.6 Validation

Validation of the reconstruction was carried out by systematically comparing the results of the simulation to the physical evidence found that was documented in the official police records. The accuracy of reconstructed model was assessed based on four main parameters;

### **3.6.1 Crash location and point of impact**

The point of impact simulation was compared to physical evidence markers at the crash scene. The spatial coordinates obtained from the simulation were compared with the official police report to validate positional accuracy.

### **3.6.2 Vehicle motion**

Vehicle paths were modified to achieve the proper spatial and temporal alignment at the collision site. The minitruck's trajectory included an overtaking move (lateral translation of about 3.5 m, or equivalent to a sudden lane change to overtake a slower vehicle). This adjustment enabled the relative position, approach vector and the timing of both cars to intersect correctly at the point of collision, as indicated by physical evidence and documentary evidence.

### **3.6.3 Post-crash position**

The accuracy of the calibration was evaluated by comparing the resting positions obtained after the impact with the values in the official police report. The truck stopped at 11.0 m from the collision point and the rider was thrown 12.4 m from the impact point. The simulated rest position using the calibrated simulation was found to be 10.8 m and 12.1 m, which gave absolute errors of 0.2 m (1.8%) and 0.3 m (2.4 %), respectively. These deviations are within the allowable  $\pm 5\%$  range of PC-Crash reconstruction, which proves the good validation of the impact parameters and simulation.

### **3.6.4 Damage zone analysis**

Both vehicles impact areas were compared to descriptions in the police report to confirm simulated impact locations and damage severity. The motorcycle had extensive frontal damage and the truck had moderate damage to the headlight on the left side. The average magnitudes for the forces of contact for the motorcycle components were much greater than the forces for the minitruck components, and this was a reflection of the degree of damage as mentioned in post-crash vehicle inspection report. There was minimal photographic evidence but the locations of the damages and force levels were sufficiently close to what has been reported, which supports the validity of the reconstruction.

The lack of instrumental data sources (such as Event Data Recorder (EDR) outputs and speed camera videos) made it impossible to use independent velocity validation methodologies. Conversely, a systematic iterative calibration approach was used, where speed parameters for the pre-impact conditions were iterated based on convergence of evidentiary constraints from both spatial, orientational and damage. This multi-criteria calibration method thus served as the primary evidence-based validation model for the reconstructed collision scenario.

## **4. Result and Discussion**

### **4.1 Overview**

A physics-based kinematic and dynamic simulation of motorcycle-minitruck crash was performed in the PC-Crash multibody simulation environment. The incident described was a two-occupant motorcycle travelling on an urban carriageway when it collided with a minitruck, resulting in severe head injuries. The boundary condition inputs were obtained from official documentation, georeferenced satellite Google maps and the PC-Crash integrated vehicle dynamics database. The fidelity of the reconstruction was developed through a systematic iterative process of progressively refining pre-impact velocities, impact vectors and contact geometry until reconstruction results of post-impact trajectories, final rest positions and crush damage patterns matched available physical evidence.

### **4.2 Key reconstruction outcomes**

The calibrated simulation resulted in pre-impact velocities of 34 km/ph and 18 km/ph for the minitruck and motorcycle, respectively. Pre collision kinematic analysis showed that the minitruck accelerated forward at a rate of 1 m/s<sup>2</sup> and then suddenly moved to change lanes to the right, resulting in a lateral offset of 4 m and a peak lateral acceleration of 4 m/s<sup>2</sup> in an attempt to pass another slow-moving vehicle. The reconstructed impact point was 0.6 m into the motorcycle's designated travel lane from the solid double centerline marking, which confirmed lane boundary encroachment by the minitruck. Post-impact rest positions were about 10 m and 12 m away from the impact point for the minitruck and the motorcycle, respectively, which was consistent with police scene

documentation. Contact force analysis showed that the impact forces recorded on the motorcycle were higher than those recorded on the minitruck, which was supported by case recorded vehicle damage evidence.

### **4.3 Discussion**

The results validate the effective applicability of PC-Crash to mixed-vehicle collision reconstruction, when input parameters are carefully defined and systematically calibrated. Pre-impact velocities of 34 km/h for minitruck and 18 km/h for motorcycle, were determined using a multi-criteria iterative calibration procedure, in which outputs from the simulations were compared to spatial, orientational and damage-based physical evidence. The significant difference in contact forces between the two vehicles is physically consistent with the differences in mass and structural stiffness between the vehicles, and directly confirms the severity of the injuries sustained by the motorcycle occupants of the collision and the biomechanical vulnerability of motorcycle users in heavy goods vehicle collisions at urban speeds. The post impact rest positions, orientations of vehicle and rider, and ejected trajectory of the rider were all in close agreement between simulation and police documented and contributed to the confidence in the kinematic reconstruction. The collision dynamics described in the simulation are subject to uncertainty, mainly related to assumptions made about vehicle stiffness and the simplified tyre-ground interaction model used in PC-Crash, which are inherent limitations and should be taken into account when interpreting the estimated collision dynamics.

### **5. Conclusion**

The given research has shown the effectiveness of PC-Crash to reconstruct and simulate mixed-vehicle crashes in data-limited situations. Besides accurately modelling the complete sequence of impact, such as pre-impact vehicle motion, the geometry of an impact point and the post-impact speed and rest positions, the simulation also converged on the final positions simulated within the range of about 0.3 to 0.5 meters over the recorded scene data. Mechanically consistent representations of the severity of the collision are provided by calibrated pre-impact speeds of 34 kmph of the minitruck and 18 kmph of the motorcycle along with extracted impact force and energy dissipation measures. The use of a multibody rider model also helped in the realistic simulation of the occupant kinematics during and after impact, thus giving significant information on the mechanisms of injury causation. This evidence supports the suitability of PC-Crash to forensic crash investigation and traffic safety evaluation. The method should be further strengthened by independent modeling of the pillion passenger, sensitivity analysis of the key input parameter. Future research should focus on validating reconstruction outputs using instrumentally measured crash data, where available

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