A Road Crash Reconstruction Technique

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Abstract

The purpose of reconstruction is to identify the critical factors involved in a road accident like pre-impact direction and velocities of colliding vehicles. In this work, two cases of crashes have been studied and reconstructed namely (1) Crash involving a truck with a Wagonr™ and (2) Crash involving a bus with a motorbike. A new methodology has been developed to collect the crash data systematically and the procedure has been implemented in the case studies. PC-Crash, software for modeling and simulation of accident reconstruction, is used in the case studies.

Keywords*:* crash reconstruction, Road crashes, PC – Crash

INTRODUCTION

The need for study of accidents is emphasized to know the cause of the accidents to enhance and modify the design of automobiles to cater to the growing demand of safe transportation. Another area, in which accident reconstruction is used, is in the area of litigation and insurance claim as carried on in some countries. Accident investigation has also been used in both criminal and civil litigations. A team of trained investigators examines each fatal case; many times, more information is needed. So the reconstructionists perform a detailed in-depth probe. The reconstruction helps the prosecuting attorney to make a decision concerning the criminal action to be taken against the driver of the vehicle. In India, not a significant progress has been done in accident reconstruction techniques. Hence the requirement exists for developing and practicing the reconstruction techniques systematically. The present work is an attempt to fulfill this need. The purpose of reconstruction is to identify factors that are critical in a road accident like pre-impact direction and velocities of colliding vehicles. Detailed investigation of crash site is made. Suitable models are developed for modeling the vehicles. PC- Crash package is used for simulations. The procedure is iterative in nature as explained later in the paper.

METHODOLOGY

A crash reconstruction exercise involves the following steps: -

- Preliminary investigation and measurement at the crash site
- Collection of forensic data
- Preparation of scaled drawings detailing accident site and relative locations of damaged vehicles
- Modeling of vehicles, pedestrians and vehicle - occupants
- Computer simulation

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Preliminary investigation of the crash site

The site of crash does not remain unaltered for lon after the crash. Hence it becomes important to collect the data from the site as soon as possible after the crash. This data includes site layout, road furniture details, road condition details and site photographs. IN addition, information is collected from witnesses, victims and police personnel. A reference point is established at the site of crash to serve as a basic reference point from which all the measurements are taken. The parameters to be measured from the site of crash include skid marks of the colliding vehicles, point of impact (POI) of the colliding vehicles, final resting position of the vehicles, debris found on the site, parked vehicles in the vicinity of the site, speed breakers around the site, lane marking on the roads, road dividers, poles and traffic lights on and near the crash site and details of buildings, walls, hoardings trees and other road furniture. These parameters are then used as inputs for modeling and simulation of the crash.

Collection of forensic data

Besides the above mentioned parameters the data from police and medical departments is also collected. The police reports include investigation results of police department. The medical report contains details of injuries of the victims

Preparation of scaled drawings

A drawing is prepared with a suitable scale on a paper. All the details, which have been collected, are drawn on the paper. This serves as a preliminary sketch for the final simulation work.

Modeling of vehicles, pedestrians and vehicle – occupants

Some default models of vehicles and pedestrians etc are available in PC–Crash software. However, if a custom built vehicle is to be simulated, then its modeling is necessary. For custom built vehicles, dimensional parameters are to be changed in the package itself to generate the models of the vehicles. The modeling of pedestrian and vehicle-occupants are done with the help of the measured physical dimensions.

Computer simulation

Purpose of simulation is to predict the pre-impact direction and velocities. But for simulation we need to give pre-impact direction and velocities as input for the package. Initially we predict the approximate pre-impact direction and velocities with measured crash data and will be used in simulation. The pre-impact direction and velocities are varied in an iterative fashion such that the simulation data will be tangible to that of actual crash data. Hence the procedure is iterative in nature. The measured data is used for comparison of the simulation and actual crash.

CASE STUDIES --- CASE 1: CRASH INVOLVING A TRUCK WITH A WAGONR^{TM}

The site of crash was a road crossing at which two straight roads intersected at right angles. It was a wide road with usually a modest traffic. There was no circular junction at the intersection of the road. All varieties of vehicles ply on the road network.

Description of the crash:

The Wagonr^{TM} was traveling on a straight road and was approaching a road crossing when it was struck by the truck, which was also approaching the same crossing, but from the perpendicular direction. Some digital photographs of crash site have been taken and are given in Figure 1(a) to Figure 1(e). Apparently, the right front of the truck hit the left front side of the Wagonr^{TM} and it dragged the Wagonr^{TM} with it for a distance of approximately 2 meters from the Point of Impact (POI), Figure 1(a). After this, both vehicles skid away from each other. Finally, Wagonr^{TM} came to rest at 31 m and truck at 34 m from POI. All the required parameters are measured on the crash site. This crash proved to be a fatal one as it claimed one life while another victim was seriously wounded. The Wagonr^{TM} was badly damaged while the truck survived with minor damages. This again indicates the effect of larger inertia on the behavior of the vehicles colliding. Detailed scaled drawings of crash site have been developed and reported in Figure 1(f).

The model for simulation of dynamic performance of the vehicle needs data like weight of the vehicles, location of the centre of gravities of the vehicle, vehicle dimensions like length, wheel base track width, height of the vehicle etc, yaw, Pitch and Roll moments of inertias of the vehicle, coefficient of friction between tyre and road interaction, and coefficients of restitution and friction of the colliding bodies.

The calculation / estimation of the above critical parameters is discussed as follows:

Weight of the vehicles

Weight of the Wagonr™, 940 kg has been taken from manufacturer's catalog. At the time of crash, three persons, aged above 18 years, were traveling along with the driver in Wagonr™. The average weight of each person has been taken 60 kg. Hence, total weight on the Wagonr™ was 1180 kg. The measured unladened weight of the truck was 8000 kg; at the time of crash, the truck was empty and one person was traveling in truck along with the driver. Hence, the total weight of the truck during crash was 8120 kg.

Figure1(a) Crash site showing (1) Skid marks of truck (2) Skid marks of Wagonr™ (3) Point of impact (4) Rest position of Wagonr™ (5) Rest position of truck

Figure1(b) Crash site showing complete skid marks of truck movement

Figure1(c) Final damaged view of Wagonr™

Figure1(d) Final damaged interior view of Wagonr™

Figure1(e) Final toppled position of truck

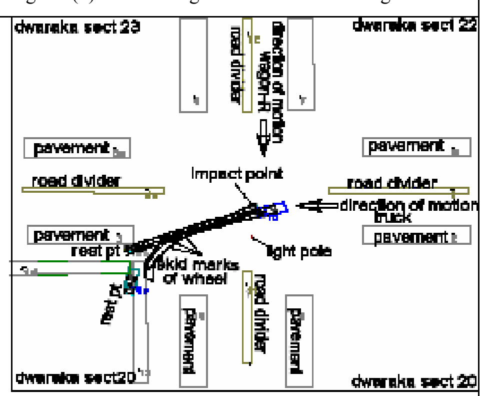

Figure1(f) Scaled drawings of crash site 1

Figure 1: Pictures and sketch for the Wagonr™ – Truck accident

Location of the centre of gravities of the vehicles

The calculation of the CG differs for the same vehicle with different loading condition. It is very difficult to calculate the exact location of the CG of the vehicle. The location of the CG has been taken from Heydinger and Bixwl (2001)[1] and the height of the CG from ground is taken as 0.55 m while the distance of the CG from front axle is 38 % to 45 % of wheelbase and is taken at 40%. The CG location for heavy vehicles is not available in the literature. Based on approximate weight and its distribution, the location of CG has been calculated and has been taken as 1.1 m above the ground and the distance of the CG from front axle is taken as 2.0 m (wheelbase is 4225 mm).

Dimensions of the colliding vehicles:

The various dimensions of the vehicles are measured from the actual vehicles involved in crash.

Moment of inertia of the vehicles:

It is also very difficult to calculate the various moments of inertias of the vehicle because it depends on the loading condition, shape of the vehicle, its CG location and the mass distribution of the vehicle. The empirical relation[2], which is used to estimate the vehicle mass moment of inertia, depends on several parameters, like center of gravity height (CG in m), overall length of the vehicle (L in m), mass of the vehicle (M in kg), roof height (RH in m), track width (TW in m) and the wheel base (WB in m)

The moments of inertia of a vehicle about its center of gravity are calculated by the method presented by Garrott[2] . For the Wagonr™, the data

CG= 0.55 (m)

L = 3.4 (m)

M = 1180 (kg).

RH = 1.6 (m).

TW = 1.3 (m)

WB = 2.35 (m)

Yaw moment of inertia Izz = 1573.31 kg-m^2

Roll moment of inertia I_{XX} = 386.36 kg-m^2

Pitch moment of inertia I_{YY} = 1524.89 kg-m^2

For the truck these values are:

CG= 1.1 (m)

L = 8.6 (m)

M = 8120 (kg)

RH = 2.9 (m)

TW = 2.4 (m)

WB = 4.225 (m)

Yaw moment of inertia Izz = 54168.6 kg-m^2

Roll moment of inertia I_{XX} = 9203.8 kg-m^2

Pitch moment of inertia I_{YY} = 53668.6 kg-m^2

Coefficient of friction between tyre and road interaction:

Friction coefficient between road and tyre is also important to know the behavior of the vehicles. Experiment has been conducted to calculate the coefficient of friction between road and vehicle tyre. Two different types of experiment have been conducted, first one was between road and new tyre and second one was between road and old tyre. Friction coefficient between new tyre and road was found 0.72. Friction coefficient between old tyre and road was found 0.67.

Coefficient of restitution and coefficient of friction of colliding bodies:

From the crash scene, the physical damage in the colliding vehicles is large, indicating a large energy loss and a small coefficient of restitution. Coefficient of restitution has been taken e=0.1 as per Brach[3] and Coefficient of friction between the colliding bodies has been taken 0.5[3] for oblique impact.

Calculation of the initial velocities of two vehicles

Step one: Wagonr™ is referred as vehicle 1 and truck as vehicle 2. Let u_1, v_1, be the velocities of vehicle 1 before and after impact and let u_2, v_2 be the velocities of vehicle 2 before and after the impact. Velocity lost due to skidding, is calculated using the relation $v = 15.97\,(S\,\mu)^{1/2}$, where S is in meters and "v" in km/hr. The skid marks for vehicle 1 and vehicle 2 after impacts are respectively 12 m and 31.4 m.

For vehicle 1, post-impact velocity is,

$$v_1 = 15.97\,(S_1\mu)^{1/2}$$

$$v_1 = 44.67 \text{ km/hr}$$

Similarly, for vehicle 2, post-impact velocity is

$$v_2 = 15.97\,(S_2\mu)^{1/2}$$

$$v_2 = 65.7 \text{ km/hr}$$

Step two: Assume that the two vehicles collides each other at approximately 90-degree. The final position of Wagonr™ and truck made an angle from x-axis θ_1 = 10 degree and θ_2 = 41 degree respectively from the actual crash scene. Pre-impact velocities of vehicles (u_1, u_2) are calculated as follows:

Using law of conservation of linear momentum along x-direction,

$$m_2\, u_2 = m_1\, v_1 \cos\theta_1 + m_2\, v_2 \cos\theta_2$$

It is assumed that the both vehicles are making angles θ_1 and θ_2 with x-axis.

$$u_2 = 73.56 \text{ km/hr}$$

Using law of conservation of linear momentum along y-direction

$$m_1 u_1 = m_1\, v_1 \sin\theta_1 + m_2\, v_2 \sin\theta_2$$

$$u_1 = 35.62 \text{ km/hr}$$

Simulation Results

Simulation is done in PC-Crash. Models for vehicles are developed. The initial velocities from the above equations are given as the initial input velocities (u_1 = 35.62 km/hr, u_2 = 73.56 km/hr) in PC-crash. The prediction of final position of the two vehicles in PC crash is different from their actual final position. One possible reason could be the energy loss during impact by plastic deformation of two colliding bodies is not appropriately considered in calculations of pre-impact velocities. Incorrect calculation of the various input parameters or limitations of the software could also be a probable cause of difference in the final position of vehicles.

Since the inputs parameters have been estimated empirically, there is a lot of uncertainity in these values. These parameters like the initial velocities and directions of impact were then iterated upon so as to better match the recorded data. Figure 2(a) shows various positions of the two colliding vehicles which includes the position of the vehicle before impact, at the impact and at rest positions. The direction of motion of vehicles and its wheel trajectories has also been shown. Changes in velocities and the total distance traveled by both the vehicles are shown in Figure 2 (b). In this figure, A is the point where both the drivers started applying the brakes. Point B and C are the pre and post impact point of Wagonr™ respectively on the curve 4. At the point B the velocity of Wagonr™ is 58.4 km/h and at point, C it is 68.3.km/h. Point D and E are the pre and post point of truck respectively on the curve 2. The velocity of the truck at point D and E is 68.5 km/h and 62.1 km/h. The slope of the curve indicates the deceleration of the vehicles. Final toppled position of truck, Figure 1(e), obtained from simulation is different from that of actual crash Figure 1(e). From the Figure 2(b) various velocities of the vehicles are given below;

Pre impact velocities,

For vehicle 1 (Wagonr™) u_1= 58.4 km/hr

For vehicle 2 (truck) u_2= 68.5 km/hr

Post-impact velocities,

For vehicle 1(Wagonr™) v_1= 68.3 km/hr

For vehicle 2 (truck) v_2= 62.1 km/hr

And the direction between two vehicles θ= 75 degree

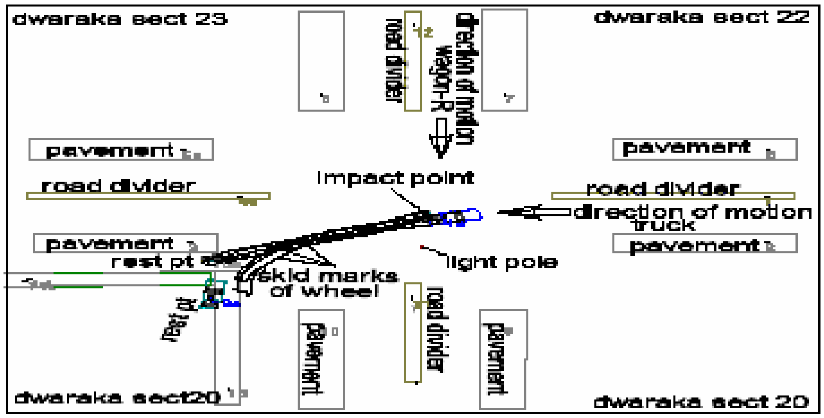

Figure 2 (a) Post impact positions of vehicles as obtained from crash reconstruction simulation

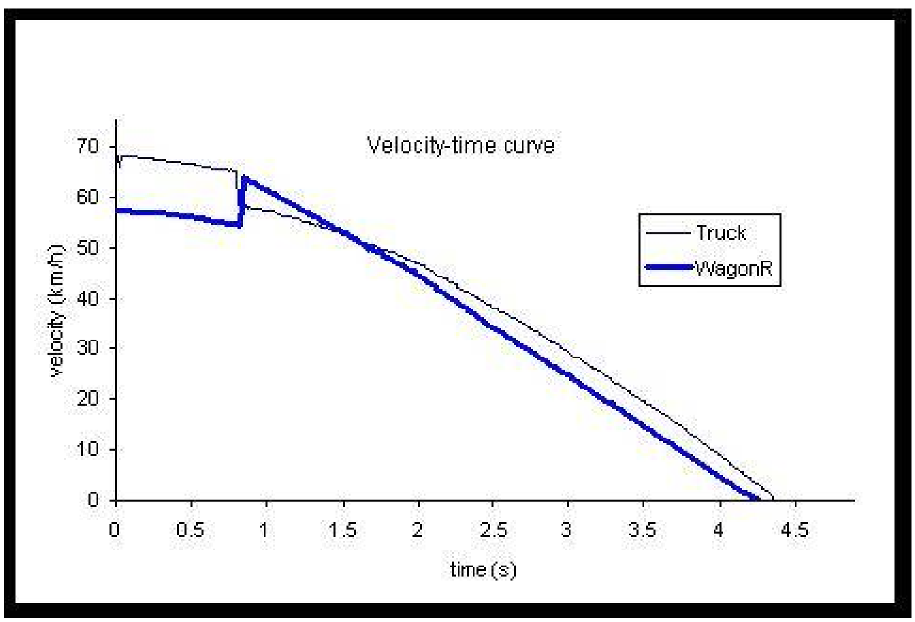

Figure 2(b) Velocity time history of two vehicles

Figure 2 Simulation results: (a) Post impact positions, (b) Velocity time histories

CASE (2) CRASH INVOLVING A BUS WITH A MOTORBIKE

In this case, the site was a busy spot. It was a straight road, with a heavy traffic plying on it. The road is a two-way road and has road-dividers between. The road has footpaths on both the sides. There is a traffic signal at some distance from the site, which is immediately followed by a bus stop

Description of the crash

A bus started from the red light and was accelerating towards the spot in consideration. Just ahead of the bus, a motorbike (A Hero-Honda model) was moving. The motorbike was immediately preceded by a moving auto-rickshaw. The auto-rickshaw suddenly applied brakes, the motorbike driver reacting to the sudden deceleration of the auto-rickshaw, to avoid any collision, overtook the auto-rickshaw on its right side.

However, the speeding bus tried to overtake the motorbike and hit it from right side. The motorbike skid along with the bus and stopped after skidding around 13.8 m. The motorbike rider got strangled with the front wheel and then dragged on road with motorbike, and eventually died on the spot Figure 3(d). The crash was fatal in nature claiming the life of the motorbike driver. The death of the victim was on the spot. The motorbike was heavily damaged from the sides where the impact took place Figure 3(a). The bus also had some small dents on the left front side bumper Figure 3(a, b). The site of the crash is sketched in Figure 3(e).

Modeling of vehicles has been done with the procedure given for the previous case.

Weight of the vehicles:

Weight of the bus, 8000 kg has been taken from manufacturer's catalog. At the time of crash, 20 to 25 persons were traveling in the bus. The average weight of each person has been taken 60 kg. Hence, a total weight on the bus was 9500 kg. The weight of the motorbike (Hero-Honda) has been taken 116 kg from manufacturer's catalog. Only driver was driving on the bike at the time of crash. Hence, the total weight on the bike during crash was 170 kg. The CG location of the bus has been estimated at a height of 1.1 m above the ground and at a distance of 40% of wheelbase from front axle.

The different dimensions of the bike are from its specification sheet (wheelbase 1235 mm, length 1980 mm, height 1060 mm). To estimate the CG location of bike, approximately lumped mass distribution of different major part of the bike has been taken. The CG location has been estimated at 0.62 m above the ground at 0.41 m from the frint axle (wheelbase 1235 mm).The other dimensions of the vehicle are measured from the actual vehicles that are involved in crash.

Moment of inertia for the bus has been estimated as in the previous case. The yaw moment of inertia *Izz* is estimated as 50672.5 kg-m^2, the roll moment of inertia I_{XX} as 9667.7 kg-m^2 and the pitch moment of inertia I_{YY} *as* 27112.72 kg-m^2.

Since the motor cycle is modeled as a multi-body system, the moments of inertias for each component are estimated and are defined separately along their different axis.

The value of friction coefficient has been taken from previous case. Between road and tyre, the coefficient of friction is 0.70. The values for coefficient of restitution and friction coefficient has been taken as that of previous case.

Calculation of the initial velocities of two vehicles

Figure 3(e) shows the scaled crash site. Bus is referred as vehicle 1 and motorbike as vehicle 2. The weight of the bike is negligible as compared to bus, so during impact, change in velocity of bus is negligible. Hence it is assumed that pre and post impact velocities of bus are same. The pre impact velocity of bus can be calculated by using skid marks of tyres of bus. From the crash scene, the length of skid mark (S) is 13.8 m. Using the Newton's law of motion and assuming final velocity is zero, $V = 15.97\ (S_1\mu)^{1/2}$, where 'S' is the length of skid marks in meter and 'V' is initial velocity of bus in km/h. The initial velocity of the bus is thus estimated at 47.8 km/h. The calculation of pre impact velocity of motorbike is difficult, because the skid marks is not available for that.

SIMULATION RESULT

Simulation was done in PC-Crash. Models for vehicles were developed. The prediction of final position of the two vehicles in PC-Crash simulation is different from their actual final positions. Because of the uncertainty in the estimation of the initial parameters, these parameters were iterated in an attempt to match the final recorded locations of the vehicles. For the simulation, where pre impact velocity of bus and motorbike were kept 41 km/h and 21 km/h respectively with angle of 30 degree between them are used, the simulation results match well with that of actual crash.

Figure3(a) Bus involved in crash

Figure3 (b) Crash spot

Figure3 (c) Damaged side view of motorbike

Figure3 (d) Damaged rear view of motorbike

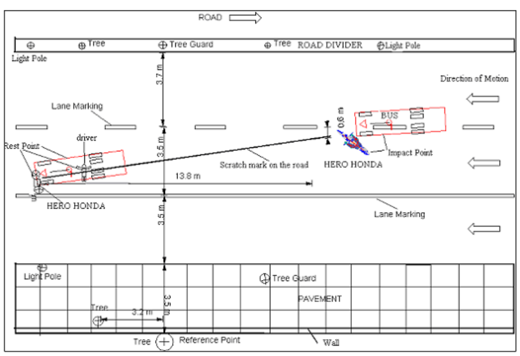

Figure3 (e) Scaled drawings of crash site 2

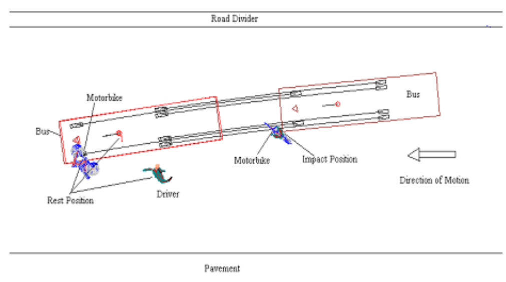

Figure3 (f) Various positions of two vehicles and their pre impact direction

Figure 3: Photographs and sketch of accident between Bus and Motor Cycle

Figure **3**(f) shows various positions of the two colliding vehicles. This includes the position of the vehicle before impact, at the impact and rest positions. The direction of motion of vehicles and its wheel trajectories has also been shown. The change in velocity of bus is shown in Figure 4. In this figure curve 1 shows the change of velocity of bus after impact. Slope of curve 1 shows the deceleration of bus during motion. In the same figure, the change in velocities of motorbike and its driver after impact are also shown. Curve 2 of Figure 4 shows the variation of speed. From Figure 4 pre impact velocity of the vehicles are given below Pre impact velocities of vehicles are as follows,

For vehicle 1 (bus), $u_1 = 41$ km/hr

For vehicle 2 (motorbike), $u_2 = 21$ km/h

Pre impact direction $\theta = 30$ degree

CONCLUSION

In present work it is shown that combining the studies of crash site and PC-Crash simulations, pre-crash velocities and directions can be predicted successfully. Two cases have been illustrated namely (1) Crash involving a truck with a Wagonr^{TM} and (2) Crash involving a bus with a motorbike. The work describes a methodology that can b=e used for judicial purposes as well as by automobile manufacturers for improving their designs by understanding the nature of crashes on roads. It can also be used by traffic planners to improve road layouts.

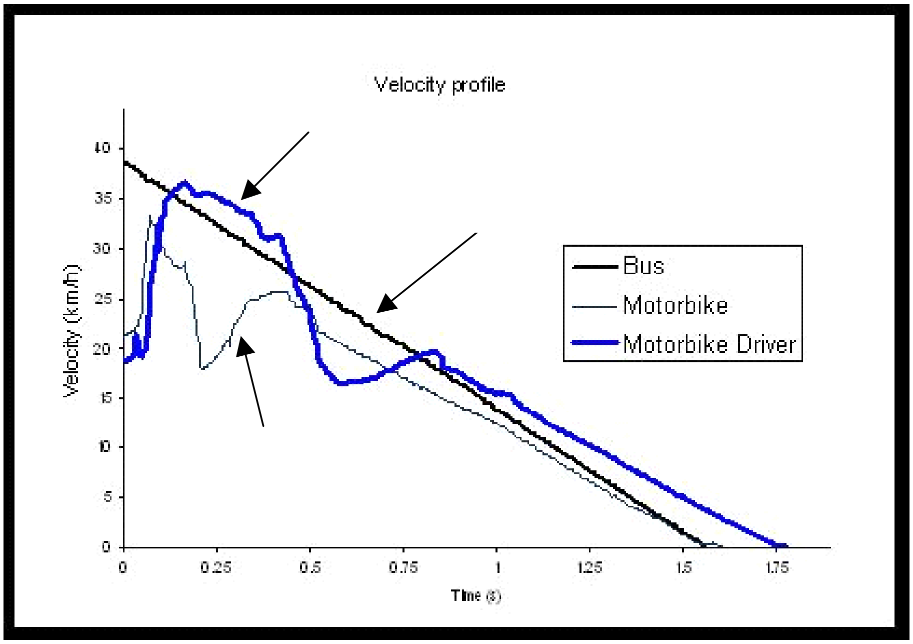

Figure 4: Change in velocity of bus and total distance traveled by bus after impact

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