The forensic reconstruction of road traffic accidents

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The Forensic Reconstruction of Road Traffic Accidents

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Abstract

This project aims to approach the issues of collision damage quantification and accident scene reconstruction in a critical manner. A series of accident scenarios that demonstrate modern-day vehicle collisions will be presented. The collision damage will be studied with regard to the scene, environment and the path and speed of each vehicle. The scientific focus will involve how the accuracy of the process in comparison to forensic measurements made at the scene, and how well the reconstruction process describes the features of the incident.

The work will show how a software package tailored for traffic accident investigators can study the impact damage resulting from a collision, plus variables such as the speed and trajectory of the vehicles involved, to improve the reconstruction analysis and reduce overall doubt in any judgments.

As the use of road networks continues to expand globally, accidents are prevalent in every country where cars and other vehicles are present. By gaining a better understanding of how such accidents occur, the occurrence and cost of these avoidable events may be reduced. The use of accident modelling software is established specifically for this purpose; to provide an unbiased platform for implementing cases from a basic parking bump to a motorway pile-up, enabling such variable effects as weather, road surface and the type of tyres to be accounted for.

Candidate's Statement & Acknowledgement

Overall this thesis describes the work that has gone into determining how well a commonly used process of accident analysis can be applied to a real-life scenario. It is often assumed that purchase of an item of software will provide a specific solution to a certain problem; less commonly the question is asked as how well suited the software truly is and how adept this solution is at meeting its designated function. This was the aim of the work presented here.

The collaboration of Gwent Constabulary should be noted for provision, advice and criticism at most stages of the research. The depth and scope of material provided was given generously and without bias, and this research would not have been possible without this help. In addition to this acknowledgement, the following immensely useful people each deserve a hundred cheers and a thousand beers:

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1. Introduction

The resulting costs of poor judgments due to lack of reliable evidence are so substantial and widespread it is difficult to calculate the figure precisely, even on a per country basis. A typical vehicle accident involving one or more injured persons will incur costs of police time, legal representation, court officials, jury payments and a fee from an expert witness. There is also the matter of imprisonment and lost earnings to consider. If property or other surrounding environment is damaged, similar aspects of the costs are repeated. If the injuries are serious or debilitating, personal liability issues arise which in turn initiate much more serious time and cost to resolve, not mentioning amounts of compensation. Subsequent costs such as medical care, physical and mental rehabilitation for the duration of recovery time of an injured person are likely to be added.

It is easy to see how freely these costs multiply to produce huge financial implications. The value of a US vehicular fatality was stated to be in the range of £1-4 million ($2-7m) (Blincoe 2002). This amount of money seems exaggerated, but is supported by a 2009 report (Copeland 2009) placing the average fatal accident at a cost of £4m ($6m). The American Automobile Association calculated this figure by using data from the Federal Highway Administration and encompassing the cost of medical, emergency, rehabilitation with administrative and legal costs, finding the figure had risen sharply since a previous assessment in 2005.

To demonstrate the total costs, the US Dept. of Transportation quoted that 33,808 fatalities resulted from vehicle accidents in 2009 (NHTSA 2009).

Using the product of average fatality cost and fatality rate, the amount for 2009 in the US alone is £127 billion.

The vast amount of money spent on the legal matters, and subsequent actions to resolve the outcome of an accident, can fortunately be reduced by using means to strengthen the facts in each case. When the doubt in any liability can be reduced, a more robust decision can be made and each case considered more accurately.

1.1 Accident Investigation

In reconstructing a typical traffic accident, there will a limited amount of information gathered at the scene by police. This information will then, typically, be relayed to a Road Traffic Investigator (RTI) on the instructions of a third party, such an insurance company. On commencing the investigation, the RTI will have details describing the accident scene, such as photographs, weather, resting position of vehicles, damage to nearby objects and so on. Some time will have passed since the incident and it is then up to the RTI to model the situation with the information available, and ultimately to present an opinion on the cause of the accident. Only in a special case will the actual scene of the accident be visited, hence, the investigator is often reliant on data that another organisation has gathered.

One of the most important terms used in such a case is the change in speed at a collision. This is used to calculate the original speed of vehicles, and is mainly extracted from the impact damage. The standard method of measuring impact damage uses a tape measure to estimate the crush depth to the vehicle body at a few points, and is typically specified in inches. It is easy to see how the low precision, loose methodology and measurement variability can produce a calculation which yields a range of speed values. Hence, the spread of estimated speeds which result from this approach increase the doubt regarding the cause of the accident, making it harder for a RTI or other party to present a reliable judgment on the incident.

This project aims to approach the issues of collision damage quantification and accident scene reconstruction in a critical manner. A series of accident scenarios that represent modern-day vehicle collisions will be presented. The collision damage will be studied with regard to the scene, environment and the path and speed of each vehicle. The scientific focus will involve how the collision damage is quantified and measured, and how this damage relates variables that describe the features of the incident.

1.2 Reasons for Commencing Research

This research began out of a joint proposal to promote the study of and development in the field of road traffic accidents. Before the research began, a compatible CPD course at Sheffield Hallam University was already established for a number of years, focusing on the analysis of vehicle light-bulbs as evidence for RTA cases. The attendance of many police RTA investigators to this course had established reliable links and networks with professionals in this, and similar fields.

One of the most challenging aspects of beginning research in the Forensic Science sector is that of legality and privacy of information. Many organisations are subject to highly stringent regulations that prevent the discussion and investigation of cases, making collaboration with academic departments rather difficult unless existing agreements are already established. These conditions mean that since the close of the Forensic

Science Service in 2012, a large proportion of data has been held and managed by private companies. The result of these changes is that recent caseloads of incidents which have been subject to Forensic Investigation are extremely challenging to obtain.

To overcome these difficulties, a research methodology to study RTA cases was jointly agreed by Syed Hasan, Alan Smith and Simon Urquhart in December 2011. The research would take the shape of a MPhil, combined with the development of a CPD course to train private and public sector personnel. The academic study detailed in this Thesis would contain reconstructions and a critique of current RTA investigations, whereas the CPD course would use findings from these methods to design and deliver a short course. The existing network of contacts at SHU would then be used to promote this course and gather revenue if possible.

1.3 Project Objectives

The main objectives of the project are:

1. To program and demonstrate a series of reconstructed accident scenarios (or “cases”) that clearly demonstrate a range of common traffic accidents. Redacted case files will be obtained from a voluntary agreement with a UK police department.
2. Specify the speed and damage occurring to each vehicle in each case, quantifying the extent of the damage and how this is dependent on the specific vehicle, scene or environmental variable being considered.
3. Use the findings gathered to form a critique of the existing method of investigation and reconstruction, such that the decisions made from this

aspect of the accident reconstruction process may be made with less error. Priority should be given to any cases that can benefit accident prevention.

4. An additional objective is proposed that, if the research and investigations were sufficiently in-depth, the findings and feedback could then be brought to the software manufacturer and discussed, with the aim of improving the limitations of the reconstruction program.

2. Literature Review

A summary of recent studies involving modelled vehicle collisions are included here, mainly focusing on the PC Crash simulation system and studies involving crush damage from collision. The literature pertinent to this research has been grouped into four major sections with an introductory note for the clarification of some of the overlapping terminology used in this field.

2.1 An Introductory Note on Modelling systems for Vehicle Collisions

The development of algorithms for vehicle crash modelling has now been ongoing for a few decades. There is some overlap between models and the terms used, which can lead to some confusion.

Discussed first of all is Brach's model, which uses vehicle momentum as its basis. This system has a founding in impact mechanics, using an algebraic formulation, which helped its integration into computer-based modelling. The software used in this study, PC Crash, uses this model as its main basis.

Second is the CRASH model, incrementally developed in the USA, which uses the crush damage from each vehicle to predict the change in velocity (Delta-v) resulting from the collision. The CRASH model has been successively refined from its original version, to CRASH2, to CRASH3. The 'mark 3' version is now become a common standard, and is now simply referred to as the "CRASH" algorithm now that previous versions of it are obsolete.

Historically, the CRASH algorithm was developed to support a US accident reconstruction system, called SMAC. The CRASH section was used to calculate delta-V, which was then inputted to the SMAC routines. These two programs are now used side by side and integrated as one module, most notably in Visual Statement's 'Edge FX' software where the SMAC model is available as a plugin.

Just to make matters a little more confusing, the commonly used "PC-Crash" collision modelling software manufactured by DSD, Austria, is not based on the CRASH algorithm. The system here follows momentum modelling but with many extra parameters, including the option to use the CRASH algorithm along with other collision models.

2.2 Momentum Model

The majority of collision modelling based on the principles of momentum has been completed by Raymond M. Brach. One of the earliest papers on vehicle collision analysis (Brach 1977) demonstrated how the momentum of collisions could be considered with equations of impact. From this process the moment impulse could be calculated.

A later publication (Brach 1983) focused the methods more closely into the form of a Planar Impact Mechanics (PIM) model. This system uses a coordinate system for the position of vehicles, conserving the linear and angular momentum of both. The equations used are numerous and verbose, but overall the method demonstrate that collisions between two vehicles can be modelled with some robustness, not to mention the use of restitution coefficients. The system also enabled delta-V to be calculated, which was done so for several documented collisions.

Subsequent work (Brach 1987) developed the momentum model to focus on the accuracy of energy loss in a collision, considering the factors of crush energy and crush measurement. Many aspects of the published papers are collected in a book (Brach 1990) summarizing the work at that time. Practical problems and numerical solutions are included in this volume.

Further work (Brach & Smith 2002) utilized the RICSAC data a full 24 years after publication. A re-evaluation of the familiar reference collision data set involved fitting accelerometers to vehicles, finding that real energy losses in collisions are higher than those in theory. A further book was published (Brach & Brach 2005), updating the methods to current standards by including such aspects as tyre attributes, friction variables, yaw marks and vehicle rollovers. By this point Brach's model was very well-developed. A later paper (Brach, Brach & Welsh) looked at fine-tuning the model, implementing a parameter for the geometry of the vehicle crush area.

2.3 CRASH Algorithm & Model

Brach has published many papers and revisions to his model since its conception in the 1980s. It is easy to forget how limited the computation resources were at this time; Day & Hargens (1985) spent time working on how the computational demand of crash modelling could be reduced, looking at the differences between the EDCRASH and CRASH3 model. The variance between the collision models has always been the subject of investigators and was reviewed by Brach (1987), comparing his own methods with the CRASH algorithm. Brach used a series of collision to calculate the delta-V values for each respective case, although the impartiality of any conclusions made here is not easy to establish.

Later studies (Brach & Brach 1998) updated the comparison of the two methods again by focusing on crush energy. It was pointed of that the direction of impact, which may often be assumed, is a major source of variance for such modelling methods. The paper mainly focused on the energy loss in a collision, stating that crash algorithms could benefit from more integration with planar impact mechanics.

The CRASH algorithm has had many adjustments and reformulations, for example Prasad's (1990) work on damage. Here the approach was modified to reconsider the energy absorbed by a vehicle when a front or rear collision occurred. Residual crush was used and a second input to the algorithm, which was then compared using NHTSA data.

Prasad (1991) used the CRASH algorithm in an inventive way to study side impacts of vehicles. Here the aim was to look at the severity of impacts by testing the validity of residual crush against delta-V values. The data was taken from a NHTSA database set, allowing the crush behaviour for a large number of vehicles to be analysed. Prasad (1991b) additionally produced a study to cover the aspect of a missing vehicle in a collision, for example a hit and run. Prasad used presumed structural factors to reformulate a current method by staging and simulating collisions.

Similar specified analysis was completed by Neptune (1995) by looking at typical 'left-turn' crashes, which in the USA would represent turning across one or more oncoming lanes. A method for calculating delta-V values in such a scenario was given, and could be used where the point of impact was known but not the rest positions of the vehicles. Neptune (1998) also revised the CRASH *and* SMAC models by adjusting the force-deflection calculations used in the two methods. A single model accounting for these changes could be used by both models, allowing data sets to be shared between the two methods.

Further work in the USA aimed to expand on the SMAC/CRASH algorithmic methods by staging a series of vehicle collisions, under the name of RICSAC (Research Input for Computer Simulation of Automobile Collisions), published by Jones & Baum (1978). Here cameras and accelerometers were attached to vehicles for a set of 12 staged collision scenarios; at the time of publication there was no set of data so comprehensive or readily available. The information became immediately popular as a standard reference set for collision modelling, being used for crash investigation comparisons then and for many years afterwards.

A wealth of studies have covered the RICSAC data, such as a re-evaluation by McHenry & McHenry (1997). Here the program was reviews and a validated, together will appended accelerometer measurements. Use and analysis of the CRASH algorithm by the McHenry company is quite prolific, among which works is a study looking at the effect of restitution in the process (McHenry & McHenry 1997b). The method was adjusted when considering the maximum dynamic crush is a collision, for the use of the CRASH and SMAC models. It was noted that the deformation of a vehicle increases as restitution decreases. Further promotion of this modelling approach supplies an excellent and detailed synopsis of the method from a set of conference proceedings (McHenry 2001). This document also discusses the popularity of the CRASH algorithm is popular, and the potential for improvement in some aspects of its considerations. It should be noted that from around this point, CRASH and CRASH3 tend to be termed the same.

As the foremost calculation of the CRASH algorithm is delta-V, there is significant focus on the accuracy of this output. Lenard et al. (2000) usefully stated that CRASH algorithm underestimates Delta-V for European cars, notably by 5% for impacts with deformable barriers, by 6% for side barrier impacts and 10% for rigid barrier impacts. The deviation of car-to-car impacts was less significant, said to be overestimated by 2%. Other suggested improvements to the CRASH algorithm have involved considering the delta-v of multiple vehicle collisions (Jewkes 2001). Here it was proposed that the delta-v analysis of collisions involved more than 2 vehicles could be improved by only considering each pair of vehicles in turn.

Studies on the uncertainty involved in the CRASH calculation were demonstrated by Fonda (2004), noting that in the collection of data from collision scenes, data on the limits of uncertainty is quite rare. The study showed the effects of using the algorithm with varying levels of measurement accuracy, and the overall result of this. More numerically detailed analysis (Rose, Fenton & Ziernicki 2004) studied the CRASH algorithm in terms of mass vectors, and the interactions between them. Here it was demonstrated that a numerical solution could eventually be found for these vector interactions.

2.4 Crush Measurement & Quantification

The focus of collision modelling has not always been a concentrated one. The modern methods used in this project have evolved from several different approaches to investigating, analyzing and solving road traffic accidents. Individual methods have used some, none, or several of the models and algorithms that have been discussed.

An early publication established of the most widespread and useful terms still used in current modelling such as PC-Crash. The Equivalent Barrier Speed (EBS) was first used to describe the energy absorbed in the plastic deformation of a vehicle collision (Campbell 1974), but has remained in crash modelling ever since. This aptly named term estimates the speed a vehicle would have to travel into a rigid barrier to cause the same equivalent damage from the collision being studied. At this point, the term was only intended for frontal impacts. The EBS is also called the Barrier Equivalent Velocity (BEV) by some parties, being an interchangeable term.

Delta-v is the next most common term used in applying collision models; the use of this is most appropriate, as it is the deceleration, or change in momentum, that causes resultant forces and damage in road traffic accidents. Common problems in calculating this term were demonstrated by Robinette, Fay & Paulsen (1994). The concept of delta-v was thoroughly defined here, stating that vehicle kinetic energy, momentum and EBS should be included when calculating this figure.

Carpenter & Welcher (2001) found a method of implementing EBS into vehicle collision analysis by using material coefficients, focusing on the stiffness of the vehicle body and the crush energy from a collision. The method could then be used to predict the coefficient of restitution of a crash. It has often been noted that neglecting restitution can create problems in reconstruction (Burkhard 2001). Here the relationships between EBS, the coefficient of restitution and delta-v were discussed, comparing the effects of collisions with movable and unmovable barriers.

A comparable study by Cipriani (2002) used restitution analysis on low speed collisions. This compared predictive theoretical methods with full scale testing, focusing on the absorption of collision energy into vehicle bumpers. It was suggested that modelling vehicle bodies as a homogenous material with a linear (Hookean) stiffness coefficient was unsuitable, and that it could be beneficial to engage a bi-linear stiffness model instead.

Recording data from crash scenes, whether controlled or real-life, is a process that suffers from a high degree of variance and a susceptibility to error. Bartlett (2002) looked at the uncertainty in traffic accident reconstruction in terms of the measurements taken in common scenarios. Here the distribution of accident data was reviewed, and methods to reduce the measurement errors in factors such as damage and tyre marks were suggested.

A similar study (Chen, Tanner, Cheng & Guenther 2005) also aimed to reduce the uncertainty in accident reconstruction. Here a force-balance method was proposed, mainly based on Newton's 3rd law. The principle noted that force on both vehicles would be equal at a point in a collision. This was suggested as an alternate to reconstruction from post-crash damage, as the insufficiency of crush data from collisions is a common issue.

Crash severity was also studied by Gabler, Hampton & Hinch (2004), who outlined other problems in calculating delta-v. A large proportion of accident data covers head-on collisions, whereas in this study the issues with sideswipe collisions, side impacts, and rollovers were discussed.

A major part of this study is focused upon relating the post-collision damage of a vehicle to the pre-collision speed. Often in modern road traffic accident investigation, this take place at the scene by studying the damage to the vehicle body. Methods vary somewhat, depending on organisation and country, and there are few universally established conventions for investigating these scenarios.

A relatively early paper on quantifying vehicle damage from a collision was given by Tumbas & Smith (1998). Here the change and transfer of energy was considered as part of using crush information in accident reconstruction. It was noted that although crush damage was often used as a stating point in such investigations, there was no firm procedure for measuring such data. A protocol for doing so was proposed.

Similar findings were given by Strother, Woolley & James (1990), who found discrepancies in published crash test data. Common sets of frontal stiffness coefficients implemented in the CRASH algorithm were compared to data from US vehicle crash tests. It was found that the algorithm tended of overestimate the energy absorption of vehicle bodies, mainly at the severe end of the collision scale. Related work by Fonda (1999) looked at how crush energy was determined, reviewing the circumstances and methods in which calculation of this measurement can by oversimplified. It was discussed how the ease of calculability and use of algebra for this measurement can often overrule the consideration of accuracy. Another report on the accuracy of stiffness coefficients (Varat, Husher & Kerkhoff 1994) pointed out the shortcomings of assuming linear deformation in a collision for analytical purposes. Here the linear stiffness model was critically compared with nonlinear data, concluding that a more advanced consideration method was required.

A significant body of work on crush measurement and vehicle stiffness coefficients has been published by James A. Neptune, who favours a mechanical approach to the subject, often giving full equations of his work. A method of quantifying vehicle stiffness coefficients (Neptune, Blair & Flynn 1992) suggested that engineering experience should be used to apply judgment when using such a method. Here the lack of availability of stiffness data was commented upon, as was its accuracy. Fortunately, protocols for deriving these values were also given.

Further improvements to the method were also given by Neptune & Flynn (1994), introducing a method to improve upon the simplistic technique of using a single stiffness coefficient for a vehicle body. It was recognised that a vehicle is not, and does not resemble a linear material. In the study, stiffness coefficients were adjusted for each crush zone and matched via force to corresponding contact zone on the other vehicle in the collision. The method and some examples for calculating stiffness coefficients in this manner were also given, with useful equations and diagrams.

An expansion of this research was later provided by Neptune & Flynn (1998) by extending the work of side crashes and offset frontal collisions (i.e. on the wing section), again provided with equations and examples. The paper demonstrates how a bi-linear stiffness coefficient model is appropriate for some collisions, for example with passenger compartment damage. It was also shown that frontal stiffness coefficients were similar to overlap coefficients, provided that the bulky engine compartment contained the collision damage. In a similar manner, the work was appended with a further paper by Neptune (1999) looking at the overlap in frontal crashes. It was noted again that single-value stiffness coefficients were inappropriate for such collisions, and proposed a method to improve the analysis for partial and full overlap frontal collisions. This involved specifying stiffness values relating to the degree of overlap between the overhead shapes of the two vehicles involved.

Similar work by Woolley (1999) aimed to expand on the single-stiffness concept, by reviewing a method of non-linear damage analysis. Here, methods of defining a non-linear coefficient for the stiffness of a vehicle body were given for front, side, rear and pole impacts. The change in shape of the materials could be expressed using a power law in these cases. A comparison of this method was given to linear stiffness and bilinear stiffness techniques, although, integration of such a method to a program such as PC-Crash would require most of the vehicle modelling code to be fully rewritten.

Some useful statistics were published by Welsh (1999) in a report on crush energy and characterizing the structure of vehicles. Here the issues with assuming that crush profiles can reach a maximum were discussed, and the nonuniformities that challenge such assumptions. It was proposed that narrow-objects fit the constant force model, but that wide-object impacts need something more. Prasad (1990) also studied the energy dissipated in the crush of vehicle bodies, using a method of repeated testing. Using repeated impacts on the same vehicle, it was shown that the relationship between delta-v and vehicle crush could be shown to be linear in some examples.

A well-known problem with this type of collision modelling is the lack of accuracy at low-speed collisions. A study focusing on relating modelled stiffness coefficients given by Burkhard (2001) brought up the issue of low accuracy as a result of a limited amount of crush, which would typically result in a collision at lower speeds. Usefully, it was found by comparing lower and higher-velocity collisions that some coefficients were similar regardless of the speed of impact. A compatible, practical body of work on this subject was published in a volume by Huang (2009). This book contains plentiful illustrations of the collision analysis and modelling processes, with graphs and comment on the interactions in modern vehicle crash scenarios. Some test data is also given.

Regarding an alternative methodology on crush analysis, Ishikawa (1994) took an approach which related the centre of impact to the deformation of the vehicle in a collision. By using this method and the help of normal and tangential restitution coefficients, the crush profile could indicate the point of impact, at the instant of maximum deformation of the vehicle body. Restitution can often be omitted in crush analysis, and also modelling; it should be noted that the PC-Crash software relies on an estimate of vehicle-to-vehicle restitution which is set as 0.2 as standard. A study focusing on restitution modelling from Rose et al. (2006) looked at validating this aspect into crush analysis. This was tackled by modelling vehicle body constants into delta-V calculations for several collisions. The results were validated by presenting four collisions, that showed improved accuracy when restitution was considered in the crush analysis.

The uncertainty in the crush analysis method is a common area where improvements are continually targeted by researchers in this field. An investigation into relating crush to stiffness coefficients by Singh (2004) managed to describe the uncertainty relationships for these figures. By investigating rigid barrier tests and integrating a mathematical method of measuring the crush envelope of the corresponding vehicle, it was shown how accuracy of this approach could be improved.

Further improvements to the crush analysis method were suggested by Viangi (2009), who reported on how oblique impacts between vehicles relate to energy loss in a collision. Here a method was introduced that included the direction of crush in regard to damage. It was stipulated that by using this process, a more accurate calculation of damage could result. In turn it was shown how this would also produce a more accurate measure of both impact energy loss and delta-V. Comments on this report were given by Brach (2009), who offered an adjustment factor to add to Viangi's work. This factor could improve estimates of crush energy calculation, by applying the direction of crush to each crush zone.

2.5 Computer Collision Simulation

The methods of using software to reconstruct a traffic accident scene are quite a recent development, having been chiefly made possible by the processing power of the PC in the 1990s and thereafter. The multi-body models currently employed today have substantially improved graphical capabilities since the invention of RTA reconstruction programs such as PC-Crash, nevertheless it is important to state that the aim of these programs is *not* to illustrate an accident scene. Police services, particularly in the USA, use graphic-based reconstruction packages such as Crash FX for these purposes. This program is designed to simulate crash, accident and crime scenes and does allow for vehicle movement and collisions, but does not provide any advanced improvement of crash modelling from speed and crush data. Likewise, highly analytical programs such as LS-DYNA (Schweizerhof, Weimar, Munz & Rottner 1998) are specialized FEA modelling packages that fall outside the scope of this study. The use of LS-DYNA is prevalent amount auto manufacturers when seeking to improve crashworthiness of their vehicles, however, modelling in this manner is not effective for large defomations, and therefore unsuitable for this research.

PC-crash has been the focus of this research for as it is a continually updated software platform as it contains many features that enable the physical interactions of a collision to be included. The use of a global vehicle database is an advantage here in comparison with US-based programs such as Crash FX, and also the inclusion of crash-test stiffness data. Some detail into these features is given by the program's author, Dr. H. Steffan (2009). An explanation into how the software models tyre, suspension and gravity forces into dynamics is given, with further detail into such advanced considerations such as wind forces. The momentum-based collision model at the heart of the program is based on the work of Kudlich (1966) and Slibar (1966), the basic principles of which are the same as much of the other modelling discussed here. By far the most accessible and comprehensive translation of the work comes from Steffan's (2009) paper on accident reconstruction methods with application to PC-Crash.

A more comprehensive paper for illustrating how this software is applied to a typical traffic accident collision is given by Prentkovskis, Sokolovskij & Bartulis (2010), in the *Transport* Journal. This paper demonstrates how vehicle attributes and speeds are used in the overall application of the program to an accident scene. Velocity graphs are given for a few basic 2-car collisions, along with some impact mechanics theory that serves as a good introduction to the principles of this research. Another good paper to start on the basics of using this software is given by Sokolovskij & Mikaliunas (2006), which demonstrated how a typical vehicle-to-vehicle collision is set up and simulated in PC-Crash. This paper also gives helpful diagrams, equations and information at each step of the process.

Earlier work from Ishikawa (1985) demonstrated how somewhat primitive computing was used to reconstruct accident scenes. Here a model using the same principle as Brach's momentum-based system was established that could consider a scene as a 2D reconstruction. Remarkably for the time, and limiting computational power, this system could predict vehicle deformations, post-collision trajectories, and tiremarks.

Once graphical capabilities had progressed to a point where 3D simulations could easily be modelled on a mid-range PC system, programs such as Dr. H. Steffan's PC-Crash became established. A relatively early paper by Steffan & Moser (1996) presented how trajectory models for several vehicles colliding in a simulated graphic environment are could be simulated. This includes the kinematics of post-collision crashes, encompassing tire forces, ABS, steering, suspension and yaw. The collision model relies on momentum and restitution rather than linear stiffness coefficients of the vehicles, although inter-vehicle friction is considered.

The robust modelling of Brach (1998) was given a corresponding report on such methods, looking at impact problems with rigid bodies: essentially these were the founding assumptions of collision modelling programs at the time. Brach outlined a series of equations for 3D impact modelling the collisions of rigid bodies, using a purely theoretical approach, characteristic to his writing. Overall the point was made that the hefty numerical demand of this approach was well suited for computer modelling and simulation.

This admittedly helpful support was later backed up in a paper from Geigl, Hoschopf, Steffan & Moser (2003), who took the validation of the process a step further towards the pragmatic. Here kinematics were reconstructed with a focus on the movement of dummy occupants in a vehicle collision. The study showed good agreement for the kinematic and kinetics of staged real crashes and PC-Crash simulations of the same scenarios. Various impact angles were investigated, showing graphs of acceleration for the head and chest areas of the dummy occupants. It would be reasonable to liberally consider Dr. Steffan's motivation in promoting his own software platform, however, despite any point of view the agreement between real and simulated acceleration curves is a convincing and effective argument for its use. It should also be mentioned that, for example, in modern NCAP crash testing there are upper limits for g-forces on dummy occupants that manufacturers must pass under for a vehicle to be manufactured legally. A legal standard such as this may help to focus more simulation work on modelling-based processes, rather than rely solely on the expensive and protracted staged crash methods.

More occupant-based study using PC-Crash was completed by Balazic, Prebil & Certanc (2003). Here the analysis used PC Crash to reconstruct a specific vehicle accident, which involved an overloaded van and a severe frontal crush of an Audi. First of all, the velocities of both vehicles were estimated. The injuries to passengers were scrutinised, and the simulated acceleration of bodies was reconstructed, looking at if seatbelt could physically manage to restrain the forces involved in the crash. Later work by Trusca, Soica, Benea & Tarulesu (2009) compared the simulations of the program to real data derived from car-to-car crashes. Here dummy occupants were fitted with accellerometers, with an aim to investigate the forces on the passenger head and neck region in a rear-end collision. Reasonable agreement was found between the real and simulated data, although there was plenty of noise between the two data sets. These types of accidents have been the subject of recent UK laws due to the excessive number of whiplash claims; as the damage is soft tissue only, this remains a medical grey area which is hard to diagnose with certainty.

Such modeling programs have a useful tendency to be updated with new features, as modern vehicles are made with updated features in time. Recent years have seen a widespread use of vehicle dynamics management, such as electronic stability control. Ammon (2005) studied how these controls relate to friction and grip on the roads. The shear and frictional forces on tyres were examined under different conditions, i.e. going over bumps and blocks, and the changes in adhesion to road surfaces were studied. The effect of electronic stability controls on these scenarios was also investigated.

As modelling programs continued to develop, the possibility of reconstructing cases that were previously over-complicated became open. Oblique and side-swipe crashes have not been rare in this kind of literature, but a report by Eichberger, Schimpl, Werber & Steffan (2007) focused on “frontal impact, small overlap” collisions. Here the Austrian database of car-to-car crashes was studied, paying attention to ‘near head-on’ accidents. It was pointed out this is circa 9% of all the recorded traffic accidents. Using PC-Crash, it was shown that these type of crashes were quite dangerous due to lack of energy absorption in this direction impact, combined with chance of wheel ‘rim locking’. When this occurs, the front wheels of two impacted vehicles interlock, bringing about a high risk of severe injury in this type of crash.

A following paper on pure frontal-impact simulation using PC-Crash was given by Eichberger, Hirschberg & Cresnik (2008). This study matched the data of the model to a two-car collision, looking at several ways in which the deceleration of the vehicle and subsequent passenger could be modified to yield safer crashes. Several suggestions were given, although a helpful table included in the paper produced a data set of crush zone stiffness of vehicle bodies, indexed by vehicle class.

Such real-to-simulated investigations on collision modelling do not always compliment the software involved, but can shine a light on where improvements should be made. A study by Andrews, Partain & Refroe (2007) compared how PC-Crash modelled a staged rollover collision in comparison to actual video data. Here the sequences of the vehicle rollover were directly compared with the simulated version, in detailed and well-illustrated sequences. It was found that the rollover features of the program show to be reasonably accurate when compared with real crash data, but that the program tends to overestimate yaw rate. Similarly, the initial stages of vehicle movement that cause a rollover were examined by Viba, Liberts &

Gonca (2009). This work looked specifically at the kinetic energy of a vehicle turning a corner with excessive speed, hence causing a rollover. The paper goes into some exhaustive detail of how kinetic energy is lost in such circumstances.

A somewhat unique report on a very specific real-to-simulated PC-Crash work was produced by Ambroz, Korinsek & Prebil (2011). This work studied the ‘blackspot’ areas of road suffering from concentrated amounts of traffic accidents. The approach was to use the software to model simulated data which was then compared with real-time data acquired from a camera mounted on the head of a driver in a test car. The viewpoint of the driver going through the blackspot zone could then be resimulated into the program by using eye-tracking software. Overall, firm conclusions were lacking in this investigation, although the work certainly outlined an interesting concept with which to find the concealed paths of other vehicles in a collision scene.

3. Relevant Theory and Analysis

The following theory was developed for integration into the PC-Crash program by Dr. H. Steffan, and is given in a condensed form from both the Technical and Operating Manuals for the program (Steffan, 2011). The theory is described in a manner that allows comparison to the collision models discussed in the Critical Literature Review, although without most of the extensive algebraic formulation.

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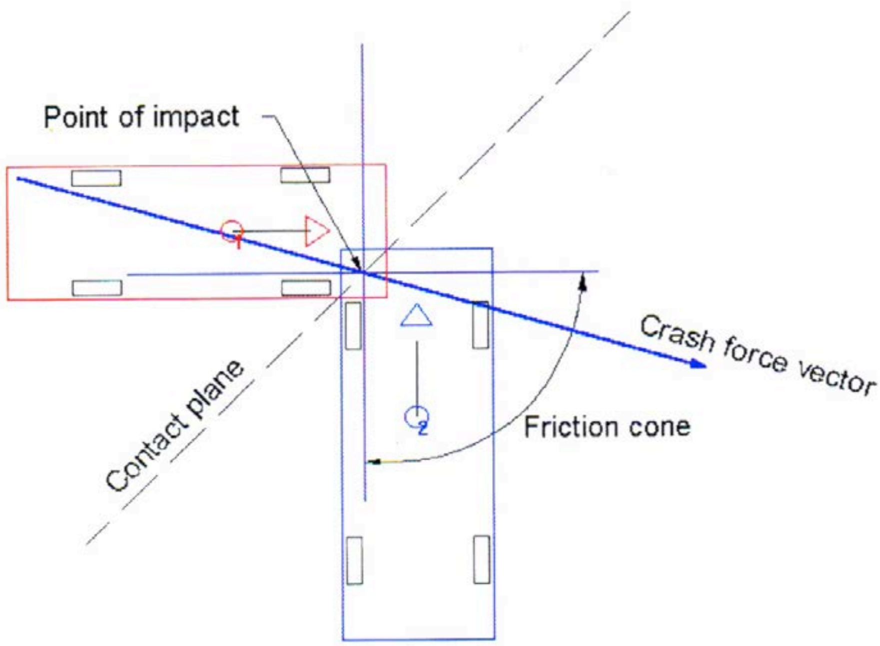

Fig. 3.1: Schematic of Impact Model used in PC-Crash.

The impact can be divided into two phases of compression and restitution. When a full impact is being considered, the velocities of both vehicles are identical at the impulse point, which occurs at the end of the compression phase. After this point, the vehicles will separate. The coefficient of restitution used in the software is defined as the ratio between restitution impulse and compression impulse:

$$\varepsilon = \frac{S_r}{S_c}$$

The total impulse can be given by:

$$S = S_c + S_r = S_c\left(1+\varepsilon\right)$$

The model then uses the defined, or estimated, contact plane between the two vehicles calculate the respective force vectors. Figure 3.1 gives a schematic demonstration of this; full derivation of the force vectors is given in the PC-Crash manuals (Steffan, 2011).

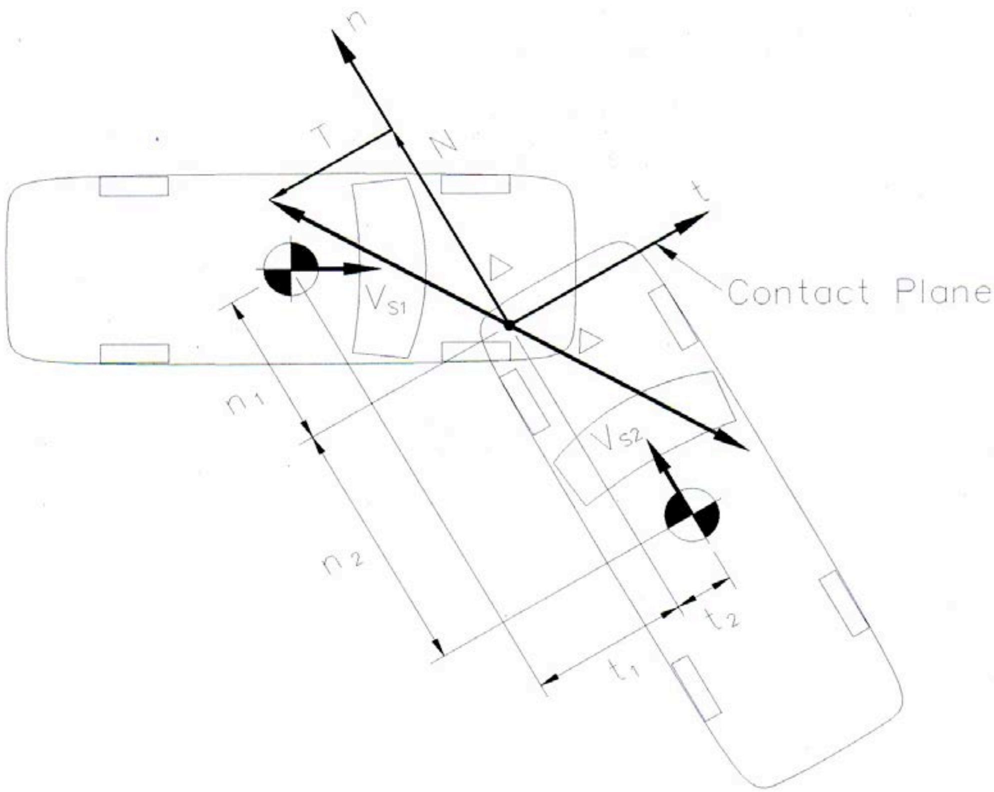

Fig. 3.2: Geometric Schematic of Impact Model showing Contact Plane.

In the case of a sliding impact, some assumptions are required. Here the impulse point must be positioned along the contact plane between the two vehicles. In addition, it is assumed that:

- No relative movement normal to the contact place occurs at this impulse point at the end of the compression phase. This assumption may seem counter-intuitive, but is given some validation when considering that an example contact time is 100ms or less.
- The normal component of this impulse may be influenced by the coefficient of friction between the two vehicles.

- The direction of momentum transferred is limited by the coefficient of friction μ.
- The ratio between compression and restitution impulse is defined by the coefficient of restitution as with full impacts.

The point at which forces are exchanged often occurs when the outline of the vehicles overlap (i.e. the vehicle bodies are compressed in the collision), and attention needs to be given to the accuracy of this point. It is recommended by the manual that to maintain accuracy, the vehicles are positioned at the impact point in a manner that represents the amount of crush to each respective body as precisely as possible. If this procedure is not possible or information is not available, the software is able to estimate the contact position of the vehicles within a given time segment. It is also recommended that the point of impact is defined by the user, for example with knowledge of the point of maximum vehicle crush and some regard the parts of the vehicle body that would provide resistance and rigidity in the damaged area.

The software requires that the coefficient of restitution is inputted by the user; typically this will be in the range of 0.1-0.3. Lower values are suitable for collisions with high crush to the vehicle bodies, whereas less serious collisions with perhaps low velocities should use higher values.

As described in the literature review, the Equivalent Energy Speed (EES, alternatively known as Equivalent Barrier Speed) is an important feature in collision modelling and is integrated into the PC-Crash software. This is calculated from the mass, crush depth and energy lost in the collision by use of the following equations:

$$\frac{EES_1}{EES_2} = \sqrt{\frac{M_2}{M_1}\frac{S_{def1}}{S_{def2}}}$$

$$EES_2 = \sqrt{2E_D/M_2\left(\frac{S_{def1}}{S_{def2}}+1\right)}$$

M_i= mass of vehicle *i* *(kg)*

$S_{def,i}$=crush depth to vehicle *i (m)*

E_D = energy lost by both vehicles due to damage in collision (*J*)

The Contact Plane is a vital element of the collision model used in the software, and may be calculated automatically or given by the user.

3.1.1 Police RTA Case calculations

The software described in this document works in a similar manner to the methods used by RTA police investigators. In analysing the outcomes of a previously documented collision, a method using Newtonian physics is used, some parts of which are described here.

The principle of the conservation of momentum is often utilised when the speed of a vehicle, pre- or post-impact, is not known. The well-known equation balances the momentum post-impact from the bodies with mass M_i and velocity V_i with that of the pre-impact momentum where the bodies are assumed to have the same mass but velocity U_i *:*

$$M_1V_1 + M_2V_2 = M_1U_1 + M_2U_2$$

If, for example, the approach velocity of one vehicle, U_1, is unknown, then the equation may be rearranged if the other values for mass and velocity in the equation are known:

$$U_1 = \frac{M_1V_1 + M_2V_2 - M_2U_2}{M_1}$$

Units for this calculation should be in mass (kg) and velocity (ms^{-1}).

Other such calculations use established methods involving the coefficient of friction between road and tyres to estimate the stopping distance from skid marks. This basic but effective method has been in use by RTA investigators for a few decades (Byatt & Watts 1981) and typically assumes a high coefficient of friction such as 0.9.

If the initial velocity *U* and final velocity *V* are assumed to be dependent on the braking force caused by the friction of the tyre surface and road surface, with coefficient of friction mu, and the gravitational acceleration *g*, the vehicle will travel a distance of *s (m):*

$$s = \frac{V^2 - U^2}{2\mu g}$$

In a similar fashion the time taken for this deceleration, *t*, can be calculated:

$$t = \frac{V^2 - U^2}{\mu g}$$

Such calculations are useful in obtaining estimates of braking time and distance. For the purpose of the collision simulations detailed in this document, police calculations of speed, time, position and distance are used directly for input variables.

3.2 Research Methodology & Reconstruction Approach

The process of reconstructing a traffic accident using the modelling and software specified is described here, with the aim of allowing this process to be followed in future. For the purposes of this research, this approach is described by an outlined methodology to gather data and then utilise a reflective ‘critique’ to refine the reconstruction using an external RTA Investigator.

1. **Begin Visualisation.**
   - 1.1. Sketch existing incident with basic environmental layout. Whiteboard with coloured pens is an ideal basis, although pen and paper are equally useful.
   - 1.2. A potential incident can be sketched if not using an existing case.
   - 1.3. Expand sketch to include a ‘before’ and ‘after’ impact scenario.
2. **Commence Modelling Platform**.
   - 2.1. Check that the software or modelling platform is capable of implementing the most crucial features of the incident. These should include in the first instance:
     - Vehicles & features (dimensions, make, model, modifications, year)
     - Road curvature, environment, slopes & surfaces
     - Environmental objects (natural & artificial)
     - Occupants, pedestrians and other features

3. **Basic Reconstruction.**

   3.1. Begin to implement the major features of the RTA to the modelling platform for an initial reconstruction. These should include:

   - Vehicle velocities, positions, and trajectories
   - Point(s) of impact for all collisions
   - Vehicle crush resulting from impact
   - Rest positions after impact

   3.2. Once the initial reconstruction has been run, adjustment of some of the above features is recommended to achieve a suitable starting point. In particular, vehicle velocities and POIs are the first variable to adjust.

4. **Case/Expert Request.**

   4.1. When the initial reconstruction is viable, make contact with the external expert or case provider. Organise a meeting, ideally in person, or remotely, where the following information should be recorded:

   - RTA case files, including photos, reports and vehicle data
   - Legal/Civil permissions
   - Expert’s opinions of the incident
   - Other contributory factors, i.e. road condition, environment, weather, vehicle history

5. **RTA Reconstruction.**

   5.1. On receipt and confirmation of the required information from the external expert, integrate these details into the existing reconstruction

(*See Ch.4. for methodology, Steffan 2011 for technical detail)*. Ensure that the following are included as a minimum for each scenario:

5.2. Vehicles (specifically, inclusive of loads, cargo, occupants and corresponding weights)

5.3. Vehicle Data (condition, tyres, braking at time of incident, damage after impact)

5.4. Environment & Road (surfaces, layout, gradients, objects, roadside barriers). Use expert's recommended coefficients of friction where available.

5.5. Pre-impact vehicle speeds and trajectories (along carriageway, out-of-lane, estimated or measured speed)

5.6. Point(s) of impact (end/start of tyre marks, debris field, damage to nearby objects). If POIs are judged to be on vehicle bodywork, obtain photos of impacts with measurement data for comparison to modelling outputs.

5.7. Post-impact damage and crush. This is often in vehicle bodywork and well-documented by photos; also obtain detail of scratches to paintwork from sideswipes/barrier contact. Damage to tyres and wheels can also indicate contact with curbs and road surfaces.

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5.9. Rest positions of all vehicles post-impact. This may be in the form of photos or police 'markers' that delineate the rest position of a vehicle. Note that cargo and vehicle attachments and so on may also be displaced.

6. **Reassess Reconstruction** with external/case provider feedback.

   6.1. With particular regard to points (*5.6)-(5.9)*, obtain the most accurate reconstruction scenario possible. Adjust variables according to *(5.6)* first and continue in that order.

   6.2. Extract demonstrative animations of the reconstruction. Use several angles with a 3D roadside view, combined with a top-down "bird's-eye" view from above, effectively giving a 2D resemblance of the incident. The files can either be sent remotely or demonstrated to the external investigator in person.

   6.3. Gather information and the opinions of the investigator on the accuracy of the reconstruction. This should include commentary of all aspects of the data required for points *(5.1)-(5.9).* Separate this data into the following categories:

      6.3.1. Accurate, validated information

      6.3.2. Incorrect or inaccurate information

      6.3.3. Factors or data that require estimation unless more information is forthcoming regarding the incident.

7. **Reprise Reconstruction.**

   7.1. Use corrected or more accurate information from *(6.3.2)* should be immediately integrated to the reconstruction. The scope of this information will vary, however, it is recommended to first apply corrections to:

      - Tighten the margins on vehicle velocities and trajectories
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- Reappraise POIs, contact points and vehicle-to-vehicle friction
- Improve the simulation environment to represent the real-life scenario
- Recalculate rest positions and vehicle damage.

7.2. Use correct and validated information to node down specific points of accuracy for future use. This may include, for example:

- Frictional characteristics pertaining to a specific kind of impact, e.g. a ‘rear shunt’ crash
- Damage impacts at certain speeds, particular for two vehicles of comparable mass
- Specific environmental type of objects, with weights and dimensions

7.3. Note aspects of the reconstruction where the software/platform is not suitable for modelling parts of the scenario. These items should be given due concern in future, for example:

- Unsuitable vehicle types (motorcycles, certain HGVs)
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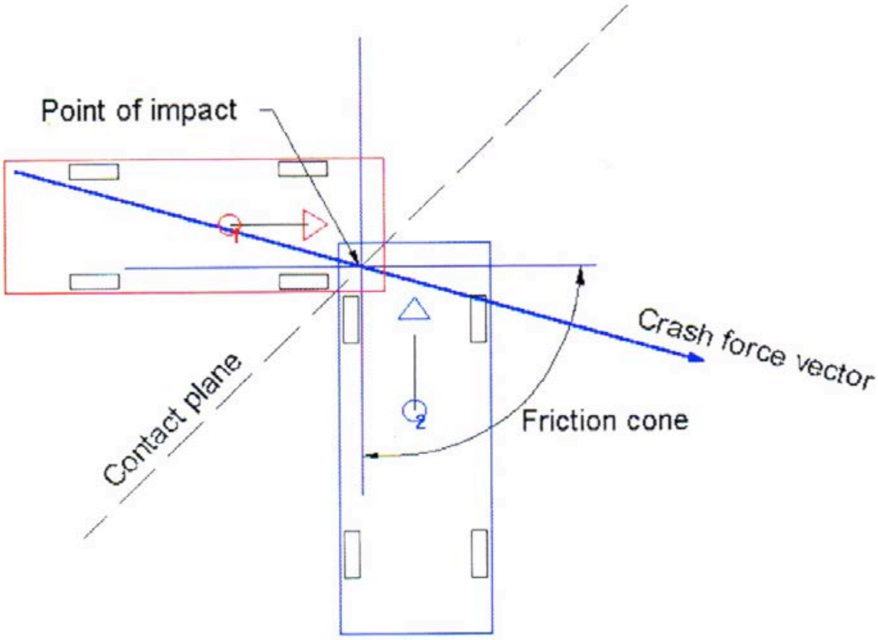

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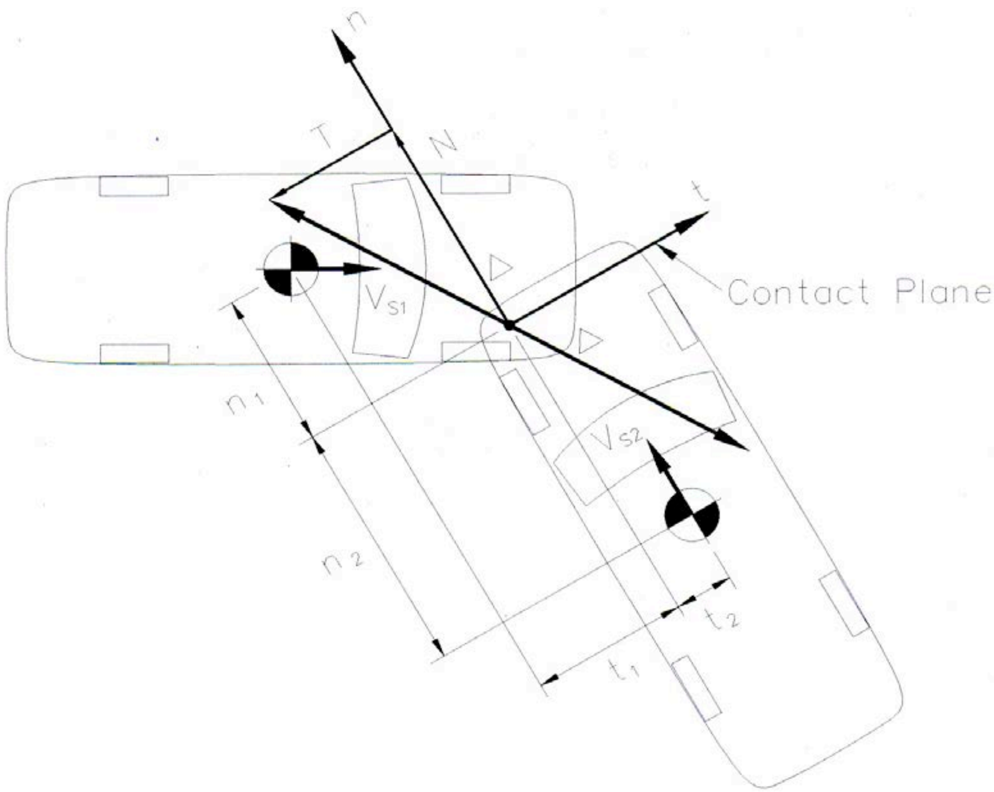

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The process described here may certainly be adapted accordingly to fit with availability of experts and case information. Further detail on integrating features to the software can be found in the software manual (Steffan, 2011).

4. Research Methodology & Approach

This study took an approach that involved a process of *meeting, modelling, demonstration* and *critique/review* for a series of traffic incidents. This chapter describes how to follow this process from the Investigator's perspective, plus that of the individual simulating the incident in question.

For each incident, the research methodology followed the structure of a basic iterative process which is described in a general fashion here. In the first stage, a meeting with an RTA Investigator would be set up to discuss suitable RTA cases for the research. Suitability of each incident for modelling would be discussed based on current legal status of the case, number and type of vehicles involved, environment surrounding the incident, evidence currently available, and so on *(See Section 3.2)*.

Once a case was agreed as suitable, material such as scene evidence would be handed over (typically in digital formats). The incident would then be reconstructed using the available information. An initial collision simulation was modelled into a 'test' scenario from evidence available at the time, encompassing features such as vehicle type, road layouts and points of impact. The simulation would then be rendered into 2D and 3D reconstructions. The reconstructions were then demonstrated to RTA police staff to gather detailed and critical feedback on the accuracy of the simulations. After this point, the simulations were then openly reviewed to enhance the accuracy of the reconstruction, using the guidance of police feedback. Findings from this critique would then be used to identify shortcomings in the process and software.

4.1 Obtaining a RTA Caseload

It was agreed between the RTA department of Cwmbran Police, Wales, and Sheffield Hallam University that access to recent cases would be made available and use of information permitted for research purposes only. Following this, a visit to Gwent Police HQ in Cwmbran was made. The first meeting with an Investigator took place in June 2012. In this meeting, a template process was proposed and followed that is summarised by the following points.

A specific RTA case was requested, based along the type of incident and vehicles involved. This decision would be made according to the recommendations of the investigator, the known capabilities of the software (i.e. availability of relevant vehicle models), and the caseload required for thesis reporting. A discussion on the suitability of the case would then take place, taking note of the following points and aiming to fulfil each of the criteria below.

Legality

The incidents considered needed to be free of any existing investigative or legal proceedings that could be compromised by distributing evidence from the case. This issue was circumnavigated by considering only cases in which a court judgement had been passed, therefore, knowledge of the case and outcome was in the public domain.

Vehicles Involved

The vehicles subjected to an impact in the case needed to have been available for modelling in the reconstruction program. This point was mainly dependent on the library of vehicles included in the software package at the time of reconstruction, which fortunately included an EU, UK & US database up to the year 2012. This did not cause any caseload issues with standard 4-wheel passenger vehicles, but some complexity arose when this was not the case.

Vehicles Unsuitable for Reconstruction

Two categories of vehicles were exempted from reconstruction: Motorcycles and HGVs. This decision was made on the recommendation of RTA investigators and with regard to the scope and timeframe of the research.

Motorcycles

Although incidents with motorcycles are common, reconstruction of incidents is challenging even for an experienced investigator. First of all, a higher percentage of motorcycle incidents involve fatalities of the rider, effectively removing one side of the description of how the incident occurred. Secondly, the loss of control of any bike leaves a variable and inconsistent pattern of road markings at the scene. Sometimes the extended parts of a bike, i.e. footrests, handlebar edges can be traced to metallic marks on the road, but this mostly effective for a 'crash and slide' incident. The less fortunate, but more common, result is that the bike may rotate and land in a varied fashion after an impact, making the trajectory and POI hard to find accurately. Thirdly, compared to solid-body vehicles, bikes are much harder to extract crush damage information from. The outline of a bike construction is more complicated than the polygonal form of a car, and in addition, less glass, panels, lighting were present to provide clues to the investigator. Bicycle cases were also excluded for the same reasons.

Heavy Goods Vehicles

HGV type haulage vehicles were exempted for different reconstruction concerns. Although it was fully possible to integrate many HGV types to the software, a typical haulage vehicle can be included as two parts (truck and trailer) with respective settings, stiffnesses and weights. However, the combined physical body of two vehicles introduced many more variables into the modelling, i.e. cargo and position, linkage characteristics, specific truck types, number of wheels, trailer steering and so on. Such information was not forthcoming in the RTA investigator's files. This made for a much more complicated reconstruction, which then proved hard to obtain a confident degree of accuracy. In addition, cases involving HGVs were not plentiful, as these tended to be handled by insurance companies after an incident, rather than be subject to police investigation.

These principles were not obstructive to cases involving single-body large vehicles such as buses or coaches, which were not overtly complex to integrate to the reconstruction program.

4.2 Meeting with Investigator & Integrating Evidence

A meeting with the Investigator would then be arranged, to follow through points *4.0-5.9* as outlined in the *Research Methodology (Section 3.2).* The case at hand would then be studied in terms of the full amount of evidence available. In all cases this consisted of digital evidence, commonly comprised of:

- Scene photographs (the main bulk of information)
- RTA reports of the incident
- RTA measurements from the scene

- Speed, distance, braking & other metric calculations from scene evidence
- Noted environmental data, such as weather, features, disturbances and collisions with roadside objects
- CCTV evidence, if available
- Overhead maps / googlemap collages of the road plan on which the incident occurred
- Evidence of active/inactive vehicle lights at the point of collision

The Investigator would then be asked what findings they had established at this point in the case. Foremost would be the root cause of each accident, following onto driver reactions, vehicle trajectories, and rest points. Each finding would be noted with comments on the accuracy of each piece of information.

Additional information on the finer points of the incident would then be discussed, for example:

- Vehicle condition prior to the accident, maintenance and modifications
- Occupants, weight, exterior damage and so forth
- How environmental conditions had influenced the vehicles involved
- Assumptions and possible causes of error

Once the case evidence and variables had been discussed to a satisfactory degree, the digital evidence for each case was collected onto a portable hard drive. Due to the amount of high-res photographs covering each event, this method proved to be quite practical. On average, 5-6 cases were discussed in each visit to the police department.

4.3 Reconstruction Process From Evidence

The reconstruction process followed a general procedure that allowed the caseload to be integrated into the PC-Crash software. The procedure for this consisted of the following steps. For each step, a guide to the methodology is given (*for technical program input, see Sections 3.2 & 4.3-4.6*).

Location of incident

The starting point of the reconstruction had to establish the point of impact(s) of the vehicles first. Once the correct road and direction of travel was certain, the necessary area required for pre-accident travel (typically 20 seconds before collision) and post-impact trajectory was found. In most cases a 1km^2 area was required to being the road layout.

Road layout

This area had to encompass all of the events detailed in the incident location. In some cases a full overhead digital map was available from the investigator, but for most cases the road layout was constructed using a series of Googlemap images. Here the satellite views were used at the highest resolution possible and the closest detail available. Several images would be grabbed, trimmed and overlaid in Photoshop to produce a high-resolution overhead map of the incident area. This map would then be imported to PC-Crash as a .tiff file, then scaled using the built-in image scaling tool.

Roadside objects & barriers

Impact with roadside objects was common in the cases involved. The program limitations means that trees, hedges and natural barriers cannot be integrated (See Section 7.2) but artificial barriers and signs can be added to the reconstructions. Where this was the case, the geometry of each barrier was retrieved from the case evidence if possible, or estimated from scene photographs. Each barrier or object was then given a centre of gravity and a mass that would represent its physical properties. Some estimation was required here; a value used for roadside barrier was 1T per m in order to simulate a rectangular or W-shaped motorway crash barrier. All barriers were modelled as rectangular blocks unless stated.

Vehicle types involved

The make, model and year of each vehicle involved in each incident was supplied in the case evidence. Each vehicle was imported into the reconstruction using the built-in database in PC-Crash. Most vehicles could be matched by make, model and year identically. Where this was not possible, a similar model could be used and adjusted for weight, wheelbase and other settings (*See Sections 3.2, 4.4).*

Occupants

Any occupants of the vehicles involved, including the driver, were then added to the reconstruction. This section of settings involved adding a weight to the position of each occupant in the car, using an assumed weight of 90kg per adult or 45kg per child. Specific personal weights of occupants were not available from evidence reports.

Vehicle POI

With the vehicles set up and environment constructed, the point of impact (POI) would then be estimated. The main evidence for establishing this point would be scene photographs, which show marks in the road, debris, tyre marks and so forth. Given that vehicle lengths, widths and other metrics are already known by this stage, this estimation was often made without too much difficulty. The second, more influential variable concerning the POI is the contact angle of the two vehicles (see Section 3.1.). This can be estimated, again from scene evidence, and is mostly determined from the angle and depth of crush damage to each vehicle. This variable was not able to be calculated with any precision and thus remained one of the less accurate variables of the reconstruction.

Vehicle Speeds

Vehicle pre-impact speeds would then be integrated to the program based on the findings from the investigator's report, often quoting a figure for each vehicle within 1 mph, or a minimum speed. This would then allow the initial position of the vehicles to be calculated, based on the time or distance to arrive at the POI. The program 'Path' tool could also be used, which allows the trajectory of each vehicle to be plotted with the mouse.

Braking of vehicles (pre/post-impact)

Where investigator reports denoted that some degree of braking was present before or after a collision, vehicle settings were modified to account for this. A specific degree of braking (related to pedal pressure) was applied to individual wheels on each vehicle, and was integrated to a time, intensity and position depending on the evidence given in the investigator report. Often this measure was at full braking with locked wheels, which was simulated by ceasing any movement of the corresponding wheels. Broken or jammed wheels resulting from impacts were also given this property. The matter of ABS braking could also be integrated if the investigator report had confirmed this was the case.

In cases where tyre marks were present and sufficiently detailed in scene photographs, the shape of these marks were integrated to the program. Usually such marks would be created when ABS braking was not present, or in the case of a vehicle drifting across the road in a skid. The shape of the marks would then be sketched onto the location map using a line tool to mark the start and end of the marks. A vehicle path would then be set to this location, and the start and end of severe braking attached to this path.

Rest positions of vehicles (post-impact)

After the POI, the program automatically calculated the post-impact trajectory and rest positions of each vehicle involved in the impact. For simpler cases involving two vehicles, this calculation was often sufficiently accurate and agreed with scene photos to some degree. For more complex cases with post-impact steering, braking and impact with objects, implementation of a path was necessary using the built-in PC-Crash feature. In these cases, the mouse was used to trace a vehicle path through known points such as tyre marks, road markings, barriers and verges.

4.4 Caseload of RTA Incidents

The RTA cases included in this Thesis were selected with regard to the criteria given in Section 3.2. This resulted in a shortlist of 21 incidents that were variable in format and content. It was then decided that a suitable approach for the work would be to pick an equal amount of introductory, intermediate and advanced cases for reconstruction and critique. The final caseload selected for this report is given in the table below.

RTA	Location	Vehicles	Impact	Evidence	Police Evidence	Police Report
1	Example	2	Moderate	N/A	Example	No
2	Plymouth	2	Minor	Photo	No	No
3	Warnham	2	Fatal	Photo	No	No
4	Danbury	4	Severe	Photo, Witness	No	No
5	Usk A449	2	Fatal	Photo, Scene	Yes	Yes
6	Usk A472	3	Minor	Photo, Scene	Yes	Yes
7	Coldra M4	1	Fatal	Photo, Scene	Yes	Yes
8	M48 Barrier	1	Fatal	Photo, Scene	Yes	Yes
9	Coedkernew	1	Rollover	Photo, Scene	Yes	Yes
10	Aberbeeg	2	Fatal	Photo, Scene	Yes	Yes

Table 4.1: Selected RTA Caseload.

A final caseload of 10 incidents was specified as a suitable number by the project supervisor, which was then agreed to be released by Gwent Police. As the information pertaining to each RTA case is variable, an example will be given from RTA5 in the above table. This was a well-detailed incident that involved the collaboration of Sheffield Hallam University and UK Police, and also included many of the calculations outlined in the previous chapter. For a more detail of the evidence, please see *Appendix I & II*.

4.5 Example of RTA Case Evidence

RTA5: Collision between two vehicles on the A449, Usk, Wales, on 15th October 2011

The following information is taken as evidence from the final report submitted by the RTA Investigator (PC Goddard) assigned to the incident.

Location: At 7.30pm on Saturday 15th October 2011 a two vehicle collision had occurred on the northbound carriageway of the A449 at a point 200 metres prior to the Usk intersection.

Fig. 4.1: Ordnance Survey map of RTA5 area.

Vehicles: (1) Ford Transit Camper van (2) BMW 320i

Road: Average width 7.45m, Lane width 3.3m,

Environment: Rural setting, No street lighting. 70mph speed limit. Nighttime.

Weather: Dry and clear weather, 11 deg C.

Scene Evidence: There were a series of combined tyre and scrape marks in lane one at a point some 79.49 metres prior to the large direction sign.

The combined tyre and gouge marks were 2.8 metres long and indicated the point of impact between the two vehicles (Fig 4.2).

Fig. 4.2: View of the impact marks of RTA5 [Gwent Police]

16.2 metres beyond the impact marks were a set of two striated tyre marks that curved to the left and exited the carriageway. These marks were from the offside tyres of the Ford Camper van. The marks continued until they struck a safety barrier. Beyond the safety barrier there were a series of plough lines and divots leading to the Camper van which had impacted into a leg of a large direction sign. The marks can be seen in Fig 4.3.

Fig. 4.3: View showing the camper van's path of RTA5 [Gwent Police]

On the centre white line and some 32 metres after the impact a locked tyre mark started and progressed across lane two for a distance of 81.6 metres ending under the front nearside tyre of the BMW 320 which was located some 116.5 metres from the point of impact. A second locked tyre mark ran parallel to the one above for the last 45.5 metres and ended under the front offside tyre of the BMW (Fig 4.4). The distance from the point of impact to the end of the skid marks was 116.5 metres.

Fig 4.4: View showing the later stages of the skid marks from the BMW

[Gwent Police]

Conclusions of RTA Investigator PC Goddard

- From the evidence collated I would conclude that at about 7.00pm on the evening of Saturday 15th October 2011 the respective vehicles of a Ford Transit camper van and a BMW 320 were travelling northbound on the A449 between Newport and Usk.
- The camper van appears to be travelling at a steady 51 - 54 mph prior to the impact.
- Over the same distance the BMW was travelling between 91 and 117 mph.
- At a point approximately 200 metres prior to the Usk exit slip both vehicles were travelling in lane one of the dual carriageway.
- For an unknown reason the BMW has collided with the rear of the Ford

Transit.

- If the Ford camper had maintained its progress then the speed of the BMW at this point would be between 99 and 103 mph.
- A post impact event recorded by one of the BMW's safety systems recorded a speed of 87 mph.
- After impact the Ford has veered to the left and collided with a crash barrier on the nearside verge. The van vaulted the barrier and collided with the leg of a substantial sign. The driver died at the scene.
- After impact the BMW has veered to the right into lane two. The brakes have been applied such that the front wheels locked and left skid marks for 116.55 metres. The speed of the BMW at this point was between 74 and 84 mph.
- With the Ford travelling at 51 mph and the BMW closing to the rear at 99 mph an impact is avoidable until the vehicles are within 27.5 metres apart.
- With a closing speed of 48 mph (99 – 51mph) between the BMW and the camper van, the camper van would have been in view for 25 seconds with a direct line of sight for the last 16 seconds before impact.

4.6 Scenario Modelling Methodology

From information given in the above reporting, the modelling scenario will be constructed primarily from these findings of the RTA Investigator, and combined with other mapping information to form a virtual environment. This process typically consists of 3 stages:

- Mapping: Creating an environment representing the scene
- Vehicles & Dynamics: Selecting the most appropriate vehicles and characteristics, with pre-impact speed and direction
- Impact: Reconstructing the moment of impact in the collision

4.6.1 Mapping

First off, a 2D environment that forms the road surface and nearby environment is constructed. This may be modelling using the in-built features of PC-Crash, although it is more illustrative to build an extended map using imported files of Ordnance Survey or Google maps resource. The latter is used for the majority of cases discussed here.

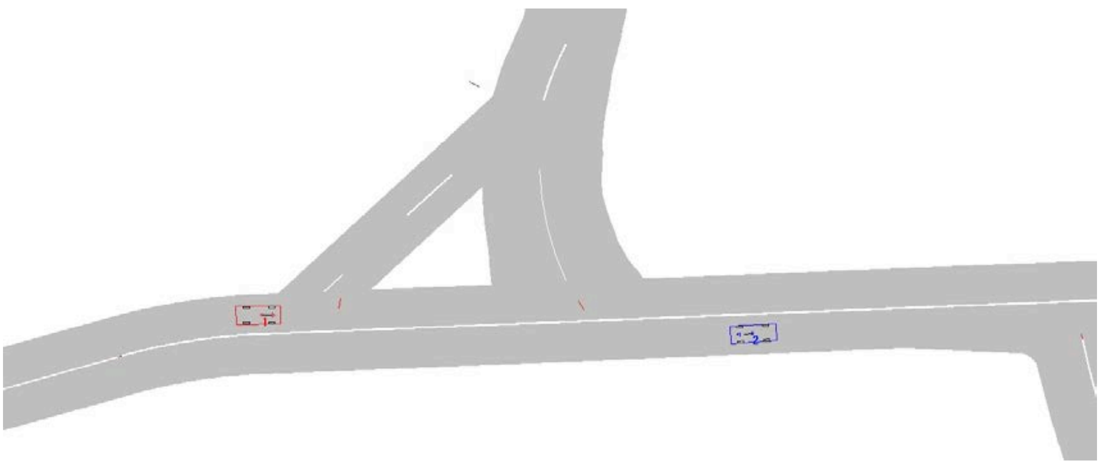


Fig. 4.5: In-built road modelling

Fig. 4.6: Imported Google map

Once a suitable arrangement of 2D overhead images has been formed, the individual parts are combined into a single .jpg file and scaled to size for importing to the software. The map may now be used in the 2D viewport of the program.

Fig. 4.7: Roadside polygons (3=barrier, 4=sign)

Roadside objects can also be constructed as a series of polygons or DXF images. For example, a roadside barrier is a common part of this reconstruction and often takes the form of a solid rectangular polygon of constant cross-section (Fig. 4.7). Similar objects such as lampposts and road signs can be constructed using the same process (Fig. 4.8). The physical characteristics of such objects, i.e. stiffness and inertia can be specified in exactly the same manner as vehicle characteristics such as kerb weight and centre of gravity (See 4.3.2). The most straightforward method is to designate a large value of mass to the object, i.e. 10,000kg for a roadside barrier.

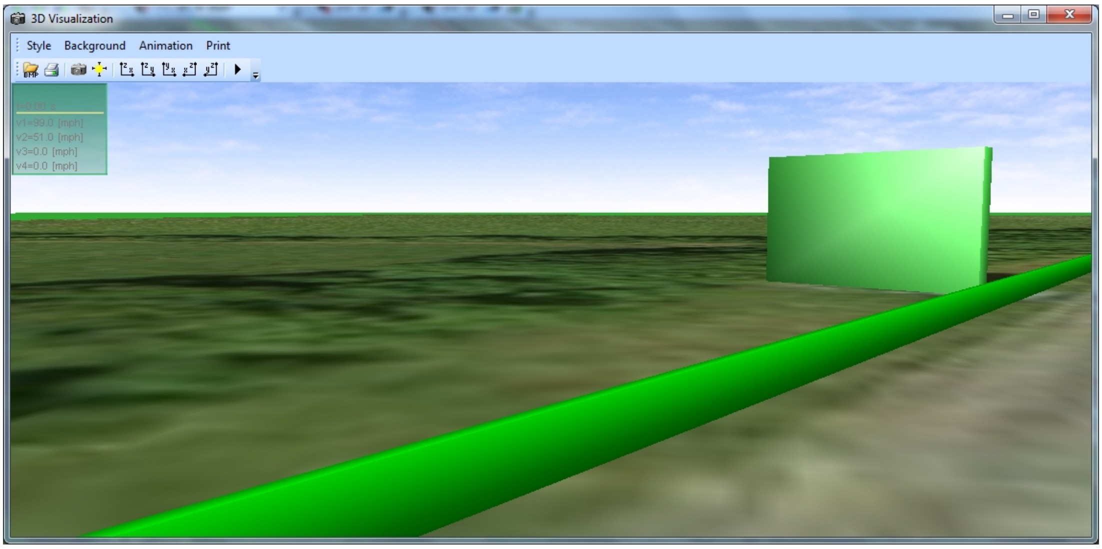


Fig 4.8: Roadsign and barrier polygons, 3D view

4.6.2 Vehicle Modelling

The range and scope of cars and other vehicles on the roads means that a basic, generic model of a car is unsuitable for collision modelling. Fortunately, the PC Crash program contains a verbose library of vehicles of various types which can be readily implemented with a few clicks of the mouse. This section demonstrates how to tailor the specifications, attributes and individual features of a vehicle in a collision to represent it with the most accuracy. The blocky appearance of vehicles can be improved by using the 3D models included in the software.

4.6.3 Vehicle Setup

The operating environment of PC-Crash is a 2D view as shown in Fig. 4.9 below. The schematic of a car body can be seen along with the range of tools used to construct a scene.

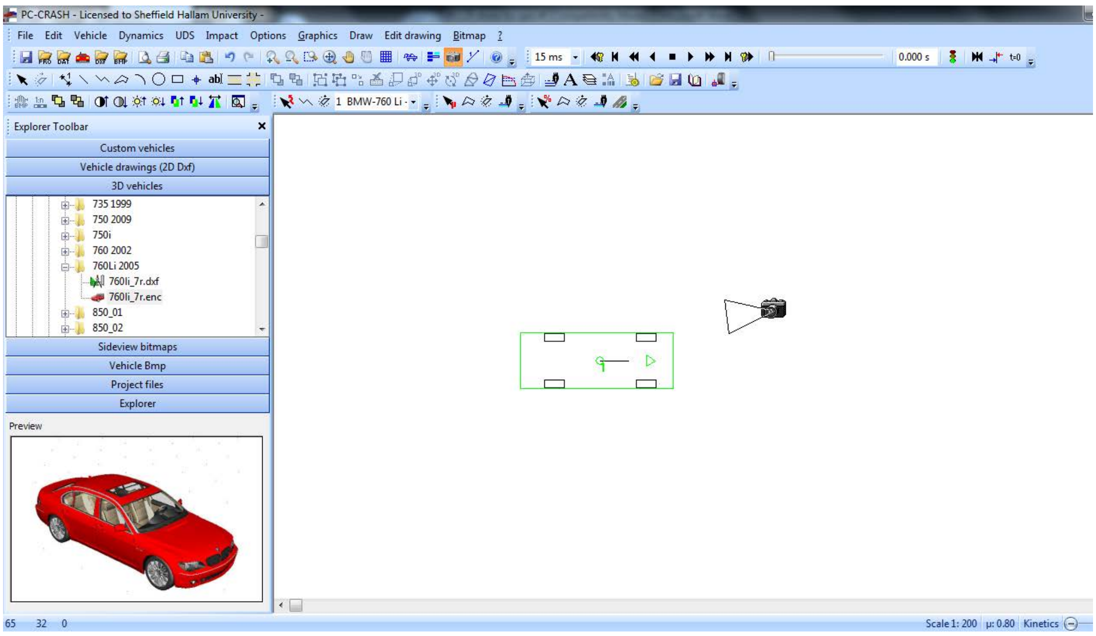


Fig 4.9: Main viewport of PC-Crash

Attention needs to be given when selecting the appropriate vehicle for the scene, as there are many options. First consideration should be given to choosing the Make, Model and Year of Manufacture first. Next, the specifics of the vehicle, such as engine size or spec (TDi, 16V etc.) should be selected.

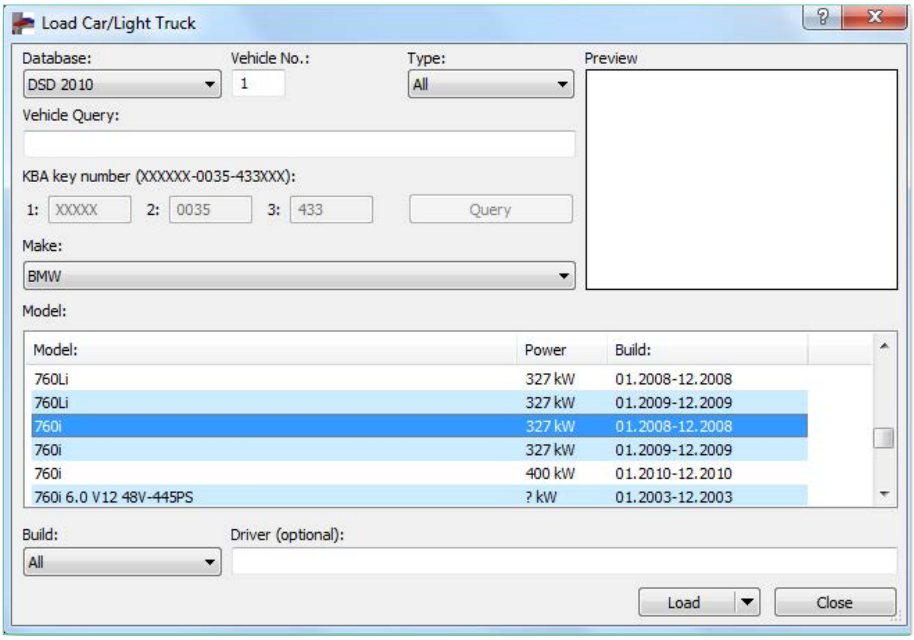


Fig 4.10: Vehicle selection from database

4.6.4 Vehicle Data

It is possible to modify the suspension, occupants, brakes and shape of the vehicle. There are 8 sets of options contained to describe the basic vehicle properties. Most significant of these is the Weight, which is also known as Curb Weight (i.e. the vehicle without occupants or cargo). The centre of gravity (C.G.) can be specified too, along with ABS, wheelbase and axle measurements. This is important when considering rollovers and other crashes where vehicles tilt significantly. Vehicle dimensions can be changes such as length or width, but these are likely to be consistent with the model. Figure 4.11 demonstrates the typical input for a vehicle.

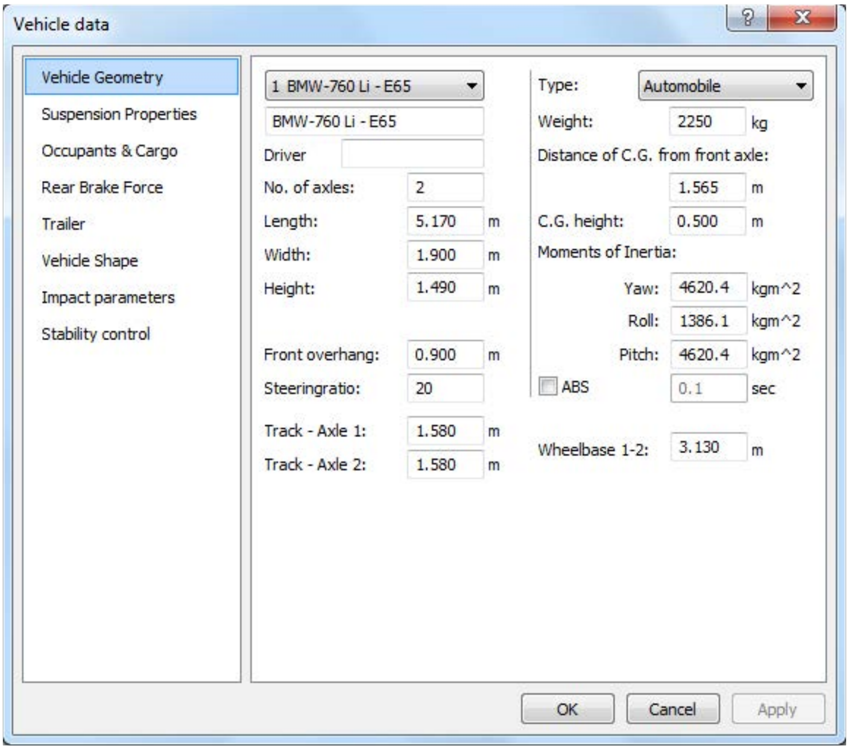


Fig 4.11: Vehicle geometry input

Vehicle Suspension may also be specified for each vehicle. The suspension and damping of the vehicle can be specified for each wheel, if known then may be inputted in *N/m* or *Ns/m*. Often this information is often hard to obtain, so "*Stiff / Normal / Soft*" options are available. A good example of using this option would be to use "Stiff" for a sports model, i.e. Audi S5.

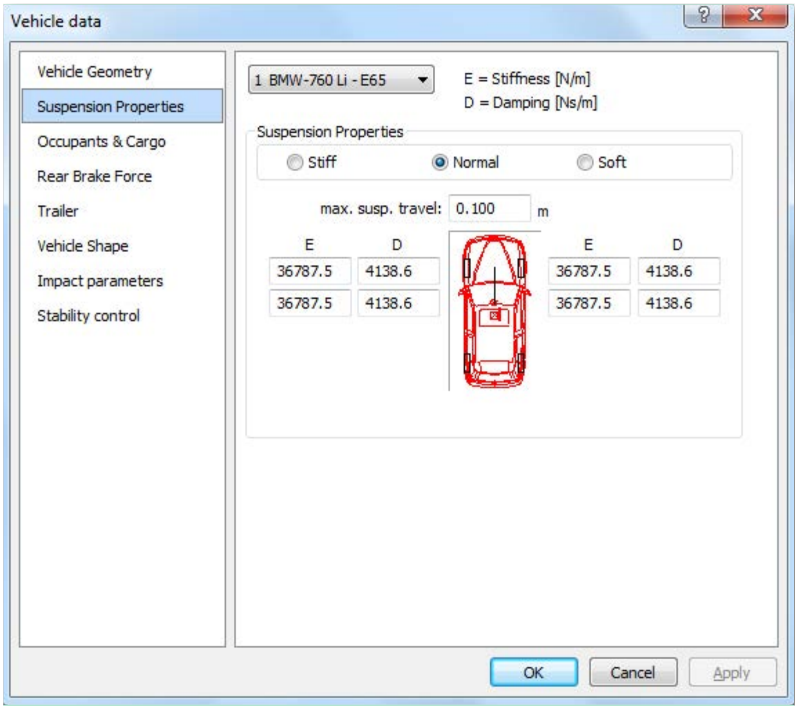


Fig. 4.12: Suspension properties input box.

Occupants & Cargo can also be specified, as the weight on anybody in the vehicle will influence physical behaviour of the model. This figure can include passengers (front or back seat), baggage and roof loads. It is recommended to use more descriptive settings for trucks and trailers, dependent on the loading of the vehicle and cargo.

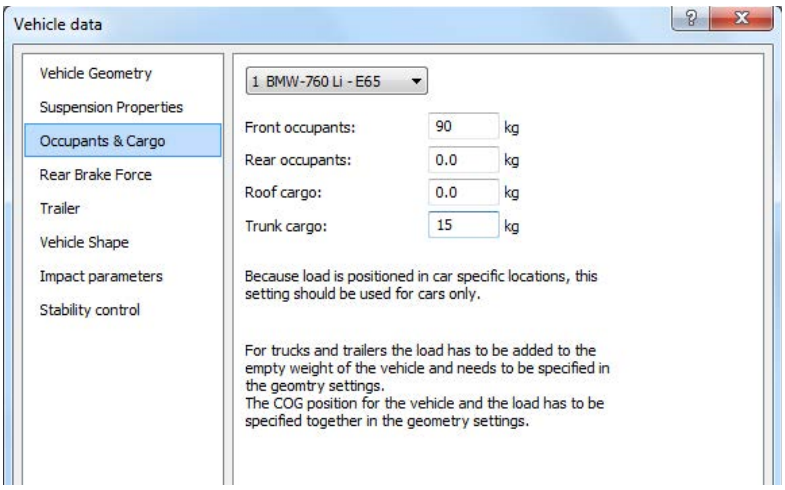


Fig. 4.13: Occupants & cargo input box.

Shape of Vehicle allows each measurement of the vehicle body to be specified. A more simple approach than putting in individual dimensions between each section of the car is to select one of these three vehicle styles: Sedan, Hatchback or Van. The letters on the schematic denote the length of each section (see Fig. 4.14)

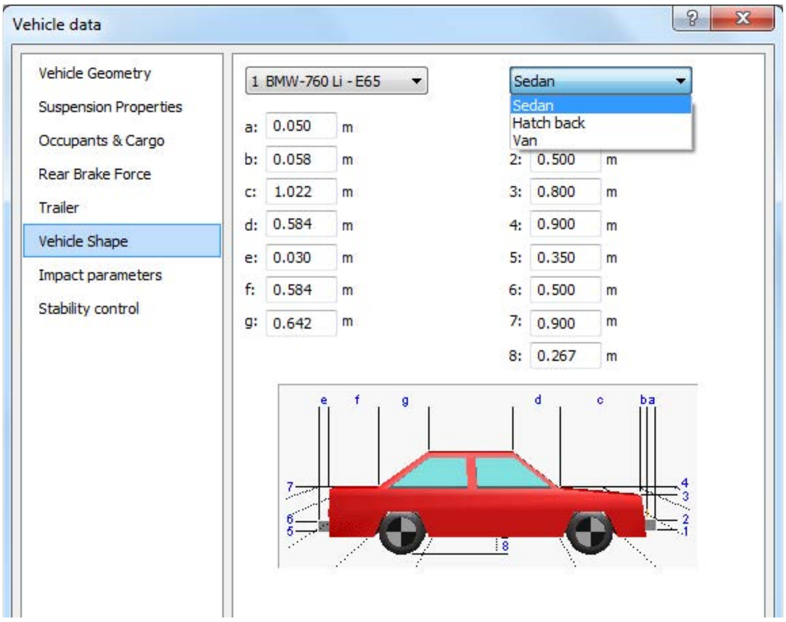


Fig. 4.14: Vehicle geometry input box.

Stability Control is available as an option if ESP (Electronic Stability Program), also known as DSC (Dynamic Stability Control) was activated on the vehicle at the time of collision.

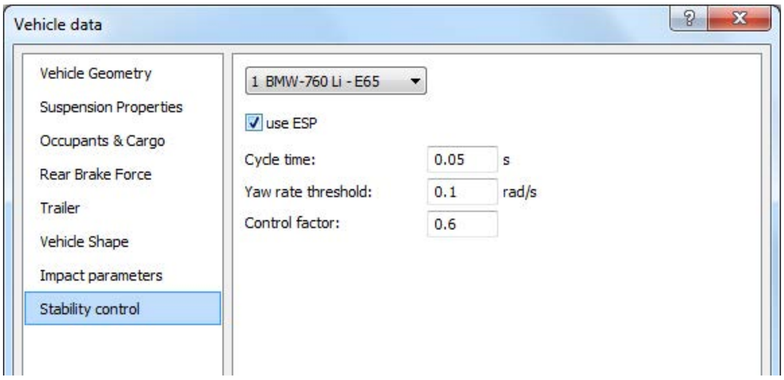


Fig. 4.15: Stability control input box.

Engine and Drivetrain specifications are also available although not all of these are used frequently and are not necessary for basic collisions. For example, if a vehicle in a crash was not accelerating, then the engine options can be kept as standard. In cases of a vehicle known to be accelerating along a path before a collision, the power and variables of the engine can be important to the accuracy of the reconstruction (See Fig. 4.16 below).

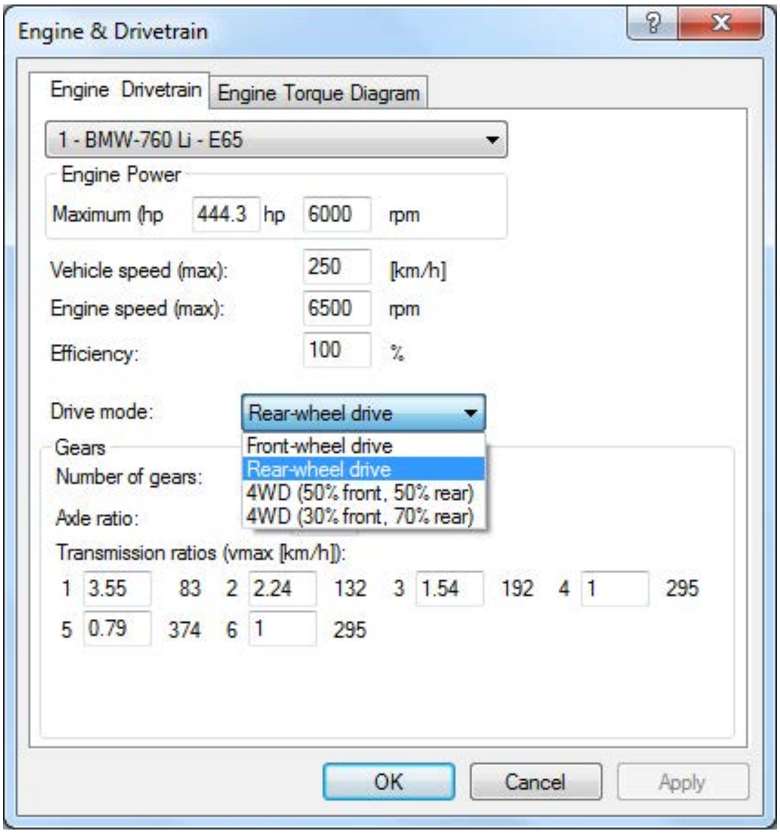


Fig. 4.16: Engine & Drivetrain control box.

Tyre Model characteristics are useful to model a stopping distance or rest position after impact. The basic tyre specifications can be given in measurements or 'R' size for the front and rear axles. This will display the dimensions of each tyre in *mm*, which can be modified, as can the "Lateral Spacing" of truck and HGV tyres (not applicable to cars). Note: Linear tyre models are only considered in the modelled cases.

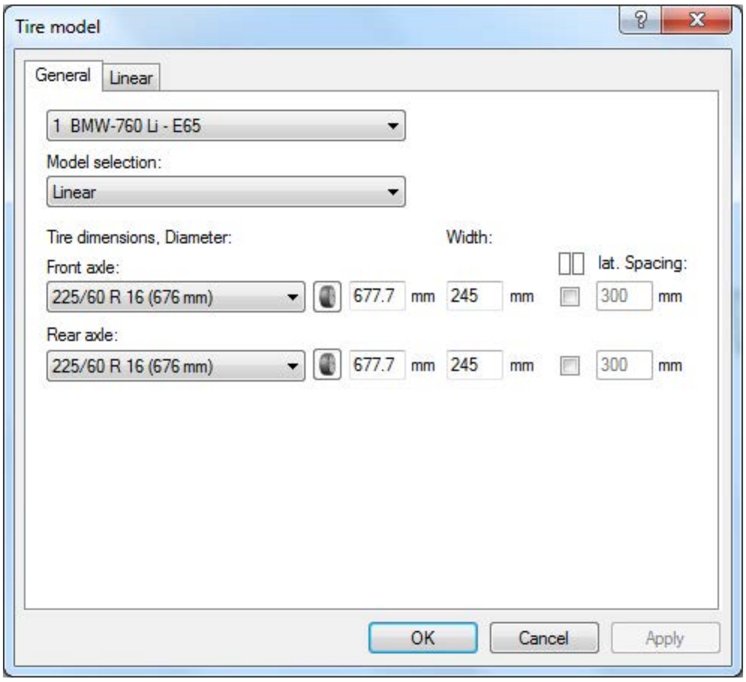


Fig. 4.17: Tyre model general input box.

Linear Tyre Model options may be modified for non-standard characteristics regarding the tyres used on the vehicle. Here the maximum lateral slip angle of each individual tyre can be specified.

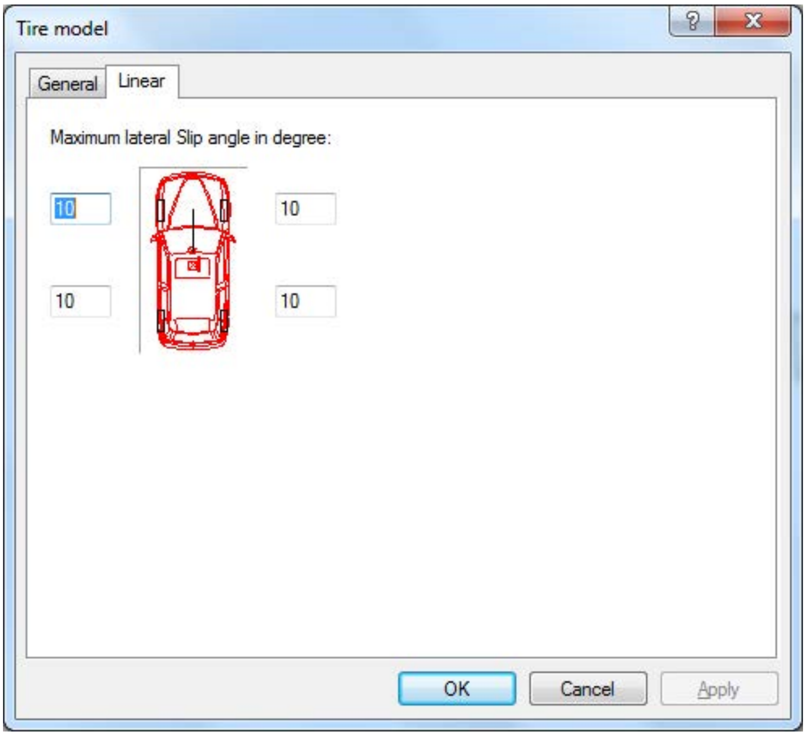


Fig. 4.18: Linear Tyre Model control box.

3D Models are of assistance in improving the graphical capabilities of the software. A vehicle catalogue of DXF files of 3D models can be used to give a more realistic look to the reconstructions. The figure below shows the catalogue icon and rendered view for a BMW 760i model. Colours can be chosen once the file is imported. It should be stated clearly that the DXF files are a purely graphical input to the program and have no physical influence on the simulations whatsoever.

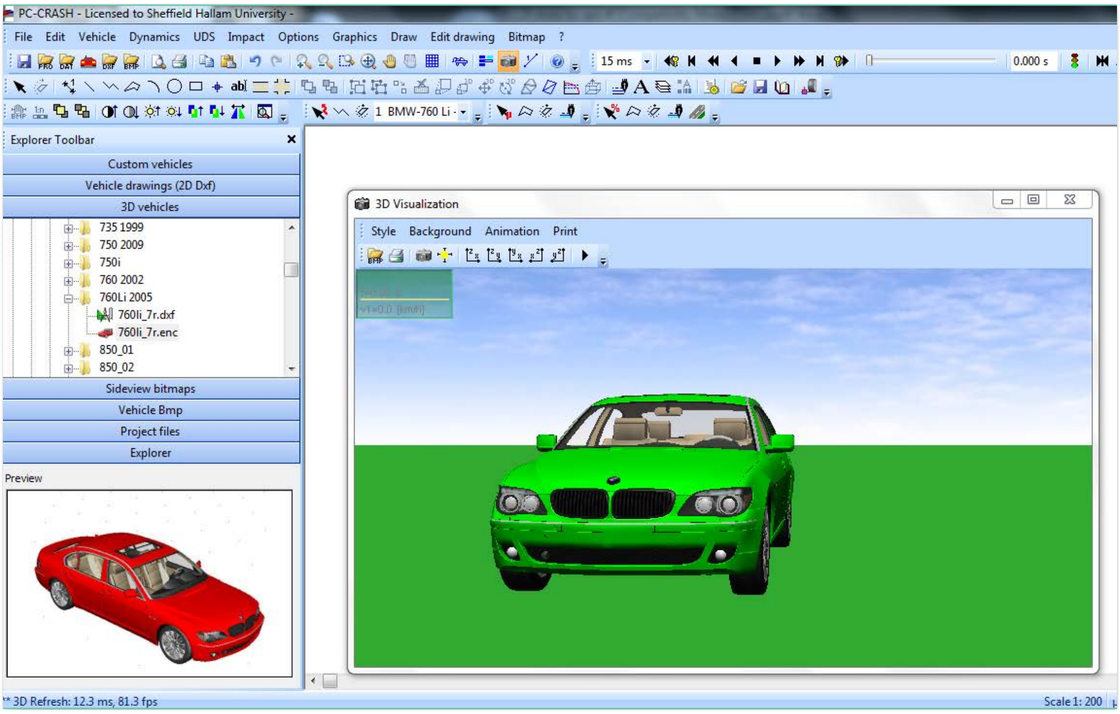


Fig 4.19: 3D Vehicle view

4.6.5 Dynamics & Trajectory

It is possible to designate a simple speed for each vehicle in the modelled scenario and cause and impact by a cross in trajectory alone, however, this is not representative of control by a driver of a vehicle. In these cases, different motion sequences for each vehicle, such as braking, acceleration, steering and driver reaction were defined in causing a collision.

The *Sequences* control enables different sequences can be combined to reflect the driver's actions for each vehicle, for pre-impact and post-impact timeframes. With this control, the time @ *t=0* seconds is assumed to be the moment of impact, such that pre-impact and post-impact driver reactions can be considered.

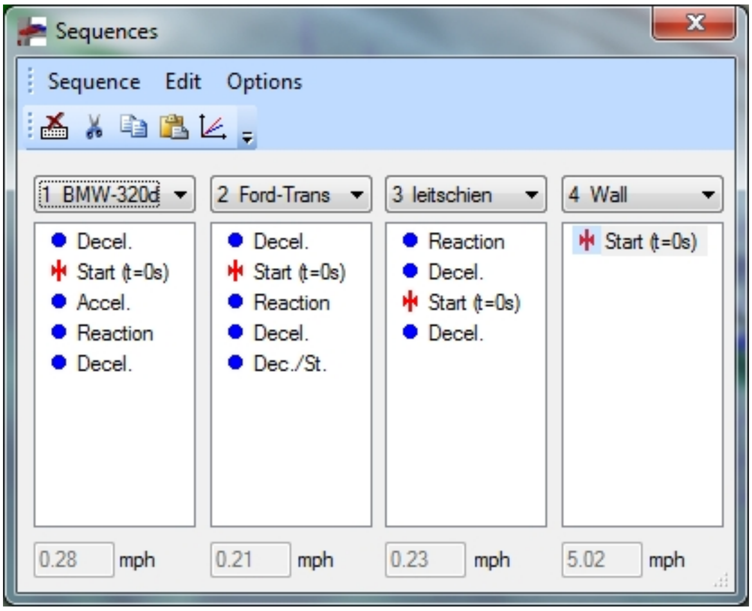


Fig. 4.20: Sequences control box.

A typical crash will consider a period of acceleration or braking before *t=0*. Figure 4.21 below shows how this may be applied, in terms of duration, pedal position and steering control. A “Lag” may be also be added, as a typical human reaction takes around 200ms to occur. “Lane changes” may also be programmed, which are helpful for Motorway incidents. The sequences control acts as a relay of these reactions, one after the other, for each vehicle involved in the scenario.

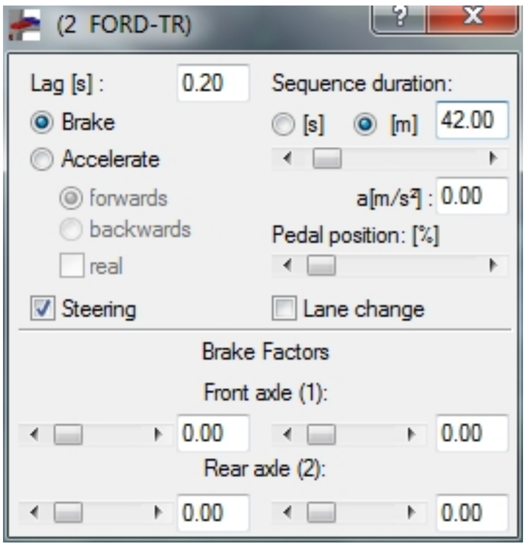


Fig. 4.21: Braking & acceleration control box.

The Brake control options are quite pertinent to crash modelling. Much of the information from the RTA caseload concerns braking distances, so it is a major part of the reconstruction detailed in this document. Each individual wheel can have a designated braking factor, and can be "locked" so as not to move. This aspect is particularly useful to model punctured tires and damaged wheels after the *t=0* point.

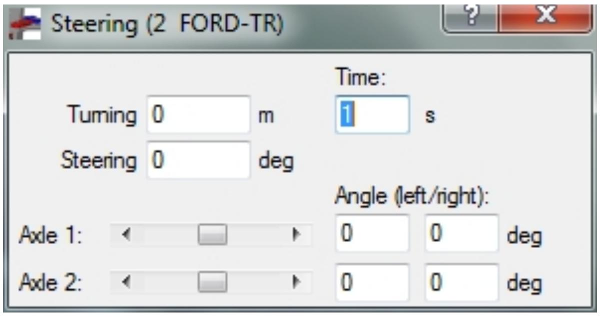


Fig. 4.22: Steering control box.

The pre-impact trajectory of the vehicles can be determined by sole use of the "Steering" commands in the Driver Reaction sequences, but the use of "paths" is a more accurate way to model this. Each vehicle can be designated a coloured trajectory "path" as seen in red in Figure 4.23.

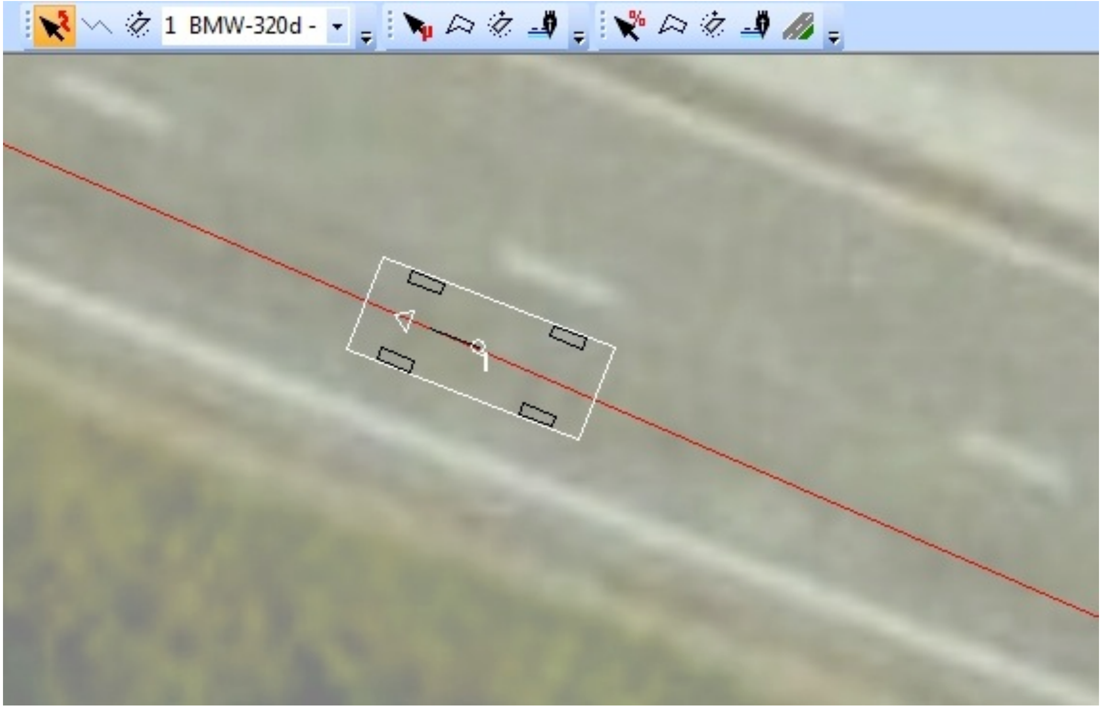


Fig. 4.23: Implementation of paths to control vehicle (red line).

Once speed, braking and other reactions have been inputted, the definition of a vehicle's steering will be determined by the pre-defined path. This feature is useful for reconstructing the movement of a vehicle from CCTV footage, where several static frames of the scene are used as evidence. Additionally, rebounds of vehicles from crash barrier, for example on motorways, often require use of the path function.

4.6.6 Impact

This is the most critical part of the collision modelling. The point at which vehicles modelling in the reconstruction first collide will determine how momentum is transferred to each vehicle for the post-impact trajectory and how much damage is inflicted on each vehicle body. The coefficient of restitution ε and coefficient of friction μ are of high influence at this point (see theory, *section 3.1*).

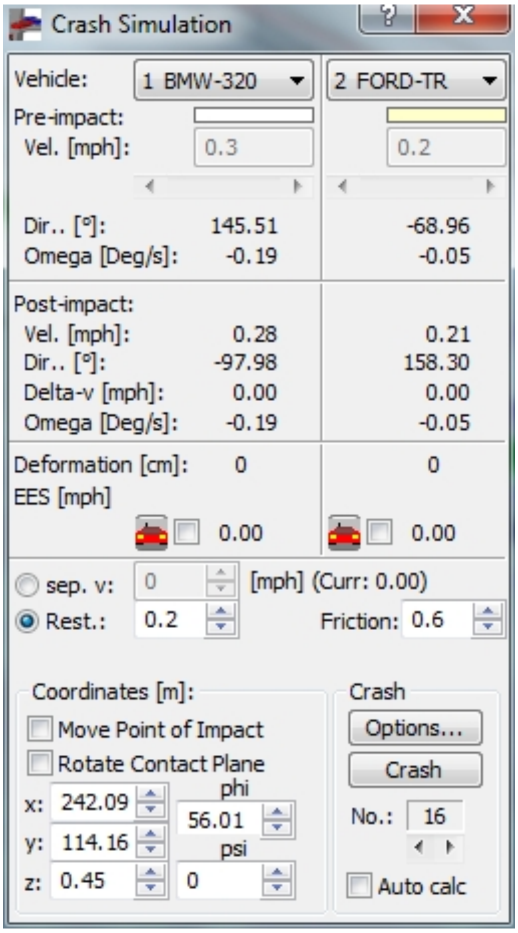


Fig. 4.24: Crash simulation control box.

The *Crash Simulation* parameters are illustrated by the function box in Figure 4.24. Here the main inputs are:

- *Pre-impact velocity*: input if not determined by accelleration/braking driver reactions
- *Rest*. (*Restitution*): usually 0.1-0.3 for most collisions [0.2]
- *Friction*: inter-vehicle friction in this instance [0.6], not to be confused with road-to-tyre contact friction

Unless specified otherwise, these values are set to the values in square brackets above for the RTA caseload.

For each collision, the Crash Simulation function then determines the Point of Impact and post impact parameters for each individual impact:

- *Post-impact velocity*
- *Direction of post-impact travel*
- *Delta-v*
- *Omega (Yaw or tilt)*
- *Deformation (in cm or EES)*

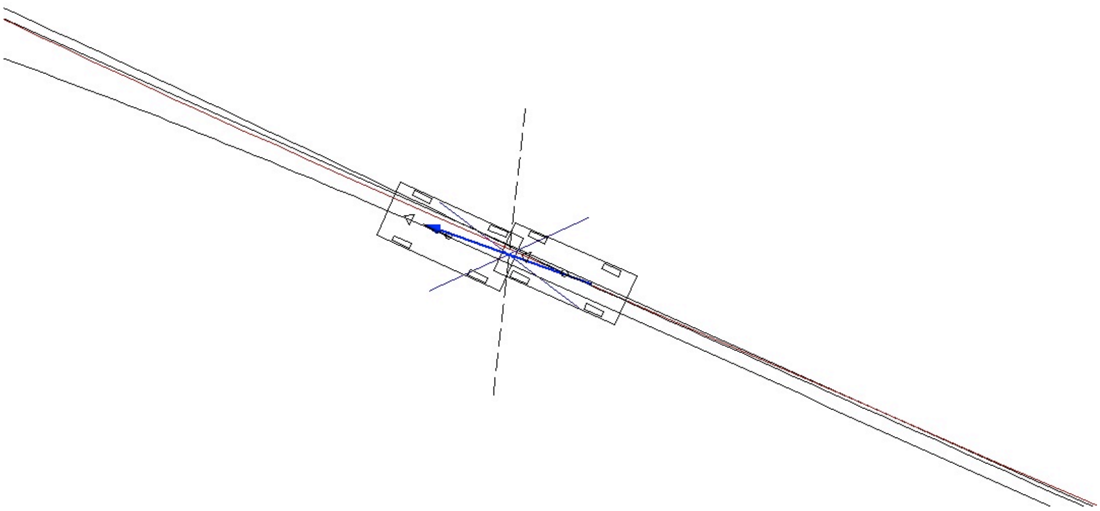


Fig. 4.25. Typical 2-vehicle impact schematic

A typical car-to-car collision is demonstrated by the schematic above in Figure 4.25. Here the contact plane can be seen as a dashed line, at a slight angle to overlap of the vehicle outlines. The resultant force vector is shown in blue, with the POI marked as a large X. The pre- and post-crash vehicle paths are also shown as long red, blue and black lines.

It is important to state that what would normally appear as a single impact is often modelled by PC-Crash as several "Crashes" in this Simulation function. This is due to several impact points occurring within the very short timeframe of the crash, which typically takes place in 30-100 ms. During this timeframe the software considers each occasion in which the vehicle shapes are in contact. Hence, it helps to consider this function as modelling the crash with several continuous periods of subsequent smaller impacts, rather than one clean contact from which the vehicles are immediately separated. Such “singular” impacts are possible, but only in the unlikely scenario when both vehicles have parallel and flat impact points that do not interlock at any point post-impact. For example, Figure 4.26 below shows a vehicle in continuous contact with a crash barrier.

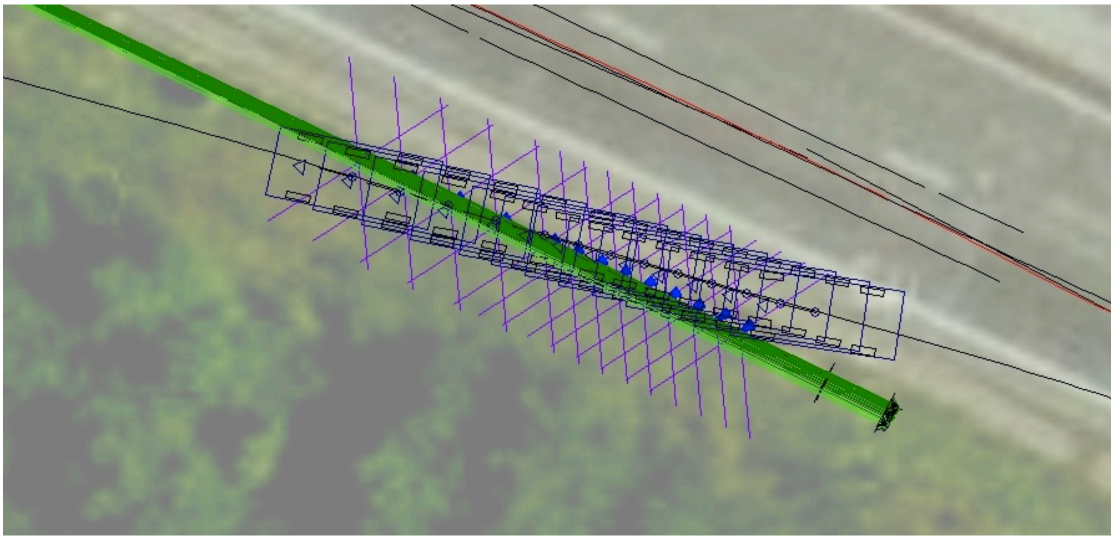


Fig. 4.26: 2D view of multiple POIs (purple X).

Following the completion of all crash simulation calculations, the software will automatically calculate the rest position of all vehicles in the simulation. There is another module for a “Crash-backwards” function to optimise this feature, although this has not been necessary for the scope of this study.

4.7 Accuracy of Evidence

Here some discussion is given to the methods in which police investigators gather evidence and how accurate these processes are. Cases from Gwent police form the bulk of this thesis and only incidents from this constabulary will be discussed here.

On arriving at the scene of an RTA, the police investigator will have multiple responsibilities. The following discusses what technical evidence is to be gathered, and how potential loss of accuracy could occur.

Witnesses

The investigator will gather statements from all persons present at the scene. This may include drivers, passenger, passers-by, local residents and also other police present at the scene. A brief statement can be taken as notes or audio which is usually then expanded on in full at the local station. This form of evidence is not technical, but highly influential; a vocal statement from a person in court may be powerful in determining a case. The loss of accuracy with this kind of evidence can be due to anything from memory, to fear, deceit and shock. Hence this is very hard to quantify in a technical context. For all cases included in this thesis, witness statements are wholly disregarded for these reasons.

Measurements

The investigator will then gather a list of RTA measurements required from the scene. This may include

- Skid marks: obtained with a tape measure or laser device. Accuracy is dependent on visibility of the marks and the device calibration. Most measurements in this thesis are given to the nearest metre, providing some error to each case. It is understood that accuracy is limited more by time rather than the precision of equipment.
- Vehicle paths: established by observing tyre marks. Plastic ‘markers’ are placed in the paths and then photographed. This is especially helpful for nighttime incidents. Accuracy is dependent on this skill of the investigator

present. Reconstructing vehicle paths via this method will have resulted in some inaccuracy, although the start and end points between impacts were the vital information for simulations. Detail on these areas was abundant with many photographs, inclusive of measurement information.

- Environmental damage & features: gathered by professional expertise, i.e. matching marks on a roadside barrier to scratch marks on vehicle bodies. This is accurate to establish a 'point of impact' to a specific vehicle, but the point in question can be variable to 0.5-1 vehicle lengths. This is an error which can be easily integrated to the reconstruction. RF: Environmental objects such as signs, barriers etc. are static and relatively easy to place on an overhead-view map. Natural environmental objects are variable in size and position and represent a great difficulty in simulation.
- Weather, temperature, conditions: measured or observed at the scene. A thermometer or laser temperature device is mostly used to get ambient conditions, but more importantly, road surface conditions. A digital/laser thermometer will be typically be accurate to one decimal place. These measurements are influential to tyre-road friction and given strong concern. Combined with information from weather reports, data in this field is typically accurate.
- Visibility, Daylight, Street lighting: a matter of observation, thus somewhat subjective. However the time of the incident will be carefully noted, allowing sunlight and weather data to be retrieved later. The subjective nature of the visibility status on the ground at the time (or some time after) of the incident could benefit from greater accuracy. For example, a foggy morning may be described as 'light fog' or 'low visibility' depending on the investigator present. Such conditions dramatically influence the driving conditions prior to the incident and can be a source of error regarding incidents.

Vehicles

It is routine to photograph any vehicles in situ and perform more detailed analysis at another location. The caseload indicated that the following measurements were performed as standard:

- Model, working order, modifications, MOT, overall condition: obtained by a police garage and records check. The main purpose is to ascertain if all UK vehicle standards were met before the incident and that the car was in a roadworthy condition. The accuracy of establishing this depends on the staff in question, as inspecting a damaged vehicle requires some forensic skill.
- Vehicle damage & crush: an important method for determining the POI and pre-impact velocity. This may included vehicle-to-vehicle and nearby object impacts. Some expertise is again required, although crush damage measurements are commonly made with a standard tape measure to the nearest cm. This was a large source of error influential to the reconstructed simulations.
- Tyres: tread remaining will be measured with a gauge (to 0.1mm accuracy) and inflation pressure can be either be measured or estimated from the profile and wear. Typically this falls within a legal/nonlegal category. Underinflated tyres are an often overlooked cause of incidents due to the increase of braking distance and loss of control.
- Lights: the use and activation of vehicle lights at the POI can be accurately assessed using a specialist technique. The filament of the bulb can be studied to ascertain whether each light was off or on at the moment of impact. An activated brake light, for example, would show a stretched ‘loop filament’ for a low-speed impact and a ‘hot break’ for a high-speed impact. Likewise, a unactivated light would show a ‘cold break’ of the filament. The process is reliable and has been used in court several times, although is thoroughly ineffective for LED lighting.
- Vehicle computer units: recent and more sophisticated vehicle technologies allow the unit computer to be taken out and connected. Here a wealth of data can be extracted, e.g. speed at impact, emergency braking, vehicle warning systems. This information has the highest degree of accuracy.

After all settings were integrated to the software, an initial reconstruction would be prepared for criticism (as shown in Chapter 5.)

4.8 Integrating Investigator's Data & Accuracy in Reconstruction

Part of the skill of an RTA investigator's job is to balance all the available information and form a firm conclusion about the incident. This is a complex task due to the multiple forms of evidence and respective accuracies.

For these reasons, the process of reconstruction is often based on a hypothesis. The most likely pre-crash scenario would be assessed and used for a trial reconstruction. The evidence would be integrated (as described in Section 3.2) and an initial reconstruction would then simulate the POI, vehicle trajectories, and rest positions.

From this point, all measurement errors from the evidence gathered would be used to refine the process. A good, common example is moving the POI; if such a point was in the middle of a road, the accuracy may be 0.5m in any direction. The software allows trajectories and rest positions of vehicles to be assessed in real-time as the POI is moved. The same principle is true of vehicle speeds, allowing the scenario to be improved significantly using these means.

Secondary refinements would typically adjust reconstruction variables such as vehicle-to-vehicle contact angle, friction, and restitution settings. These values are all either automatically calculated or set as default in the software, and adjustment of these helps to define the characteristics of the impact.

Subsequent adjustments would involve surface friction to compensate for weather conditions. Road friction is commonly measured at a coefficient of 0.7-0.9, although for wet and icy conditions this will drop. Other subsequent changes made would be vehicle settings, for example centre of gravity, occupants and loading, and perhaps tyre settings (e.g. for underinflated or worn tyres), although no tyre adjustments were required for the caseload demonstrated here.

Overall the most commonly adjusted settings in the caseload studied consisted of:

- Vehicle-to-vehicle restitution
- Vehicle-to-vehicle friction
- Road/surface friction
- Point of Impact
- Contact Angle / Angle of Impact

It is noted that the adjustment of these settings deserves further discussion to the effect of the reconstruction process. Such discussion is continued in Chapter 6.

4. Research Methodology & Approach

This study took an approach that involved a process of *meeting, modelling, demonstration* and *critique/review* for a series of traffic incidents. This chapter describes how to follow this process from the Investigator's perspective, plus that of the individual simulating the incident in question.

For each incident, the research methodology followed the structure of a basic iterative process which is described in a general fashion here. In the first stage, a meeting with an RTA Investigator would be set up to discuss suitable RTA cases for the research. Suitability of each incident for modelling would be discussed based on current legal status of the case, number and type of vehicles involved, environment surrounding the incident, evidence currently available, and so on *(See Section 3.2)*.

Once a case was agreed as suitable, material such as scene evidence would be handed over (typically in digital formats). The incident would then be reconstructed using the available information. An initial collision simulation was modelled into a 'test' scenario from evidence available at the time, encompassing features such as vehicle type, road layouts and points of impact. The simulation would then be rendered into 2D and 3D reconstructions. The reconstructions were then demonstrated to RTA police staff to gather detailed and critical feedback on the accuracy of the simulations. After this point, the simulations were then openly reviewed to enhance the accuracy of the reconstruction, using the guidance of police feedback. Findings from this critique would then be used to identify shortcomings in the process and software.

4.1 Obtaining a RTA Caseload

It was agreed between the RTA department of Cwmbran Police, Wales, and Sheffield Hallam University that access to recent cases would be made available and use of information permitted for research purposes only. Following this, a visit to Gwent Police HQ in Cwmbran was made. The first meeting with an Investigator took place in June 2012. In this meeting, a template process was proposed and followed that is summarised by the following points.

A specific RTA case was requested, based along the type of incident and vehicles involved. This decision would be made according to the recommendations of the investigator, the known capabilities of the software (i.e. availability of relevant vehicle models), and the caseload required for thesis reporting. A discussion on the suitability of the case would then take place, taking note of the following points and aiming to fulfil each of the criteria below.

Legality

The incidents considered needed to be free of any existing investigative or legal proceedings that could be compromised by distributing evidence from the case. This issue was circumnavigated by considering only cases in which a court judgement had been passed, therefore, knowledge of the case and outcome was in the public domain.

Vehicles Involved

The vehicles subjected to an impact in the case needed to have been available for modelling in the reconstruction program. This point was mainly dependent on the library of vehicles included in the software package at the time of reconstruction, which fortunately included an EU, UK & US database up to the year 2012. This did not cause any caseload issues with standard 4-wheel passenger vehicles, but some complexity arose when this was not the case.

Vehicles Unsuitable for Reconstruction

Two categories of vehicles were exempted from reconstruction: Motorcycles and HGVs. This decision was made on the recommendation of RTA investigators and with regard to the scope and timeframe of the research.

Motorcycles

Although incidents with motorcycles are common, reconstruction of incidents is challenging even for an experienced investigator. First of all, a higher percentage of motorcycle incidents involve fatalities of the rider, effectively removing one side of the description of how the incident occurred. Secondly, the loss of control of any bike leaves a variable and inconsistent pattern of road markings at the scene. Sometimes the extended parts of a bike, i.e. footrests, handlebar edges can be traced to metallic marks on the road, but this mostly effective for a 'crash and slide' incident. The less fortunate, but more common, result is that the bike may rotate and land in a varied fashion after an impact, making the trajectory and POI hard to find accurately. Thirdly, compared to solid-body vehicles, bikes are much harder to extract crush damage information from. The outline of a bike construction is more complicated than the polygonal form of a car, and in addition, less glass, panels, lighting were present to provide clues to the investigator. Bicycle cases were also excluded for the same reasons.

Heavy Goods Vehicles

HGV type haulage vehicles were exempted for different reconstruction concerns. Although it was fully possible to integrate many HGV types to the software, a typical haulage vehicle can be included as two parts (truck and trailer) with respective settings, stiffnesses and weights. However, the combined physical body of two vehicles introduced many more variables into the modelling, i.e. cargo and position, linkage characteristics, specific truck types, number of wheels, trailer steering and so on. Such information was not forthcoming in the RTA investigator's files. This made for a much more complicated reconstruction, which then proved hard to obtain a confident degree of accuracy. In addition, cases involving HGVs were not plentiful, as these tended to be handled by insurance companies after an incident, rather than be subject to police investigation.

These principles were not obstructive to cases involving single-body large vehicles such as buses or coaches, which were not overtly complex to integrate to the reconstruction program.

4.2 Meeting with Investigator & Integrating Evidence

A meeting with the Investigator would then be arranged, to follow through points *4.0-5.9* as outlined in the *Research Methodology (Section 3.2).* The case at hand would then be studied in terms of the full amount of evidence available. In all cases this consisted of digital evidence, commonly comprised of:

- Scene photographs (the main bulk of information)
- RTA reports of the incident
- RTA measurements from the scene

- Speed, distance, braking & other metric calculations from scene evidence
- Noted environmental data, such as weather, features, disturbances and collisions with roadside objects
- CCTV evidence, if available
- Overhead maps / googlemap collages of the road plan on which the incident occurred
- Evidence of active/inactive vehicle lights at the point of collision

The Investigator would then be asked what findings they had established at this point in the case. Foremost would be the root cause of each accident, following onto driver reactions, vehicle trajectories, and rest points. Each finding would be noted with comments on the accuracy of each piece of information.

Additional information on the finer points of the incident would then be discussed, for example:

- Vehicle condition prior to the accident, maintenance and modifications
- Occupants, weight, exterior damage and so forth
- How environmental conditions had influenced the vehicles involved
- Assumptions and possible causes of error

Once the case evidence and variables had been discussed to a satisfactory degree, the digital evidence for each case was collected onto a portable hard drive. Due to the amount of high-res photographs covering each event, this method proved to be quite practical. On average, 5-6 cases were discussed in each visit to the police department.

4.3 Reconstruction Process From Evidence

The reconstruction process followed a general procedure that allowed the caseload to be integrated into the PC-Crash software. The procedure for this consisted of the following steps. For each step, a guide to the methodology is given (*for technical program input, see Sections 3.2 & 4.3-4.6*).

Location of incident

The starting point of the reconstruction had to establish the point of impact(s) of the vehicles first. Once the correct road and direction of travel was certain, the necessary area required for pre-accident travel (typically 20 seconds before collision) and post-impact trajectory was found. In most cases a $1km^2$ area was required to being the road layout.

Road layout

This area had to encompass all of the events detailed in the incident location. In some cases a full overhead digital map was available from the investigator, but for most cases the road layout was constructed using a series of Googlemap images. Here the satellite views were used at the highest resolution possible and the closest detail available. Several images would be grabbed, trimmed and overlaid in Photoshop to produce a high-resolution overhead map of the incident area. This map would then be imported to PC-Crash as a .tiff file, then scaled using the built-in image scaling tool.

Roadside objects & barriers

Impact with roadside objects was common in the cases involved. The program limitations means that trees, hedges and natural barriers cannot be integrated (See Section 7.2) but artificial barriers and signs can be added to the reconstructions. Where this was the case, the geometry of each barrier was retrieved from the case evidence if possible, or estimated from scene photographs. Each barrier or object was then given a centre of gravity and a mass that would represent its physical properties. Some estimation was required here; a value used for roadside barrier was 1T per m in order to simulate a rectangular or W-shaped motorway crash barrier. All barriers were modelled as rectangular blocks unless stated.

Vehicle types involved

The make, model and year of each vehicle involved in each incident was supplied in the case evidence. Each vehicle was imported into the reconstruction using the built-in database in PC-Crash. Most vehicles could be matched by make, model and year identically. Where this was not possible, a similar model could be used and adjusted for weight, wheelbase and other settings (*See Sections 3.2, 4.4).*

Occupants

Any occupants of the vehicles involved, including the driver, were then added to the reconstruction. This section of settings involved adding a weight to the position of each occupant in the car, using an assumed weight of 90kg per adult or 45kg per child. Specific personal weights of occupants were not available from evidence reports.

Vehicle POI

With the vehicles set up and environment constructed, the point of impact (POI) would then be estimated. The main evidence for establishing this point would be scene photographs, which show marks in the road, debris, tyre marks and so forth. Given that vehicle lengths, widths and other metrics are already known by this stage, this estimation was often made without too much difficulty. The second, more influential variable concerning the POI is the contact angle of the two vehicles (see Section 3.1.). This can be estimated, again from scene evidence, and is mostly determined from the angle and depth of crush damage to each vehicle. This variable was not able to be calculated with any precision and thus remained one of the less accurate variables of the reconstruction.

Vehicle Speeds

Vehicle pre-impact speeds would then be integrated to the program based on the findings from the investigator's report, often quoting a figure for each vehicle within 1 mph, or a minimum speed. This would then allow the initial position of the vehicles to be calculated, based on the time or distance to arrive at the POI. The program 'Path' tool could also be used, which allows the trajectory of each vehicle to be plotted with the mouse.

Braking of vehicles (pre/post-impact)

Where investigator reports denoted that some degree of braking was present before or after a collision, vehicle settings were modified to account for this. A specific degree of braking (related to pedal pressure) was applied to individual wheels on each vehicle, and was integrated to a time, intensity and position depending on the evidence given in the investigator report. Often this measure was at full braking with locked wheels, which was simulated by ceasing any movement of the corresponding wheels. Broken or jammed wheels resulting from impacts were also given this property. The matter of ABS braking could also be integrated if the investigator report had confirmed this was the case.

In cases where tyre marks were present and sufficiently detailed in scene photographs, the shape of these marks were integrated to the program. Usually such marks would be created when ABS braking was not present, or in the case of a vehicle drifting across the road in a skid. The shape of the marks would then be sketched onto the location map using a line tool to mark the start and end of the marks. A vehicle path would then be set to this location, and the start and end of severe braking attached to this path.

Rest positions of vehicles (post-impact)

After the POI, the program automatically calculated the post-impact trajectory and rest positions of each vehicle involved in the impact. For simpler cases involving two vehicles, this calculation was often sufficiently accurate and agreed with scene photos to some degree. For more complex cases with post-impact steering, braking and impact with objects, implementation of a path was necessary using the built-in PC-Crash feature. In these cases, the mouse was used to trace a vehicle path through known points such as tyre marks, road markings, barriers and verges.

4.4 Caseload of RTA Incidents

The RTA cases included in this Thesis were selected with regard to the criteria given in Section 3.2. This resulted in a shortlist of 21 incidents that were variable in format and content. It was then decided that a suitable approach for the work would be to pick an equal amount of introductory, intermediate and advanced cases for reconstruction and critique. The final caseload selected for this report is given in the table below.

RTA	Location	Vehicles	Impact	Evidence	Police Evidence	Police Report
1	Example	2	Moderate	N/A	Example	No
2	Plymouth	2	Minor	Photo	No	No
3	Warnham	2	Fatal	Photo	No	No
4	Danbury	4	Severe	Photo, Witness	No	No
5	Usk A449	2	Fatal	Photo, Scene	Yes	Yes
6	Usk A472	3	Minor	Photo, Scene	Yes	Yes
7	Coldra M4	1	Fatal	Photo, Scene	Yes	Yes
8	M48 Barrier	1	Fatal	Photo, Scene	Yes	Yes
9	Coedkernew	1	Rollover	Photo, Scene	Yes	Yes
10	Aberbeeg	2	Fatal	Photo, Scene	Yes	Yes

A final caseload of 10 incidents was specified as a suitable number by the project supervisor, which was then agreed to be released by Gwent Police. As the information pertaining to each RTA case is variable, an example will be given from RTA5 in the above table. This was a well-detailed incident that involved the collaboration of Sheffield Hallam University and UK Police, and also included many of the calculations outlined in the previous chapter. For a more detail of the evidence, please see *Appendix I & II*.

4.5 Example of RTA Case Evidence

RTA5: Collision between two vehicles on the A449, Usk, Wales, on 15th October 2011

The following information is taken as evidence from the final report submitted by the RTA Investigator (PC Goddard) assigned to the incident.

Location: At 7.30pm on Saturday 15th October 2011 a two vehicle collision had occurred on the northbound carriageway of the A449 at a point 200 metres prior to the Usk intersection.

Fig. 4.1: Ordnance Survey map of RTA5 area.

Vehicles: (1) Ford Transit Camper van (2) BMW 320i

Road: Average width 7.45m, Lane width 3.3m,

Environment: Rural setting, No street lighting. 70mph speed limit. Nighttime.

Weather: Dry and clear weather, 11 deg C.

Scene Evidence: There were a series of combined tyre and scrape marks in lane one at a point some 79.49 metres prior to the large direction sign.

The combined tyre and gouge marks were 2.8 metres long and indicated the point of impact between the two vehicles (Fig 4.2).

Fig. 4.2: View of the impact marks of RTA5 [Gwent Police]

16.2 metres beyond the impact marks were a set of two striated tyre marks that curved to the left and exited the carriageway. These marks were from the offside tyres of the Ford Camper van. The marks continued until they struck a safety barrier. Beyond the safety barrier there were a series of plough lines and divots leading to the Camper van which had impacted into a leg of a large direction sign. The marks can be seen in Fig 4.3.

Fig. 4.3: View showing the camper van’s path of RTA5 [Gwent Police]

On the centre white line and some 32 metres after the impact a locked tyre mark started and progressed across lane two for a distance of 81.6 metres ending under the front nearside tyre of the BMW 320 which was located some 116.5 metres from the point of impact. A second locked tyre mark ran parallel to the one above for the last 45.5 metres and ended under the front offside tyre of the BMW (Fig 4.4). The distance from the point of impact to the end of the skid marks was 116.5 metres.

Fig 4.4: View showing the later stages of the skid marks from the BMW

[Gwent Police]

Conclusions of RTA Investigator PC Goddard

- From the evidence collated I would conclude that at about 7.00pm on the evening of Saturday 15th October 2011 the respective vehicles of a Ford Transit camper van and a BMW 320 were travelling northbound on the A449 between Newport and Usk.
- The camper van appears to be travelling at a steady 51 - 54 mph prior to the impact.
- Over the same distance the BMW was travelling between 91 and 117 mph.
- At a point approximately 200 metres prior to the Usk exit slip both vehicles were travelling in lane one of the dual carriageway.
- For an unknown reason the BMW has collided with the rear of the Ford

Transit.

- If the Ford camper had maintained its progress then the speed of the BMW at this point would be between 99 and 103 mph.
- A post impact event recorded by one of the BMW's safety systems recorded a speed of 87 mph.
- After impact the Ford has veered to the left and collided with a crash barrier on the nearside verge. The van vaulted the barrier and collided with the leg of a substantial sign. The driver died at the scene.
- After impact the BMW has veered to the right into lane two. The brakes have been applied such that the front wheels locked and left skid marks for 116.55 metres. The speed of the BMW at this point was between 74 and 84 mph.
- With the Ford travelling at 51 mph and the BMW closing to the rear at 99 mph an impact is avoidable until the vehicles are within 27.5 metres apart.
- With a closing speed of 48 mph (99 – 51mph) between the BMW and the camper van, the camper van would have been in view for 25 seconds with a direct line of sight for the last 16 seconds before impact.

4.6 Scenario Modelling Methodology

From information given in the above reporting, the modelling scenario will be constructed primarily from these findings of the RTA Investigator, and combined with other mapping information to form a virtual environment. This process typically consists of 3 stages:

- Mapping: Creating an environment representing the scene
- Vehicles & Dynamics: Selecting the most appropriate vehicles and characteristics, with pre-impact speed and direction
- Impact: Reconstructing the moment of impact in the collision

4.6.1 Mapping

First off, a 2D environment that forms the road surface and nearby environment is constructed. This may be modelling using the in-built features of PC-Crash, although it is more illustrative to build an extended map using imported files of Ordnance Survey or Google maps resource. The latter is used for the majority of cases discussed here.

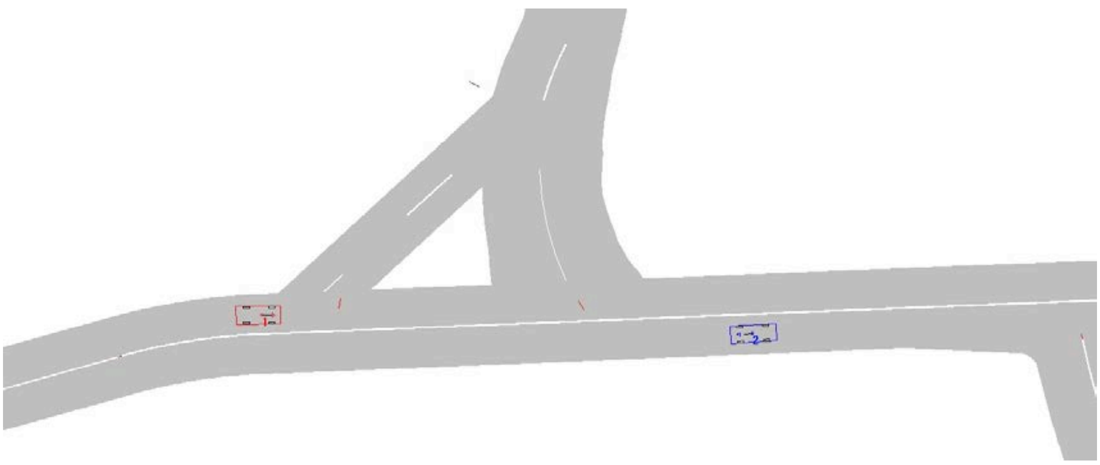


Fig. 4.5: In-built road modelling

Fig. 4.6: Imported Google map

Once a suitable arrangement of 2D overhead images has been formed, the individual parts are combined into a single .jpg file and scaled to size for importing to the software. The map may now be used in the 2D viewport of the program.

Fig. 4.7: Roadside polygons (3=barrier, 4=sign)

Roadside objects can also be constructed as a series of polygons or DXF images. For example, a roadside barrier is a common part of this reconstruction and often takes the form of a solid rectangular polygon of constant cross-section (Fig. 4.7). Similar objects such as lampposts and road signs can be constructed using the same process (Fig. 4.8). The physical characteristics of such objects, i.e. stiffness and inertia can be specified in exactly the same manner as vehicle characteristics such as kerb weight and centre of gravity (See 4.3.2). The most straightforward method is to designate a large value of mass to the object, i.e. 10,000kg for a roadside barrier.

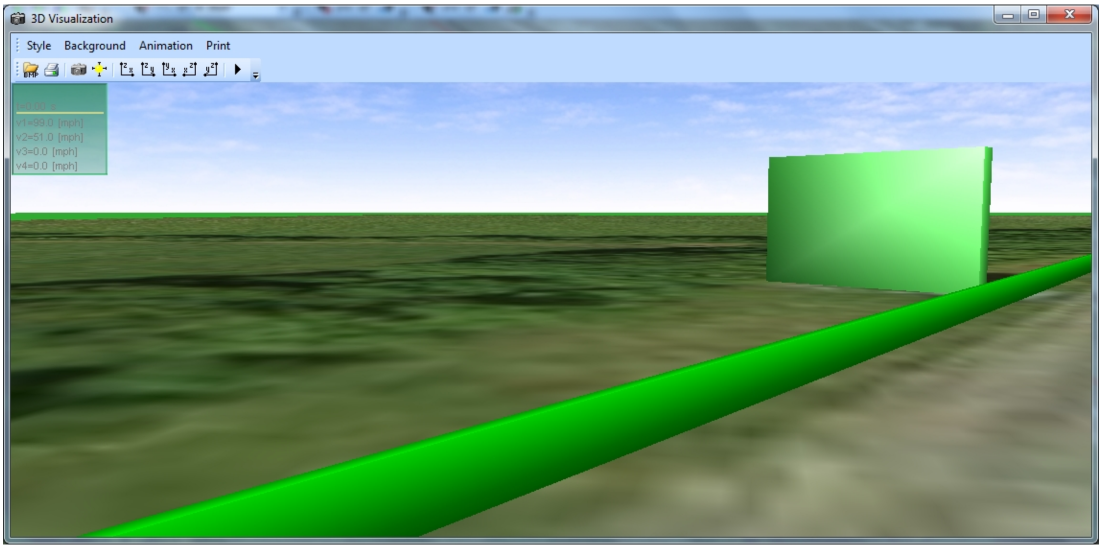


Fig 4.8: Roadsign and barrier polygons, 3D view

4.6.2 Vehicle Modelling

The range and scope of cars and other vehicles on the roads means that a basic, generic model of a car is unsuitable for collision modelling. Fortunately, the PC Crash program contains a verbose library of vehicles of various types which can be readily implemented with a few clicks of the mouse. This section demonstrates how to tailor the specifications, attributes and individual features of a vehicle in a collision to represent it with the most accuracy. The blocky appearance of vehicles can be improved by using the 3D models included in the software.

4.6.3 Vehicle Setup

The operating environment of PC-Crash is a 2D view as shown in Fig. 4.9 below. The schematic of a car body can be seen along with the range of tools used to construct a scene.

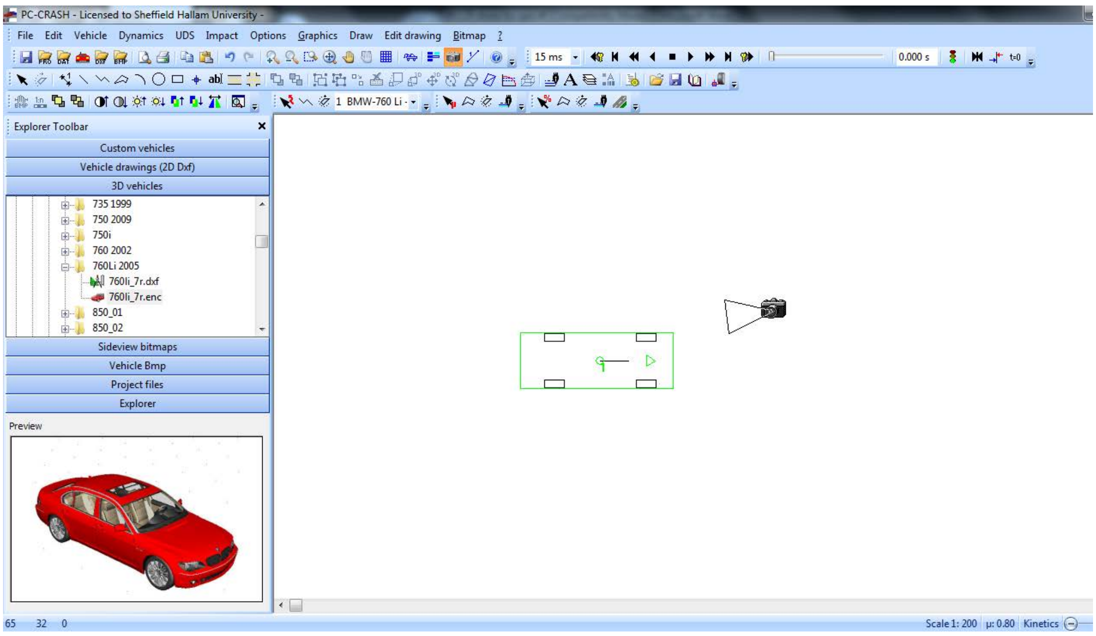


Fig 4.9: Main viewport of PC-Crash

Attention needs to be given when selecting the appropriate vehicle for the scene, as there are many options. First consideration should be given to choosing the Make, Model and Year of Manufacture first. Next, the specifics of the vehicle, such as engine size or spec (TDi, 16V etc.) should be selected.

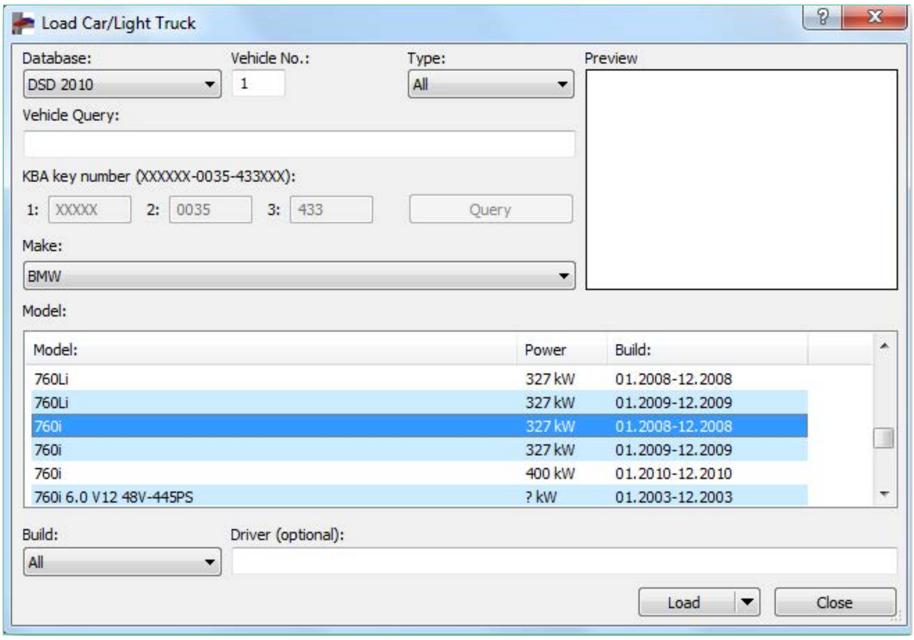


Fig 4.10: Vehicle selection from database

4.6.4 Vehicle Data

It is possible to modify the suspension, occupants, brakes and shape of the vehicle. There are 8 sets of options contained to describe the basic vehicle properties. Most significant of these is the Weight, which is also known as Curb Weight (i.e. the vehicle without occupants or cargo). The centre of gravity (C.G.) can be specified too, along with ABS, wheelbase and axle measurements. This is important when considering rollovers and other crashes where vehicles tilt significantly. Vehicle dimensions can be changes such as length or width, but these are likely to be consistent with the model. Figure 4.11 demonstrates the typical input for a vehicle.

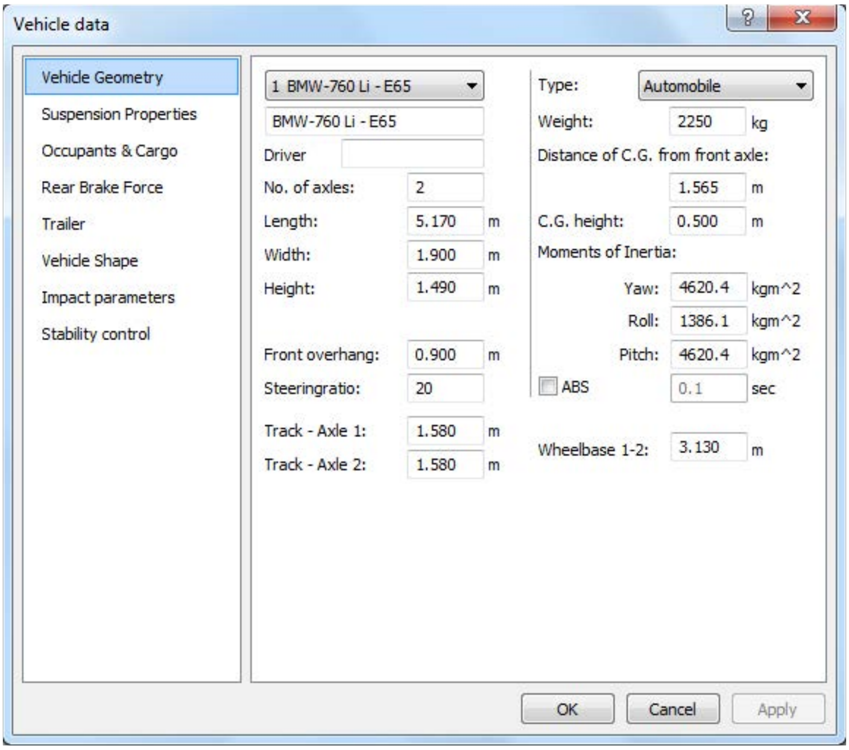


Fig 4.11: Vehicle geometry input

Vehicle Suspension may also be specified for each vehicle. The suspension and damping of the vehicle can be specified for each wheel, if known then may be inputted in *N/m* or *Ns/m*. Often this information is often hard to obtain, so "*Stiff / Normal / Soft*" options are available. A good example of using this option would be to use "Stiff" for a sports model, i.e. Audi S5.

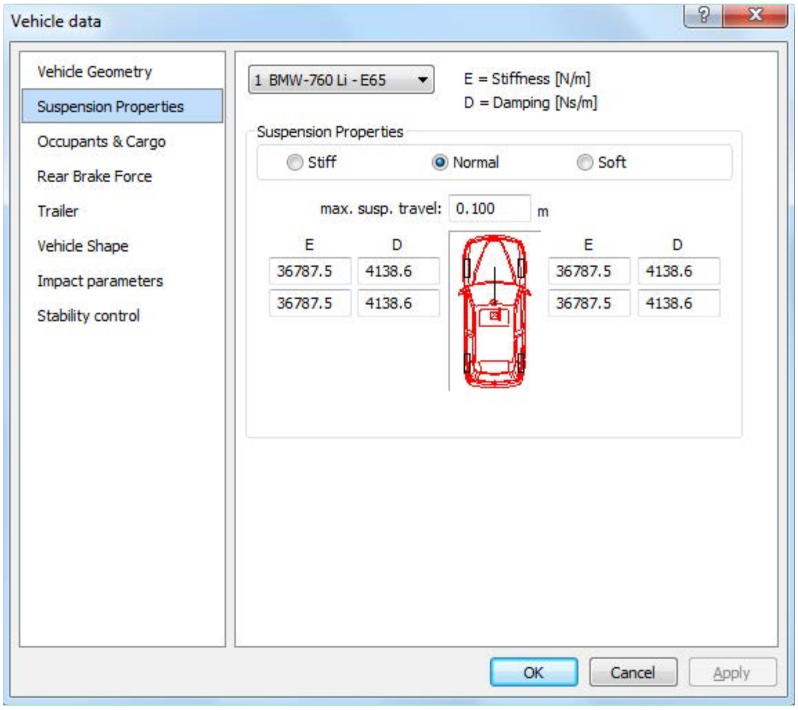


Fig. 4.12: Suspension properties input box.

Occupants & Cargo can also be specified, as the weight on anybody in the vehicle will influence physical behaviour of the model. This figure can include passengers (front or back seat), baggage and roof loads. It is recommended to use more descriptive settings for trucks and trailers, dependent on the loading of the vehicle and cargo.

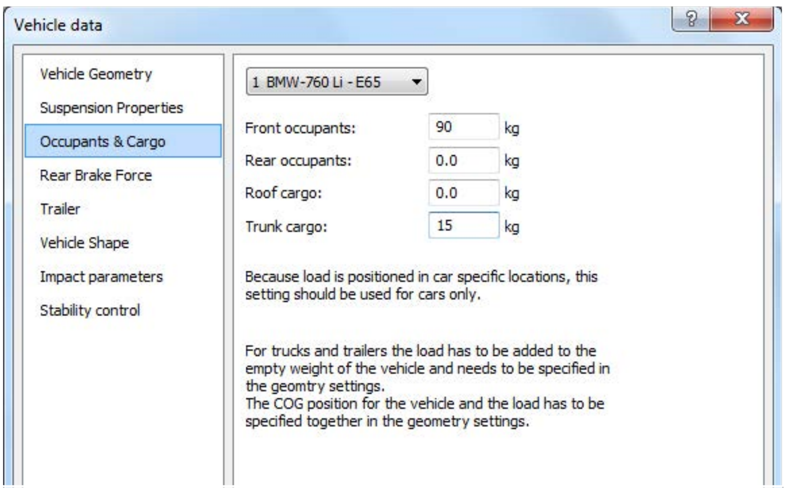


Fig. 4.13: Occupants & cargo input box.

Shape of Vehicle allows each measurement of the vehicle body to be specified. A more simple approach than putting in individual dimensions between each section of the car is to select one of these three vehicle styles: Sedan, Hatchback or Van. The letters on the schematic denote the length of each section (see Fig. 4.14)

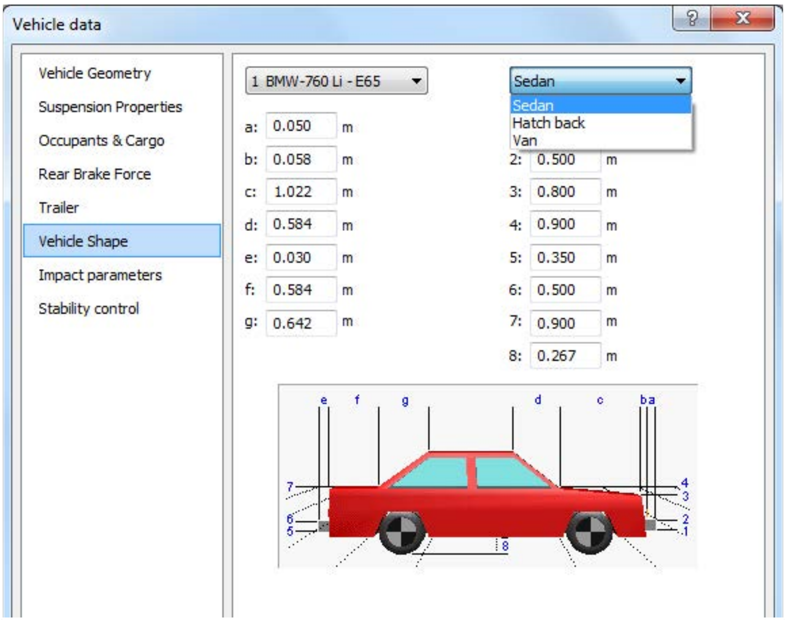


Fig. 4.14: Vehicle geometry input box.

Stability Control is available as an option if ESP (Electronic Stability Program), also known as DSC (Dynamic Stability Control) was activated on the vehicle at the time of collision.

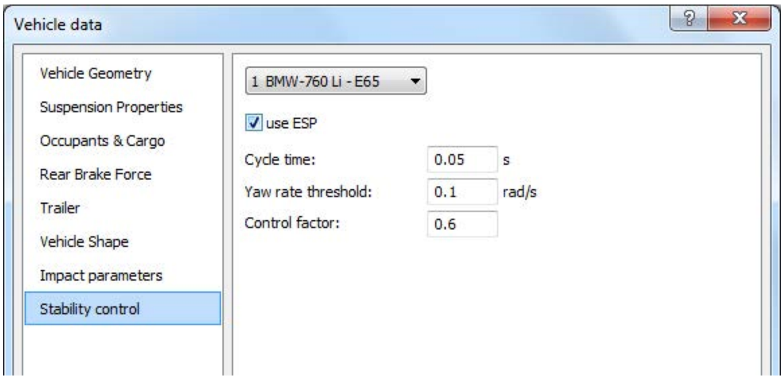


Fig. 4.15: Stability control input box.

Engine and Drivetrain specifications are also available although not all of these are used frequently and are not necessary for basic collisions. For example, if a vehicle in a crash was not accelerating, then the engine options can be kept as standard. In cases of a vehicle known to be accelerating along a path before a collision, the power and variables of the engine can be important to the accuracy of the reconstruction (See Fig. 4.16 below).

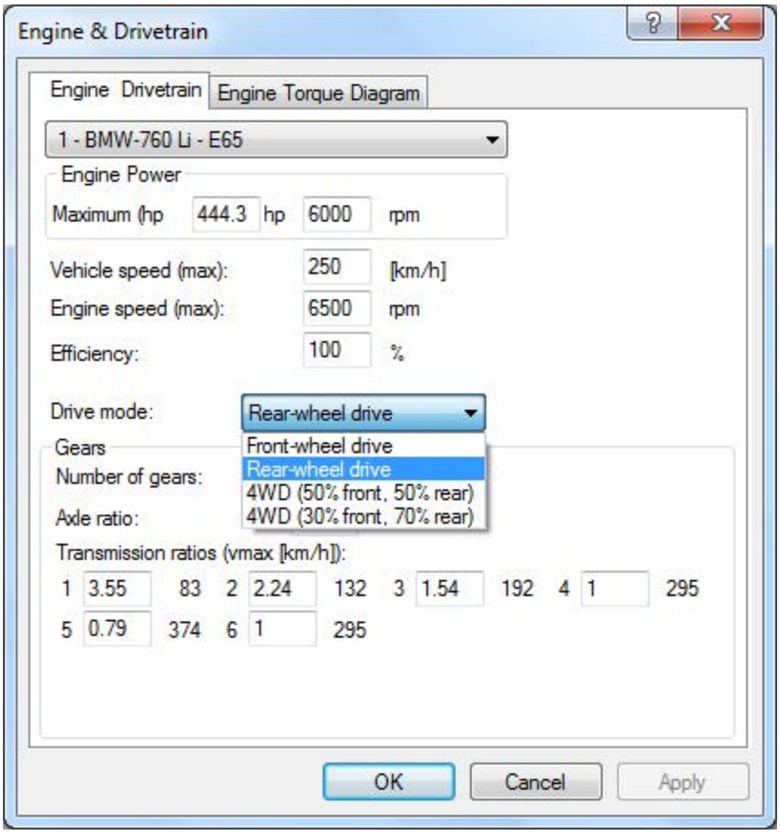


Fig. 4.16: Engine & Drivetrain control box.

Tyre Model characteristics are useful to model a stopping distance or rest position after impact. The basic tyre specifications can be given in measurements or 'R' size for the front and rear axles. This will display the dimensions of each tyre in *mm*, which can be modified, as can the "Lateral Spacing" of truck and HGV tyres (not applicable to cars). Note: Linear tyre models are only considered in the modelled cases.

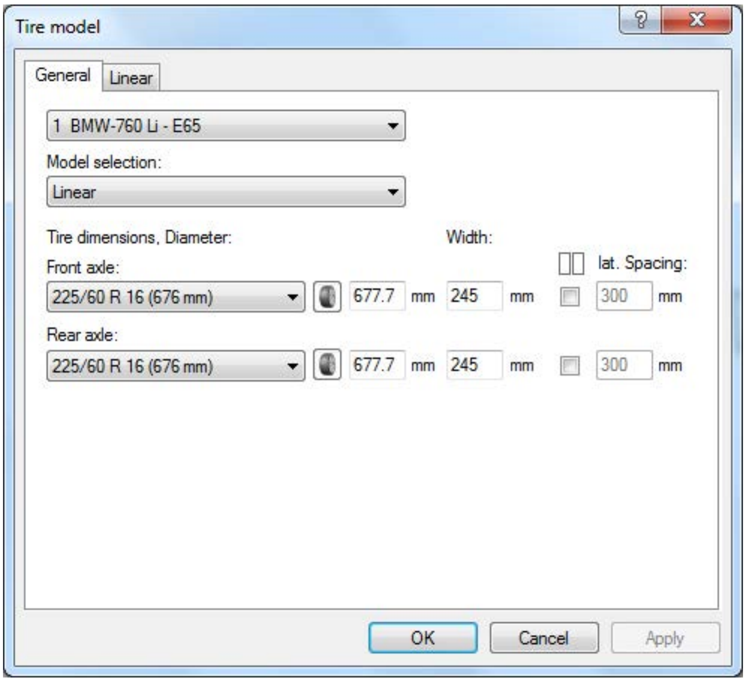


Fig. 4.17: Tyre model general input box.

Linear Tyre Model options may be modified for non-standard characteristics regarding the tyres used on the vehicle. Here the maximum lateral slip angle of each individual tyre can be specified.

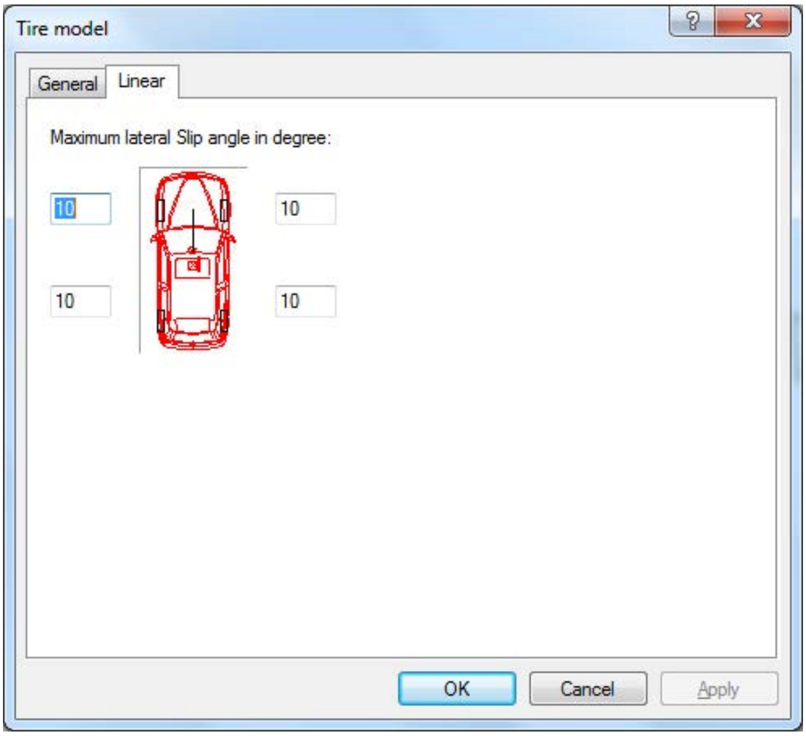


Fig. 4.18: Linear Tyre Model control box.

3D Models are of assistance in improving the graphical capabilities of the software. A vehicle catalogue of DXF files of 3D models can be used to give a more realistic look to the reconstructions. The figure below shows the catalogue icon and rendered view for a BMW 760i model. Colours can be chosen once the file is imported. It should be stated clearly that the DXF files are a purely graphical input to the program and have no physical influence on the simulations whatsoever.

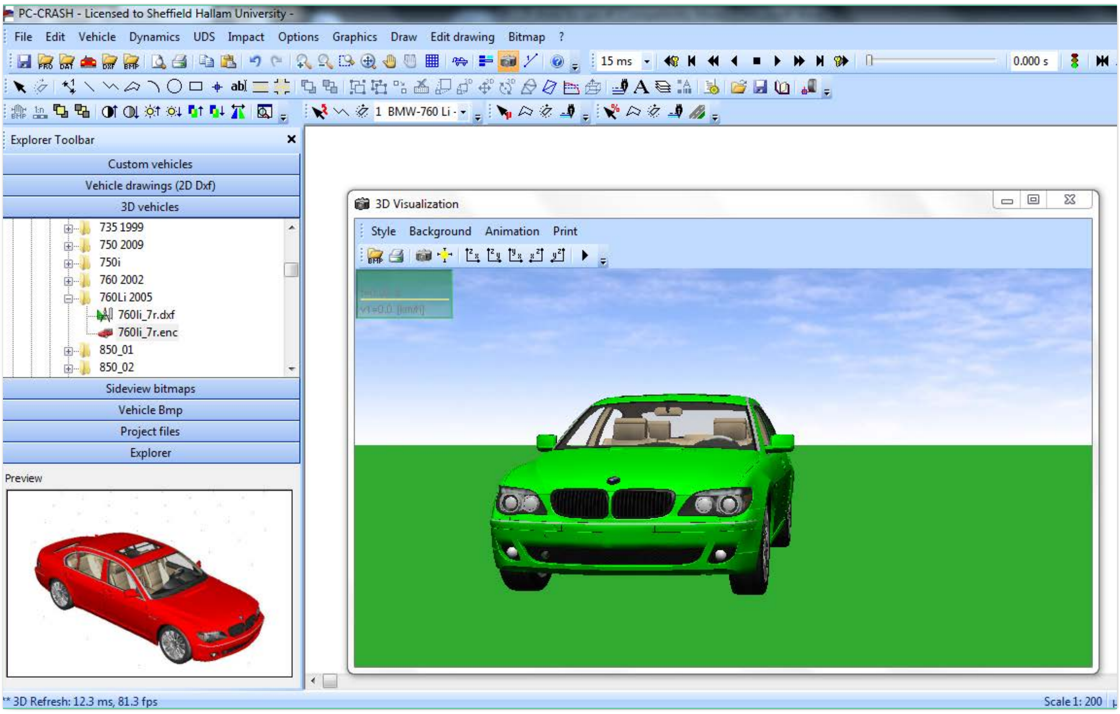


Fig 4.19: 3D Vehicle view

4.6.5 Dynamics & Trajectory

It is possible to designate a simple speed for each vehicle in the modelled scenario and cause and impact by a cross in trajectory alone, however, this is not representative of control by a driver of a vehicle. In these cases, different motion sequences for each vehicle, such as braking, acceleration, steering and driver reaction were defined in causing a collision.

The *Sequences* control enables different sequences can be combined to reflect the driver's actions for each vehicle, for pre-impact and post-impact timeframes. With this control, the time @ *t=0* seconds is assumed to be the moment of impact, such that pre-impact and post-impact driver reactions can be considered.

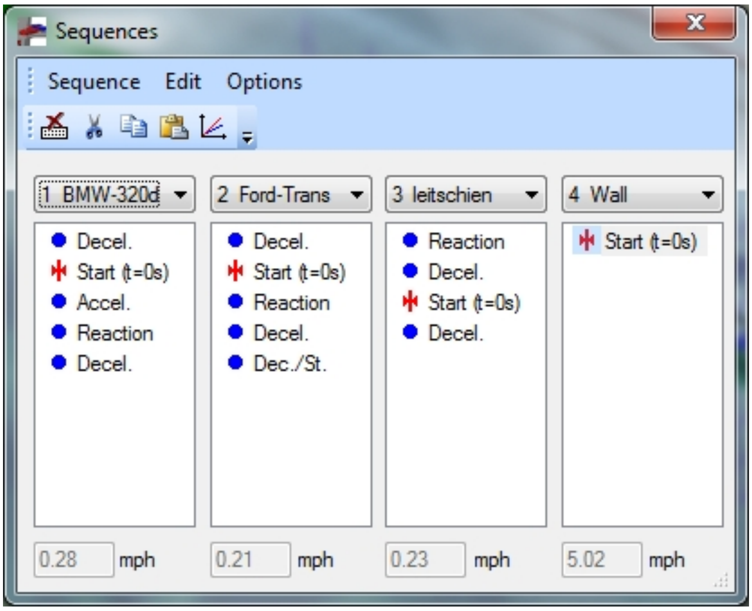


Fig. 4.20: Sequences control box.

A typical crash will consider a period of acceleration or braking before *t=0*. Figure 4.21 below shows how this may be applied, in terms of duration, pedal position and steering control. A "Lag" may be also be added, as a typical human reaction takes around 200ms to occur. "Lane changes" may also be programmed, which are helpful for Motorway incidents. The sequences control acts as a relay of these reactions, one after the other, for each vehicle involved in the scenario.

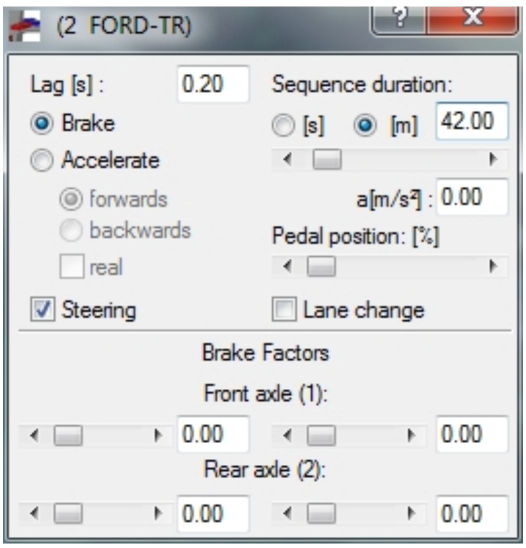


Fig. 4.21: Braking & acceleration control box.

The Brake control options are quite pertinent to crash modelling. Much of the information from the RTA caseload concerns braking distances, so it is a major part of the reconstruction detailed in this document. Each individual wheel can have a designated braking factor, and can be "locked" so as not to move. This aspect is particularly useful to model punctured tires and damaged wheels after the *t=0* point.

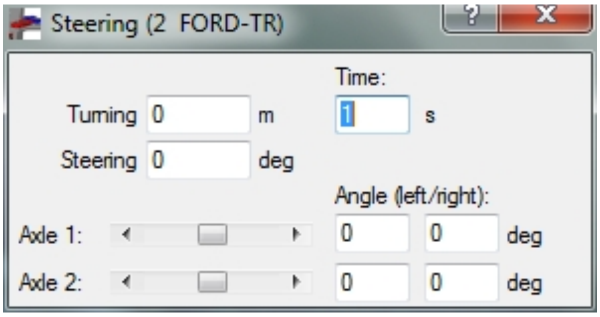


Fig. 4.22: Steering control box.

The pre-impact trajectory of the vehicles can be determined by sole use of the "Steering" commands in the Driver Reaction sequences, but the use of "paths" is a more accurate way to model this. Each vehicle can be designated a coloured trajectory "path" as seen in red in Figure 4.23.

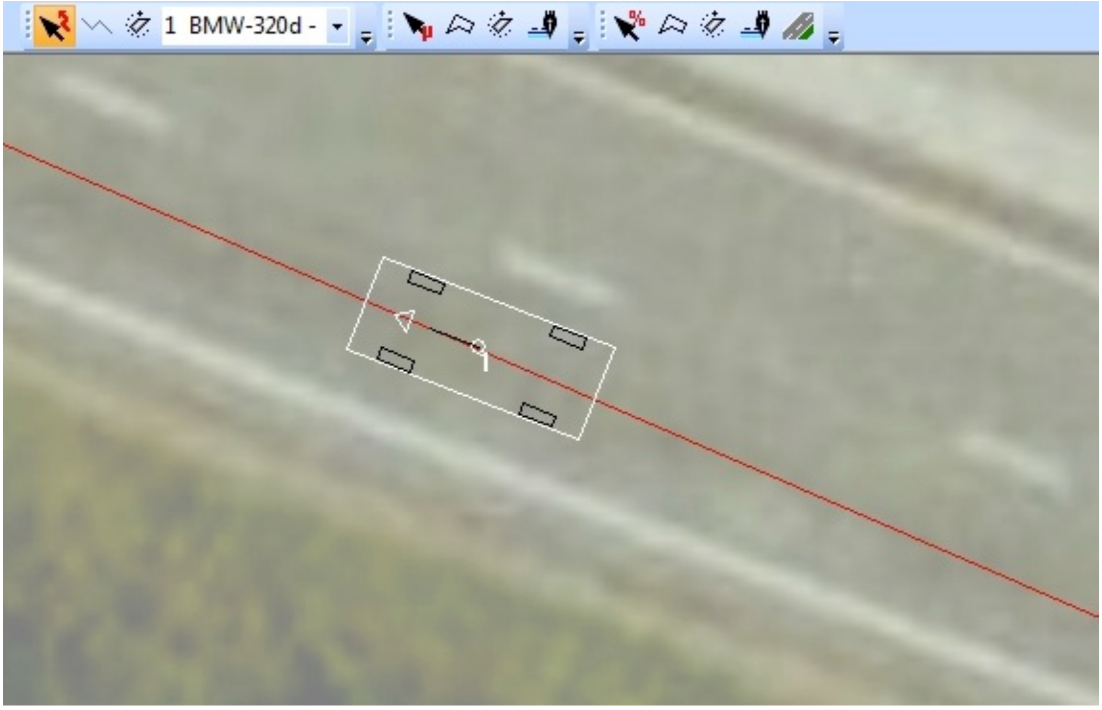


Fig. 4.23: Implementation of paths to control vehicle (red line).

Once speed, braking and other reactions have been inputted, the definition of a vehicle's steering will be determined by the pre-defined path. This feature is useful for reconstructing the movement of a vehicle from CCTV footage, where several static frames of the scene are used as evidence. Additionally, rebounds of vehicles from crash barrier, for example on motorways, often require use of the path function.

4.6.6 Impact

This is the most critical part of the collision modelling. The point at which vehicles modelling in the reconstruction first collide will determine how momentum is transferred to each vehicle for the post-impact trajectory and how much damage is inflicted on each vehicle body. The coefficient of restitution ε and coefficient of friction μ are of high influence at this point (see theory, *section 3.1*).

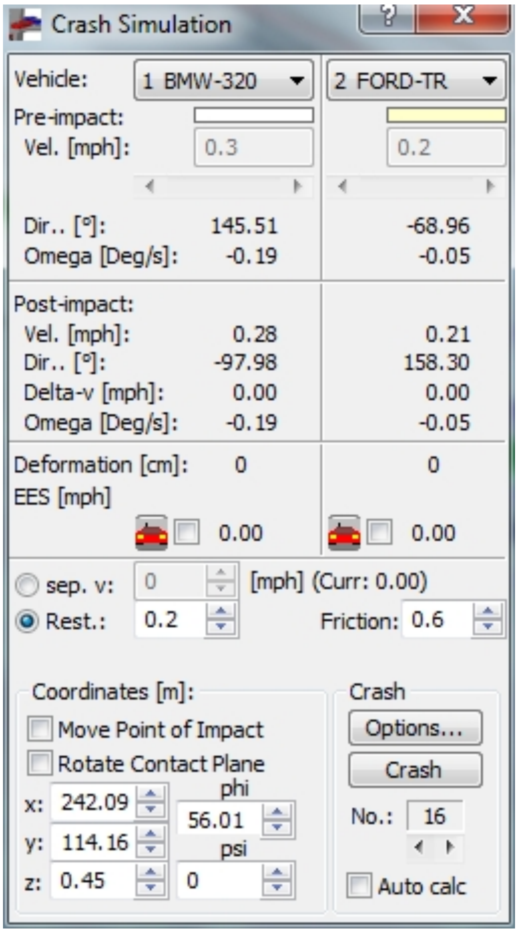


Fig. 4.24: Crash simulation control box.

The *Crash Simulation* parameters are illustrated by the function box in Figure 4.24. Here the main inputs are:

- *Pre-impact velocity*: input if not determined by accelleration/braking driver reactions
- *Rest*. (*Restitution*): usually 0.1-0.3 for most collisions [0.2]
- *Friction*: inter-vehicle friction in this instance [0.6], not to be confused with road-to-tyre contact friction

Unless specified otherwise, these values are set to the values in square brackets above for the RTA caseload.

For each collision, the Crash Simulation function then determines the Point of Impact and post impact parameters for each individual impact:

- *Post-impact velocity*
- *Direction of post-impact travel*
- *Delta-v*
- *Omega (Yaw or tilt)*
- *Deformation (in cm or EES)*

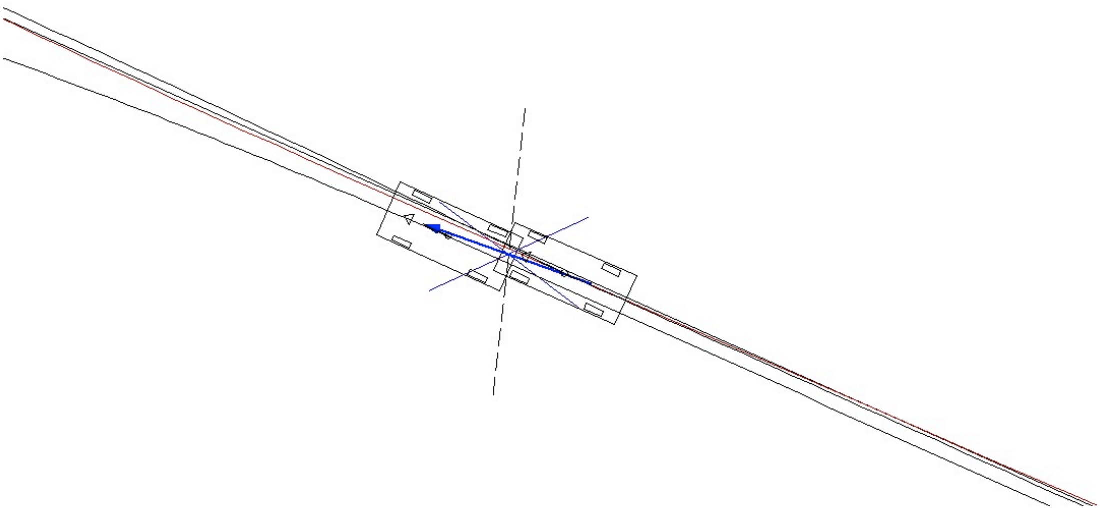


Fig. 4.25. Typical 2-vehicle impact schematic

A typical car-to-car collision is demonstrated by the schematic above in Figure 4.25. Here the contact plane can be seen as a dashed line, at a slight angle to overlap of the vehicle outlines. The resultant force vector is shown in blue, with the POI marked as a large X. The pre- and post-crash vehicle paths are also shown as long red, blue and black lines.

It is important to state that what would normally appear as a single impact is often modelled by PC-Crash as several "Crashes" in this Simulation function. This is due to several impact points occurring within the very short timeframe of the crash, which typically takes place in 30-100 ms. During this timeframe the software considers each occasion in which the vehicle shapes are in contact. Hence, it helps to consider this function as modelling the crash with several continuous periods of subsequent smaller impacts, rather than one clean contact from which the vehicles are immediately separated. Such “singular” impacts are possible, but only in the unlikely scenario when both vehicles have parallel and flat impact points that do not interlock at any point post-impact. For example, Figure 4.26 below shows a vehicle in continuous contact with a crash barrier.

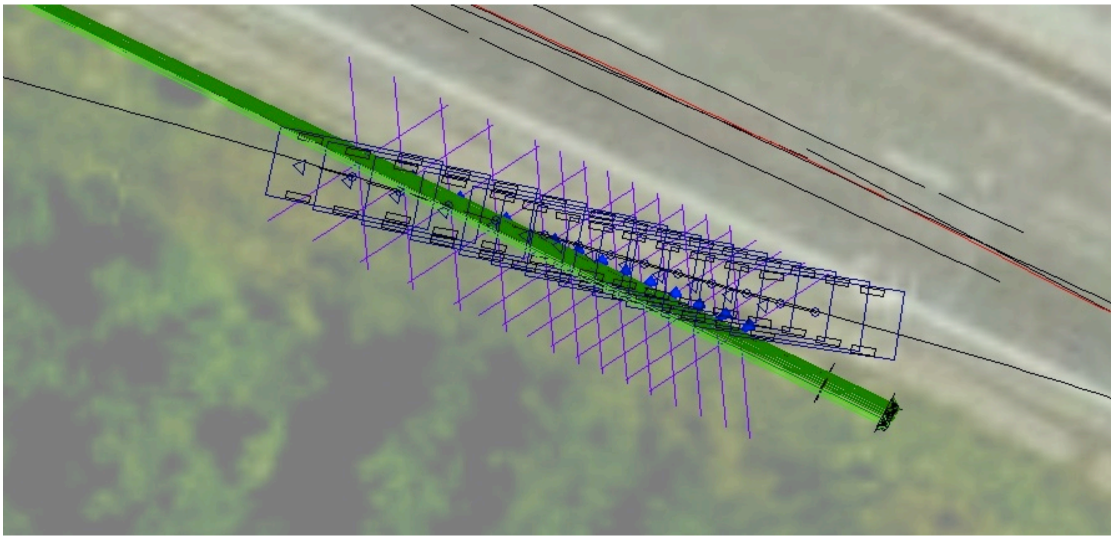


Fig. 4.26: 2D view of multiple POIs (purple X).

Following the completion of all crash simulation calculations, the software will automatically calculate the rest position of all vehicles in the simulation. There is another module for a “Crash-backwards” function to optimise this feature, although this has not been necessary for the scope of this study.

4.7 Accuracy of Evidence

Here some discussion is given to the methods in which police investigators gather evidence and how accurate these processes are. Cases from Gwent police form the bulk of this thesis and only incidents from this constabulary will be discussed here.

On arriving at the scene of an RTA, the police investigator will have multiple responsibilities. The following discusses what technical evidence is to be gathered, and how potential loss of accuracy could occur.

Witnesses

The investigator will gather statements from all persons present at the scene. This may include drivers, passenger, passers-by, local residents and also other police present at the scene. A brief statement can be taken as notes or audio which is usually then expanded on in full at the local station. This form of evidence is not technical, but highly influential; a vocal statement from a person in court may be powerful in determining a case. The loss of accuracy with this kind of evidence can be due to anything from memory, to fear, deceit and shock. Hence this is very hard to quantify in a technical context. For all cases included in this thesis, witness statements are wholly disregarded for these reasons.

Measurements

The investigator will then gather a list of RTA measurements required from the scene. This may include

- Skid marks: obtained with a tape measure or laser device. Accuracy is dependent on visibility of the marks and the device calibration. Most measurements in this thesis are given to the nearest metre, providing some error to each case. It is understood that accuracy is limited more by time rather than the precision of equipment.
- Vehicle paths: established by observing tyre marks. Plastic 'markers' are placed in the paths and then photographed. This is especially helpful for

nighttime incidents. Accuracy is dependent on this skill of the investigator present. Reconstructing vehicle paths via this method will have resulted in some inaccuracy, although the start and end points between impacts were the vital information for simulations. Detail on these areas was abundant with many photographs, inclusive of measurement information.

- Environmental damage & features: gathered by professional expertise, i.e. matching marks on a roadside barrier to scratch marks on vehicle bodies. This is accurate to establish a 'point of impact' to a specific vehicle, but the point in question can be variable to 0.5-1 vehicle lengths. This is an error which can be easily integrated to the reconstruction. RF: Environmental objects such as signs, barriers etc. are static and relatively easy to place on an overhead-view map. Natural environmental objects are variable in size and position and represent a great difficulty in simulation.
- Weather, temperature, conditions: measured or observed at the scene. A thermometer or laser temperature device is mostly used to get ambient conditions, but more importantly, road surface conditions. A digital/laser thermometer will be typically be accurate to one decimal place. These measurements are influential to tyre-road friction and given strong concern. Combined with information from weather reports, data in this field is typically accurate.
- Visibility, Daylight, Street lighting: a matter of observation, thus somewhat subjective. However the time of the incident will be carefully noted, allowing sunlight and weather data to be retrieved later. The subjective nature of the visibility status on the ground at the time (or some time after) of the incident could benefit from greater accuracy. For example, a foggy morning may be described as 'light fog' or 'low visibility' depending on the investigator present. Such conditions dramatically influence the driving conditions prior to the incident and can be a source of error regarding incidents.

Vehicles

It is routine to photograph any vehicles in situ and perform more detailed analysis at another location. The caseload indicated that the following measurements were performed as standard:

- Model, working order, modifications, MOT, overall condition: obtained by a police garage and records check. The main purpose is to ascertain if all UK vehicle standards were met before the incident and that the car was in a roadworthy condition. The accuracy of establishing this depends on the staff in question, as inspecting a damaged vehicle requires some forensic skill.
- Vehicle damage & crush: an important method for determining the POI and pre-impact velocity. This may included vehicle-to-vehicle and nearby object impacts. Some expertise is again required, although crush damage measurements are commonly made with a standard tape measure to the nearest cm. This was a large source of error influential to the reconstructed simulations.
- Tyres: tread remaining will be measured with a gauge (to 0.1mm accuracy) and inflation pressure can be either be measured or estimated from the profile and wear. Typically this falls within a legal/nonlegal category. Underinflated tyres are an often overlooked cause of incidents due to the increase of braking distance and loss of control.
- Lights: the use and activation of vehicle lights at the POI can be accurately assessed using a specialist technique. The filament of the bulb can be studied to ascertain whether each light was off or on at the moment of impact. An activated brake light, for example, would show a stretched 'loop filament' for a low-speed impact and a 'hot break' for a high-speed impact. Likewise, a unactivated light would show a 'cold break' of the filament. The process is reliable and has been used in court several times, although is thoroughly ineffective for LED lighting.
- Vehicle computer units: recent and more sophisticated vehicle technologies allow the unit computer to be taken out and connected. Here a wealth of data can be extracted, e.g. speed at impact, emergency braking, vehicle warning systems. This information has the highest degree of accuracy.

After all settings were integrated to the software, an initial reconstruction would be prepared for criticism (as shown in Chapter 5.)

4.8 Integrating Investigator's Data & Accuracy in Reconstruction

Part of the skill of an RTA investigator's job is to balance all the available information and form a firm conclusion about the incident. This is a complex task due to the multiple forms of evidence and respective accuracies.

For these reasons, the process of reconstruction is often based on a hypothesis. The most likely pre-crash scenario would be assessed and used for a trial reconstruction. The evidence would be integrated (as described in Section 3.2) and an initial reconstruction would then simulate the POI, vehicle trajectories, and rest positions.

From this point, all measurement errors from the evidence gathered would be used to refine the process. A good, common example is moving the POI; if such a point was in the middle of a road, the accuracy may be 0.5m in any direction. The software allows trajectories and rest positions of vehicles to be assessed in real-time as the POI is moved. The same principle is true of vehicle speeds, allowing the scenario to be improved significantly using these means.

Secondary refinements would typically adjust reconstruction variables such as vehicle-to-vehicle contact angle, friction, and restitution settings. These values are all either automatically calculated or set as default in the software, and adjustment of these helps to define the characteristics of the impact.

Subsequent adjustments would involve surface friction to compensate for weather conditions. Road friction is commonly measured at a coefficient of 0.7-0.9, although for wet and icy conditions this will drop. Other subsequent changes made would be vehicle settings, for example centre of gravity, occupants and loading, and perhaps tyre settings (e.g. for underinflated or worn tyres), although no tyre adjustments were required for the caseload demonstrated here.

Overall the most commonly adjusted settings in the caseload studied consisted of:

- Vehicle-to-vehicle restitution
- Vehicle-to-vehicle friction
- Road/surface friction
- Point of Impact
- Contact Angle / Angle of Impact

It is noted that the adjustment of these settings deserves further discussion to the effect of the reconstruction process. Such discussion is continued in Chapter 6.

5. Results

In this chapter, the initial modelling of the RTA caseload is presented. Each incident was reconstructed using the maximum possible amount of available evidence, together with the methods described in the previous chapters. It is important to state that only police reporting and evidence was used at this point; this allows for RTA Investigators to view the reconstructions and provide a critique of the process and its accuracy for the following chapters.

Each RTA casefile here is presented in this document as a series of “contact sheet” slideshow images that describe the 3D reconstruction. Full evidence is given in the appendices of this document, although full video files of each reconstruction are available via a public shared folder (See Appendix A). This folder is recommended for a first viewing of the caseload, and will be available for 12 months after the submission date of this document.

Commentaries

Where evidence and commentary on each incident has been provided, the source of the information is given with regard to:

- *Public: Newspapers, reports and non-private sources*
- *GP: Private domain information from Gwent Police*
- *SJU: Opinions and conclusions of the author.*

Please note all velocity and damage are software-calculated unless specified otherwise.

5.1 RTA1 Collision: Car rear end shunt (example)

Study: This example serves to illustrate the general operation and interface of the PC-Crash collision software.

Scenario: A basic setup is described where two cars collide.

In this instance, Car 1 is travelling at 30 km/h in a straight line, directly towards Car 2 which is stationary. Both cars are VW Golfs, MK5 1.6 versions. Brakes are not employed on either car. Here the restitution between the vehicles causes the motion of stopping.

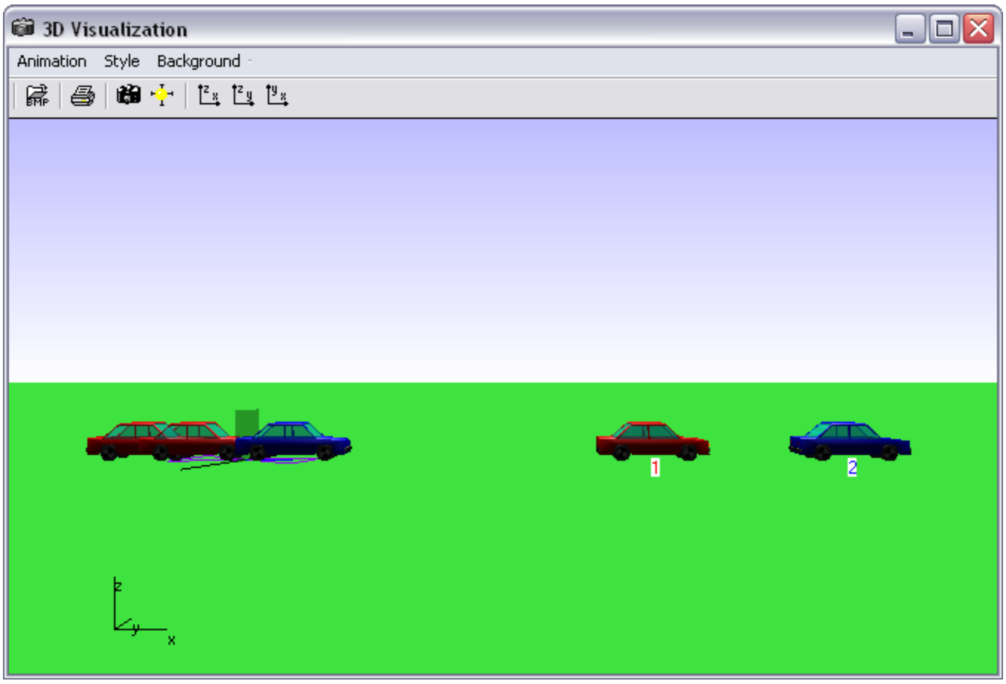
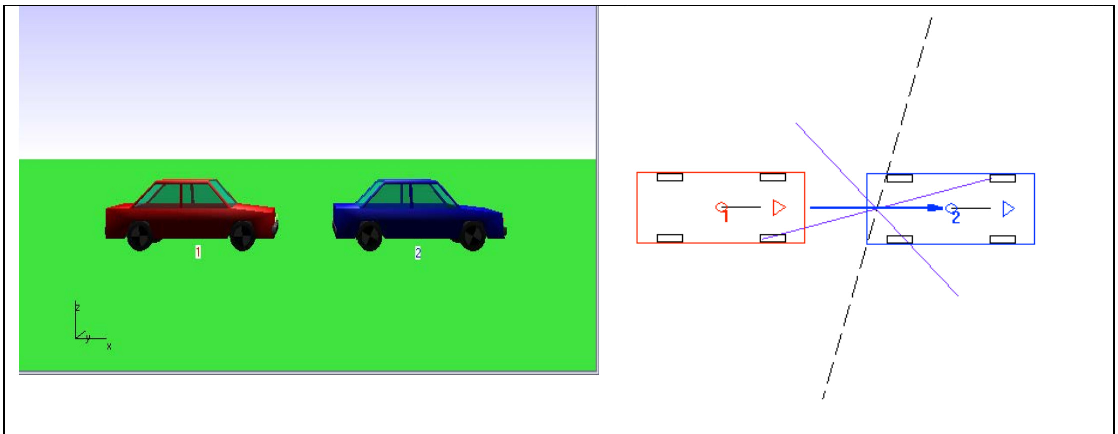


Figure 5.1(i): 2-Car Example

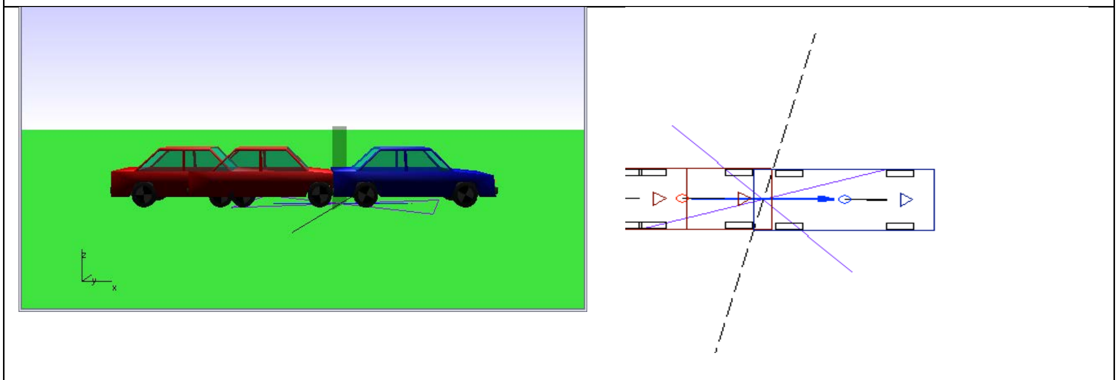
Outcome [SJU]: The momentum is transferred between the two identical vehicles. The point of impact is slightly off-centre as the cars are not perfectly parallel. This causes the plane of contact between the two cars to be at an angle to the vertical, although this discrepancy is not of large enough magnitude to be visible in the 3D representation. Deformation to each car body = 5cm.

RTA1 Slideshow

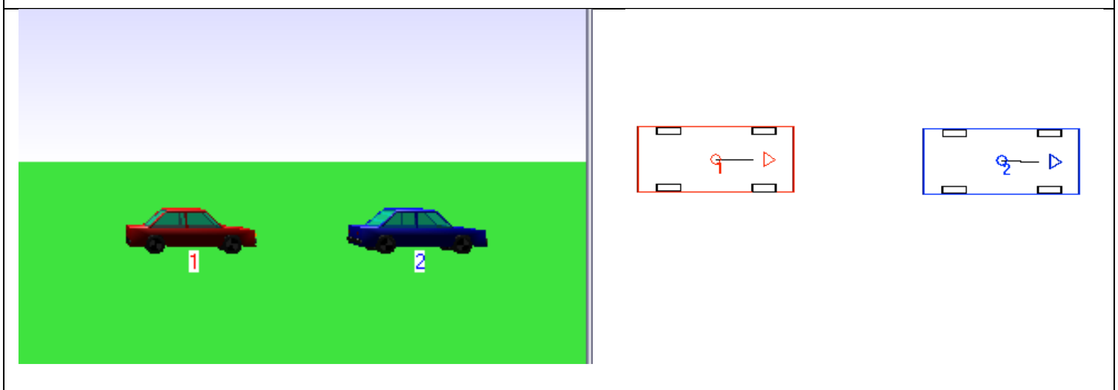
Figure 5.1 (ii-viii): 2-Car Example



3D side view of the two vehicles. Car 1 (Red) is at speed. The 2D view shows the point of impact (POI) as a purple X and the contact plane as a dashed line [SJU].



On impact, car 1 contacts the rear of car 2. The grey rectangle (in 3D view) marks the POI of a collision [SJU].



The momentum from Car 1 is transferred to Car 2, with both vehicles coming to rest.
Note that vehicle damage is not displayed on any view or schematics [SJU].

5.2 RTA2 Collision: Plymouth, Junction collision at low speed

Study: This collision builds on the previous example by comparison to real-life minor collision involving two vehicles travelling a low speed.

- 2 Vehicles
- A-road, Town/Urban area
- Evening, low light, 2012
- Minor injury

Scenario [Public]: Two vehicles collided at a traffic light, each contacting the wing portion in the crash. The collision occurred at low velocity, being a good example of an easily avoidable incident.

Figure 5.2(i): Plymouth Low-Velocity Collision

- Vehicle 1: VW Passat, stationary
- V = 0 mph, Deformation = 6cm

- Vehicle 2: Ford Focus, braking
- V = 15 mph, Deformation = 8cm

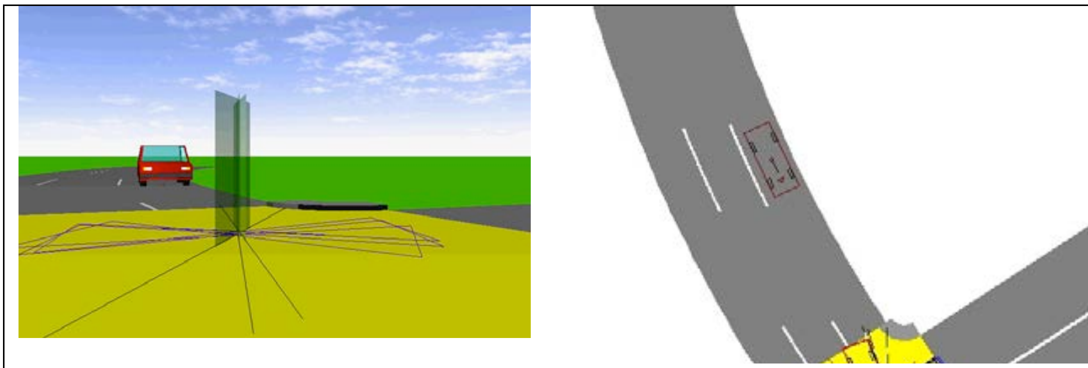
Outcome [SJU]: This case gives an elementary example of how vehicle motion and mild impact are modelled. First of all, the Passat comes to the junction, braking to a stop and turning. The area of the box junction is designated in yellow. Secondly, the Focus approaches the same junction from an adjoining road, performing the same manoeuvre but failing to notice the other car.

The Focus then impacts the Passat on the passenger side wing, causing a minor impact at a 45 degree angle to both cars. Both vehicles are moved from their initial positions slightly by the impact.

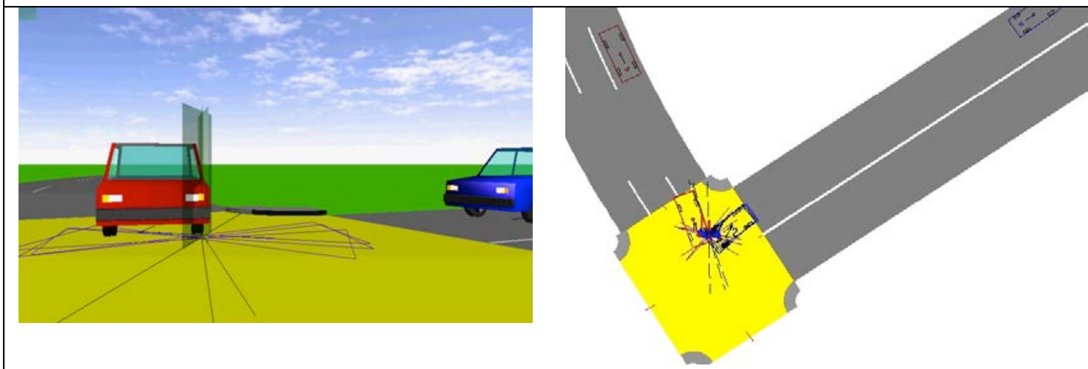
This is a lighter case compared to the other RTA incidents, but nevertheless, such minor accidents are common and are the cause of many costly proceedings which can be brought into the judicial systems for negotiation.

RTA2 Slideshow

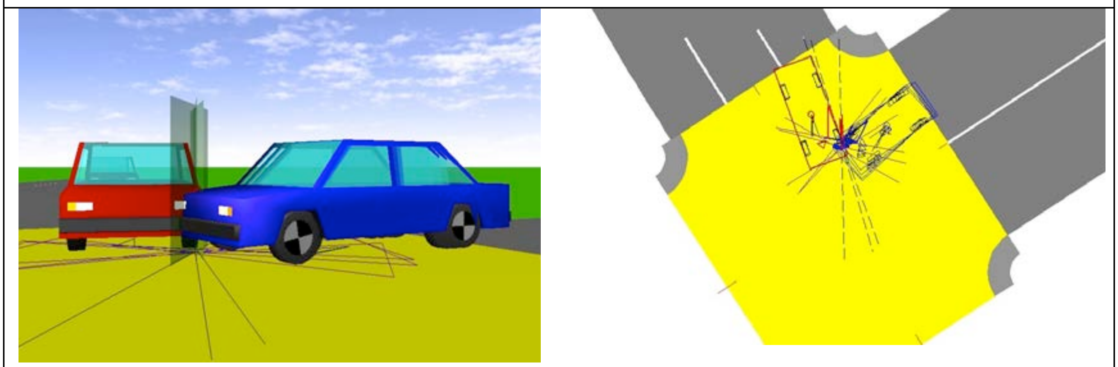
Figure 5.2 (ii-viii): Plymouth Low-Velocity Collision



3D ground view of the two vehicles. Car 1 (Red) is at speed and approaching the box junction area in yellow, with the POIs and contact plane in the middle of the junction. The 2D view shows the start and rest position of the red car [SJU].



Car 1 slows down to turn in the junction, coming to the POI and contact plane. Car 2 (blue) approaches at a greater speed. The 2D view shows the start and rest position of both vehicles at the junction [SJU].



The momentum from Car 2 causes a minor impact and deflection of Car 1, producing an 2nd POI and contact plane as the vehicle bodies move. The 2D view shows the POIs more clearly and also the small deflection to the left of Car 2 [SJU].

5.3 RTA3 Collision: Warnham, Sussex, Collision at Junction

Study: The effect of two equivalent cars colliding at medium speed, at a perpendicular angle to each other. The principle of a high-contact crash and effect of tyre friction are illustrated by the software.

- 2 vehicles, medium velocity
- A-road, Country, daylight
- 11.30 am, Sunday April 8, 2012
- 1 fatality, 5 serious injuries

Scenario [Public]: Two cars impacted in a ‘T-bone’ collision near a junction, resulting in fatality and injury.

Figure 5.3(i): Warnham High-Velocity Collision

Outcome [SJU]:

- Vehicle 1: VW Golf, at speed
- V = 60 mph, Deformation = 27cm

- Vehicle 2: Honda Accura, turning
- V = 5 mph, Deformation = 21cm

Figure 5.3(ii): Side View, Warnham High-Velocity Collision

Figure 5.3(iii): Impact to Honda, Warnham High-Velocity Collision

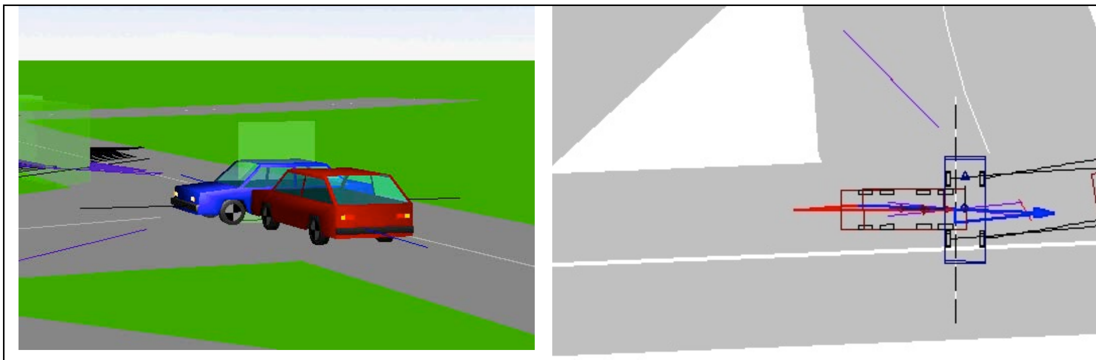
[SJU] The Honda was turning right across the road in order to reach a lane. At this point, the Golf was travelling up the road from a point in the road with lower elevation and a sharp bend. The Honda would have been concealed from view here.

The Golf then collided with the Honda at a right angle, causing high crush to the side body of the Honda, and causing the vehicles to both move along the path of the road. Tyre marks were left by both cars. The braking of the Golf and friction from the tyres of the Honda caused some deceleration, but was not sufficient to stop the cars. The momentum of the crash then caused the body of the Honda to rotate anticlockwise before passing over a narrow grass verge and into a garden fence. The braking action of the Golf stopped this car in the lefthand lane of the road.

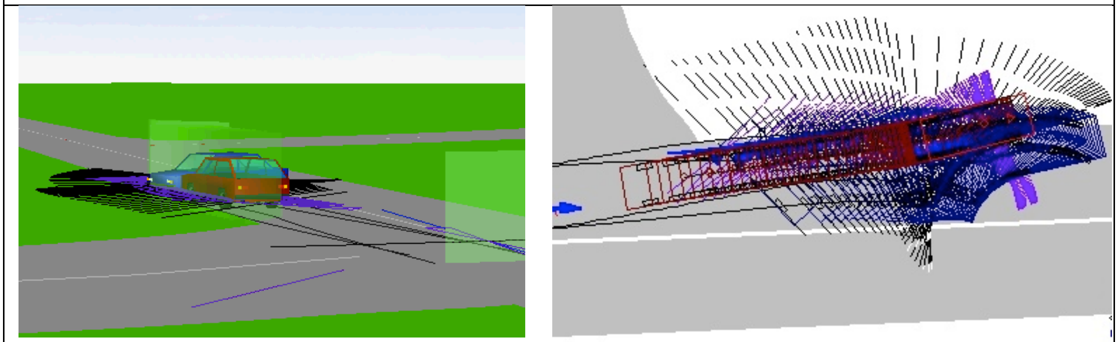
The available evidence for this collision consists of a series of photos with no witness, news or RTA statements. Nevertheless, the crush damage, rest positions and tyre marks can still be used to obtain a reconstruction of the scene.

RTA3 Slideshow

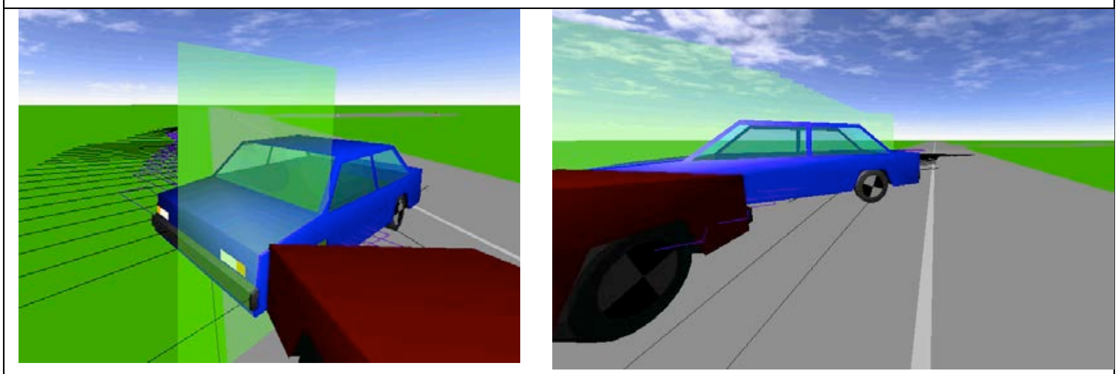
Figure 5.3 (iv-x): Warnham High-Velocity Collision



The lack of police evidence for this case means that reconstruction has to begin from the POI. At this time, Car 1 (Red) is at high speed and contacting the side of Car 2 (blue). The 2D view shows the travel of the red car during the impact via the 2 overlapping schematics; note the tyre marks from the blue car which extend to the right [SJU].



After the first POI from the junction, the collision is modelled as several subsequent impacts. The tyre friction from the blue car causes this vehicle to turn slowly in an anticlockwise direction while the red car follows the same path, losing speed. The 2D view shows the series of impact planes as several black lines that change angle as the trajectory of the vehicles progress [SJU].



Finally the vehicles separate from each other, but still have momentum. The blue car continues to skid in an anticlockwise direction to the left side of the carriageway, towards where the garden fence would be. The red car gradually loses velocity and comes to a stop in the road. Note the tyre marks of the blue car are visible as thin blue lines [SJU].

5.4 RTA4 Collision: Danbury, Essex, High-Speed Collision

Study: Collisions between multiple vehicles at a range of speeds are modelled. The different effects of speed, mass, contact angle and driver reactions are compared.

- 4 vehicles, high velocity
- A-road, Police pursuit in suburban area, morning
- 6.40 am, April 5, 2012
- 1 serious injury

Scenario [Public]: A police pursuit of a stolen vehicle resulted in collisions between four vehicles, some of which were at high speed. Severe damage resulted to some vehicles, with serious injury to one driver.

Figure 5.4 (i-ii): Danbury Multi-Vehicle Collision

Evidence from a News Report [Essex Chronicle, 2012] states that: “The accident happened on the A414, Maldon Road, Danbury just before 6.40am this morning, when the police Ford S-Max was in collision with a blue VW Beetle and a blue Toyota Aygo, while pursuing a green Fiat Stilo estate car, suspected stolen. The driver of the Aygo was taken to a London hospital by air ambulance, and two police officers were taken to Broomfield Hospital, Chelmsford. No further details are known about their injuries although they are not thought to be life-threatening. The Stilo, reported stolen from an address in Suffolk, stopped nearby and the occupants ran off. A 21-year-old man of no fixed address was arrested in Danbury at 8.45am on suspicion of theft of a motor vehicle and is currently being questioned by officers.”

Outcome [SJU]:

- Vehicle 1: Police Ford Smax, at speed
- V = 51 mph, Deformation = 17cm
- Vehicle 2: Toyota Aygo, at low speed
- V = 10 mph, Deformation = 30cm
- Vehicle 3: VW Beetle, normal speed
- V = 32 mph, Deformation = 8cm
- Vehicle 4: Stolen Fiat Stilo, at high speed
- V = 70mph, Deformation = 9cm (sideswipe impact)

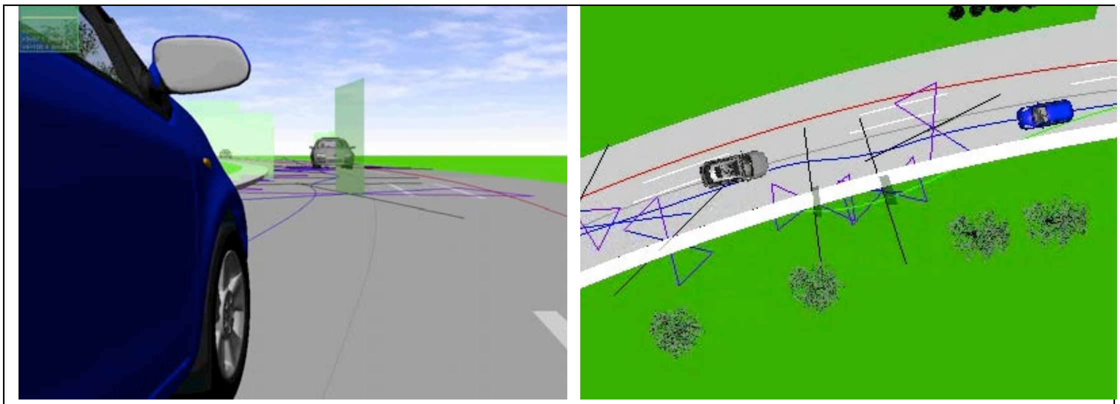
[SJU] As the stolen Fiat turned the corner at speed, the front wing impacted the Aygo. This was likely to be near to the middle section of the road due to the speed of the Fiat and element of pursuit; in addition, the Aygo would have no reason to drive near the right side of the carriageway. The impact caused the Aygo to swerve to the right slightly with the Beetle following behind. The Police S-Max then impacted the front of the Aygo at a high speed, causing major damage and a spin. The Police car was substantially damaged and braked sharply with a deflated front right tyre, coming to rest at the junction of Runsell lane. Meanwhile, the stolen Fiat had lost control on the corner, skidding to a halt at the second junction, where the front right tyre is deflated and left steering lock demonstrated the attempt to control.

Meanwhile, the Beetle impacted the Aygo at some point from the rear, circumstances of which were somewhat unclear apart from the frontal impact to the Beetle and small amount of deformation. This car then braked and veered towards the left curb, coming to a stop.

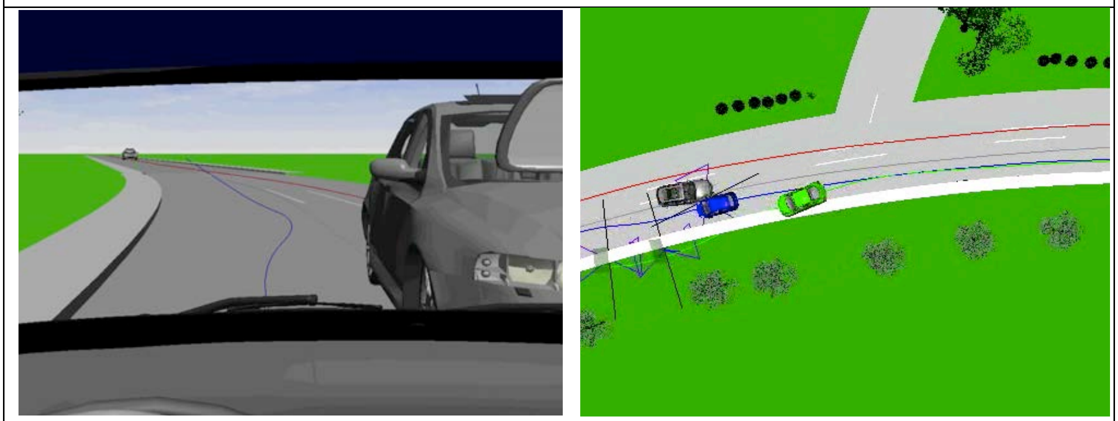
This example demonstrates how scene photographs are fundamental in the reconstruction process. A lack of information may be more misleading than vague or unreliable statements. When one or more news reports are combined, a substantial case file can be composed to form an accurate reconstruction. Moreover, crush damage is a comparatively reliable form of evidence as it is also certain to pertain to an impact with one of the vehicle at the scene, with the possibility of providing speed or directional evidence as well.

RTA4 Slideshow I

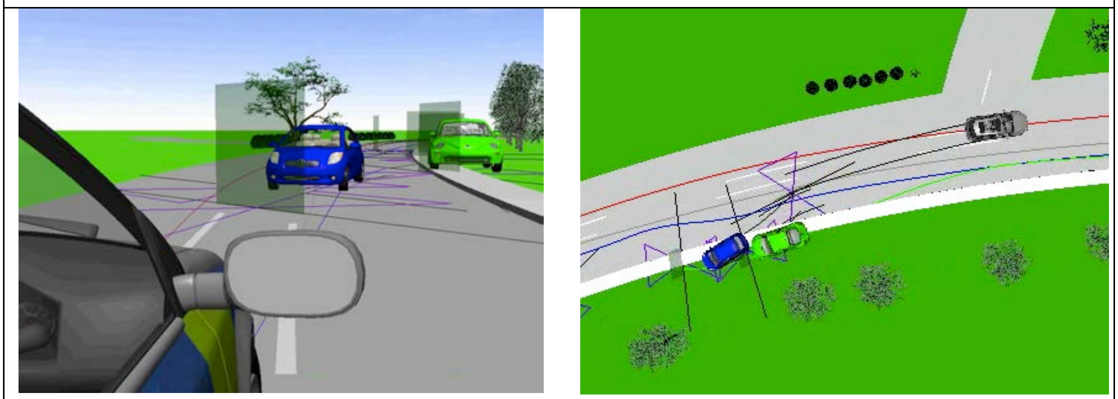
Figure 5.4 (iii-ix): Danbury Multi-Vehicle Collision [SJU]



The number of vehicles in this case mean that an extended description is necessary. In the first instance, the grey car (Stolen Fiat Stilo) is travelling at high speed round a bend towards the blue car (Toyota Aygo). The blue car is travelling in the right position in the road although the grey car has drifted across the middle section.



The grey car collides with the blue car on the front right wing section; note the oblique contact plane visible in the overhead 2D view. At this point the green car (VW Beetle) follows behind the blue car, making an avoidance move towards the curb.

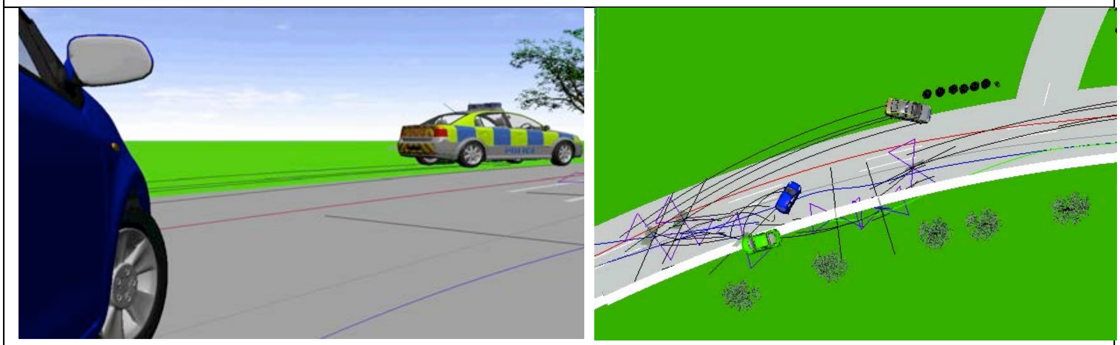


At this point, the green car shunts the blue car from behind, causing the green car to stop by the side of the road. This shunt, combined with the previous collision, causes the blue car to divert into the middle of the road. An imminent collision with the upcoming police pursuit car, following the stolen vehicle, is next to occur.

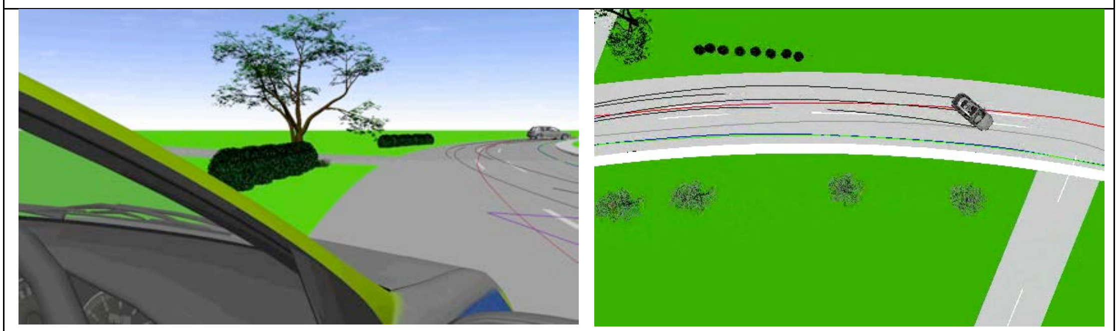
RTA4 Slideshow II

Figure 5.4 (x-xvi): Danbury Multi-Vehicle Collision [SJU]

The deviation of both the police and blue cars from their respective sides of the road means that the front of the two vehicles collide in a near head-on fashion; note the impact plane is perpendicular to the direction of travel. This is the most serious impact in this case and is responsible for severe damage to the blue car.



The blue car is spun around by the impact and comes to a stop. The trajectory of this car can be seen by the tyre marks in the overhead 2D view, as can the direction of the police car which comes to a more controlled stop to the left hand side of the road.



The police car comes to a rest within sight of the stolen grey car, which has also come to a stop by the next road junction. The high speed at which the grey car was driven caused a punctured front tyre and resulting loss of control. No further impacts were reported from this point in the incident.

5.5 RTA5: Usk BMW and Van High-Speed Collision, A449, Wales

Study: A police case involving a serious collision between two vehicles in low visibility. Circumstances were disputed by witness statements and police evidence leads to a different conclusion regarding the cause of the incident.

- 2 Vehicles
- A449, Nighttime, 2011
- 1 Fatality
- Scene attended by RTA Investigator

Scenario [GP]: Two vehicles had collided on an unlit stretch of dual carriageway. A car had impacted a van at high speed, resulting in a fatality. The van had come to rest over a crash barrier, in the trees to the far side of the grass verge.

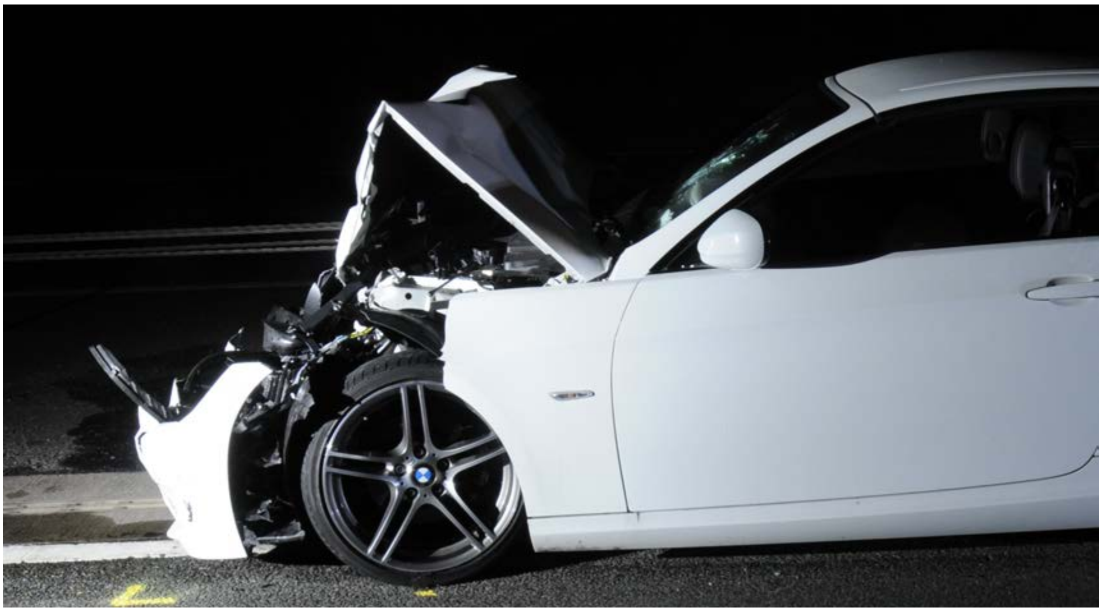


Figure 5.5(i): Usk High-Speed Collision [GP]

This two vehicle collision occurred on the northbound carriageway of the A449. A Ford Transit camper van had been struck in the rear by a BMW, which then left the road and collided with a large sign. The driver of the camper van was certified dead at the scene. It was alleged that the rear lights of the camper van were not illuminated, an important matter as this stretch of road had no streetlights.

Figure 5.5(ii): Usk High-Speed Collision [GP]

Figure 5.5(iii): Usk High-Speed Collision [GP]

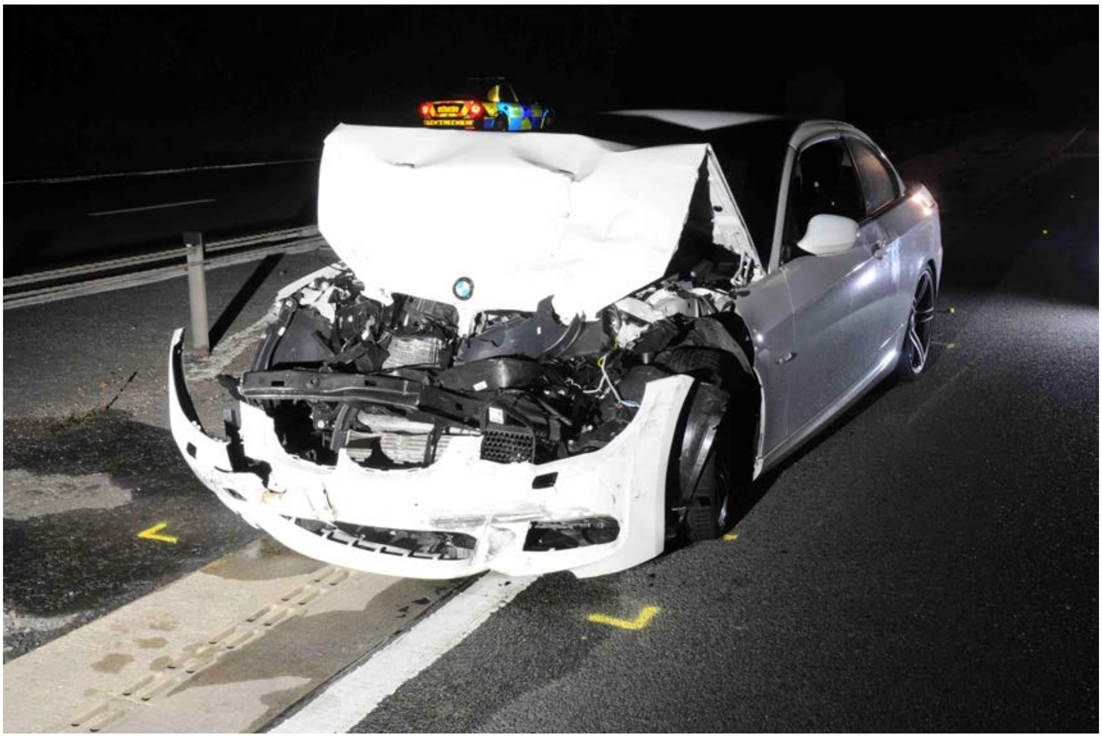


Figure 5.5(iv): Front of impacted BMW [GP]

Figure 5.5(v): Above view of van in rest position & sign [GP]

Figure 5.5(vi): View of collapsed roadside barrier [GP]

Outcome [GP]:

- Vehicle 1: BMW 320i, at high speed
- V = 99 mph, Deformation = 17cm [Measured]
- Vehicle 2: VW Campervan, at medium speed
- V = 54 mph, Deformation = 23cm [Calculated by GP]

From the evidence provided from the RTA Investigator PC C. Goddard [GP], both vehicles were travelling up the northbound carriageway of the A449 between Newport and Usk. The camper van appeared to be travelling at around 54 mph prior to the impact, whereas the BMW was travelling around 99 mph. Before colliding, both vehicles were travelling in lane one of the dual carriageway.

The BMW then impacted with the rear of the Ford Transit. Extracted evidence from the BMW computer showed that a post impact event recorded by one of the safety systems recorded a speed of 87 mph.

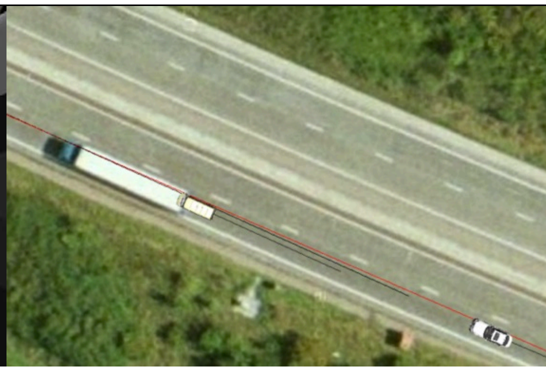
The impact caused the Ford to veer left and collide with a crash barrier on the nearside verge, vaulting the barrier and colliding with the leg of a large roadsign. Unfortunately the driver of the van died at the scene.

After this impact the BMW veered rightwards into lane two, applying braking such that the front wheels locked and left skid marks for 116m. Before the impact, the closing speed between the BMW and the camper van would have been 48mph, plus the camper van would have been in view for 25 seconds with a direct line of sight for the last 16 seconds before the impact.

This specific case demonstrates how the information supplied from the RTA investigator is most helpful in its reconstruction. The scene may be modelled quickly with a high degree of accuracy to vehicle movement and velocity, enabling matters such as crush damage and barrier impacts to be focused on.

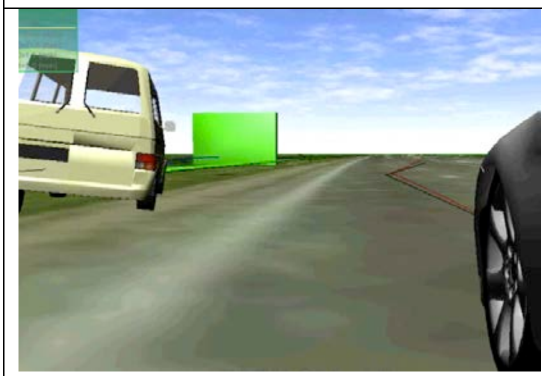
RTA5 Slideshow I

Figure 5.5 (vii-xiii): Usk High-Speed Collision [SJU]



This reconstruction begins from immediately before the impact. The yellow van (VW Camper) is travelling at 55mph along a dual carriageway, with the white car (BMW) approaching swiftly behind at approximately 90mph. Note from the overhead 2D view that the paths overlap closely.

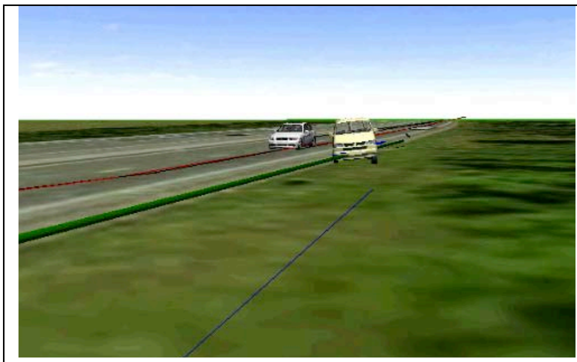
The car makes a rear impact with the van, causing the suspension of both vehicles to change dramatically and alter course of the van. The transfer of kinetic energy from the car means that the van is shunted to the left hand barrier side of the road and increases speed, whereas the car itself loses speed and performs an emergency stop in a forward direction.



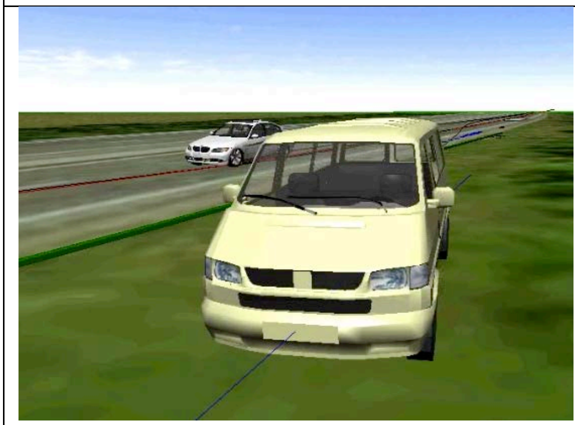
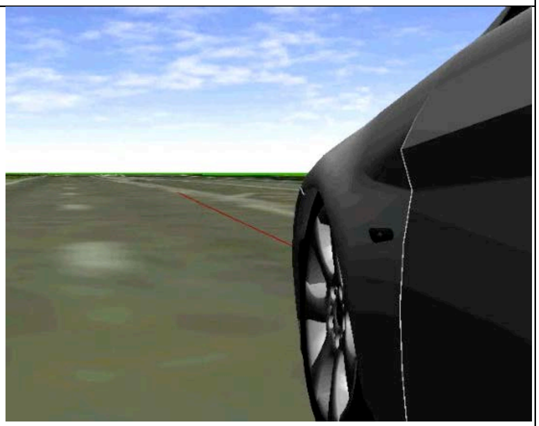
The van loses control and veers leftwards; note the altered suspension state. After crossing the carriageway the van makes contact with the emergency barrier running alongside the road, past a green road sign to the side of the trees.

RTA5 Slideshow II

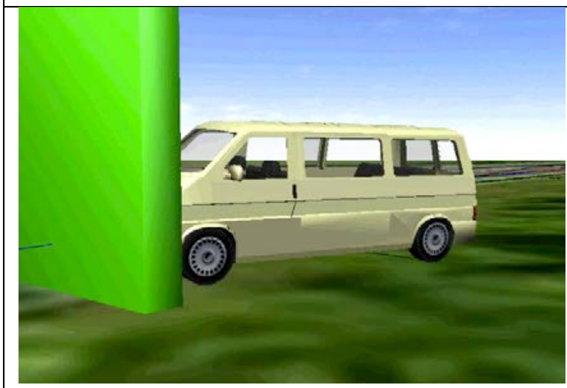
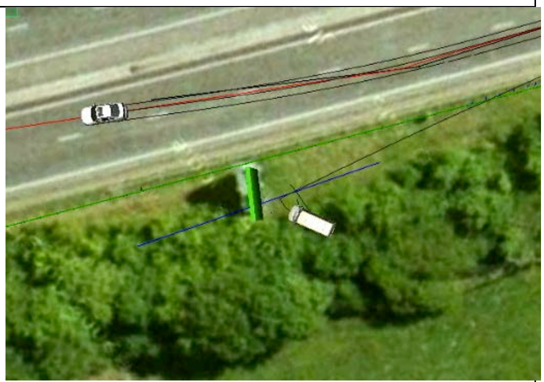
Figure 5.5 (xiv-xx): Usk High-Speed Collision [SJU]




The emergency barrier cannot restrict the movement of the van due to its mass and speed. The van passes over the barrier, into the grass verge and towards the large green roadsign.

The van is now unable to change course. The electronic management systems on the car mean that at this point it has lost speed and the front tyre are now fully braking, and locked. This causes the car to drift slightly to the right.

The van impacts the road sign, causing rapid deceleration. At this point the car has stopped, as can be seen from the tyre marks in the overhead 2D view. Meanwhile, the leftover momentum of the van carrier it from the sign into the grass and trees on the far side of the emergency barrier. The van then comes to a complete stop.

5.6 RTA6: Usk A472, Multi-vehicle, Medium-Speed Collision

Study: To illustrate the movement of car bodies and suspension which are interlinked in a collision with each other at a single instance, without dramatic crush damage to each vehicle.

- 3 Vehicles
- Country A-road, Daytime, Dry Weather
- Scene attended by RTA Investigator

Scenario [GP]: A car making a turn across the road was hit by another car in the rear. This impact shunted the vehicle forward, into the path of another car.

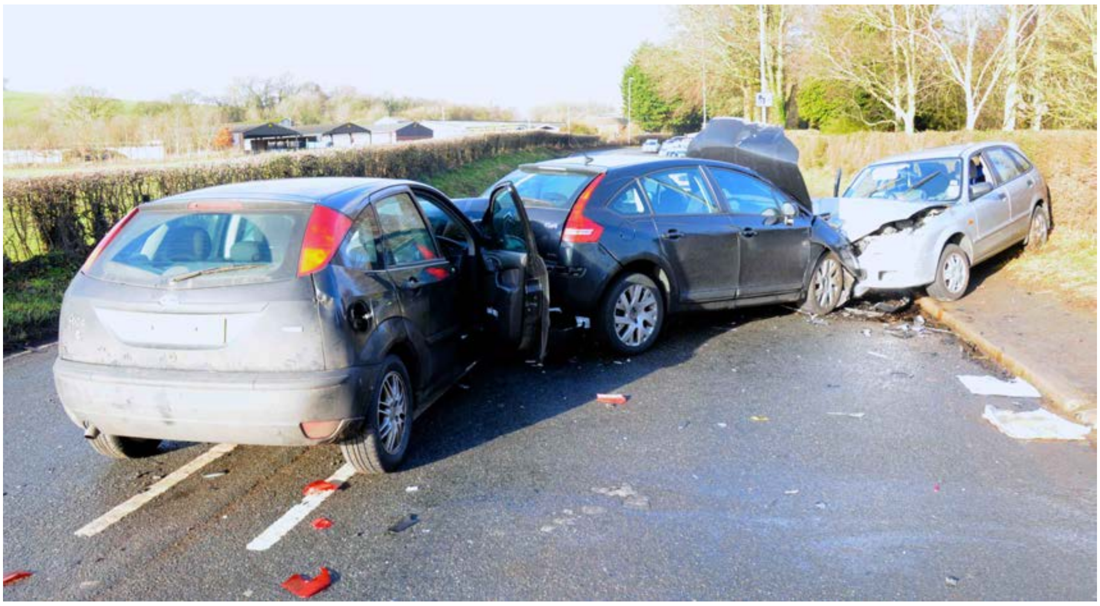


Figure 5.6(i): Usk Multi-Vehicle Crash [GP]

[GP]: The incident occurred when a stationary Citroen C4 was waiting to turn right into the grounds of Colleg Gwent. A Ford Focus travelling behind the Citroen failed to stop and struck the Citroen in the rear. The Citroen was then knocked forward into the oncoming lane and into the path of the Mazda 323 which struck the Citroen head-on.

Figure 5.6(ii): Usk Multi-Vehicle Crash, approach view [GP]

Figure 5.6(iii): Side view, Usk Multi-Vehicle Crash [GP]

Figure 5.6(iv): Bonnet overlap & damage of Citroen [GP]

Figure 5.6(v): Rear view, Usk Multi-Vehicle Crash [GP]

Outcome [SJU]**:**

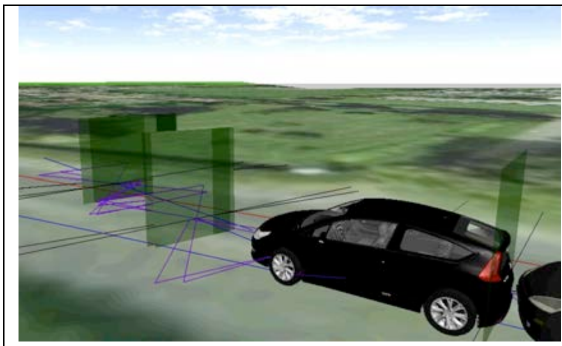
- Vehicle 1: Citroen C4, Stationary
- V = 0 mph, Deformation = 16cm
- Vehicle 2: Ford Focus, Medium Speed
- V = 35 mph, Deformation = 15cm
- Vehicle 3: Mazda 323, Medium Speed
- V = 37 mph, Deformation = 17cm

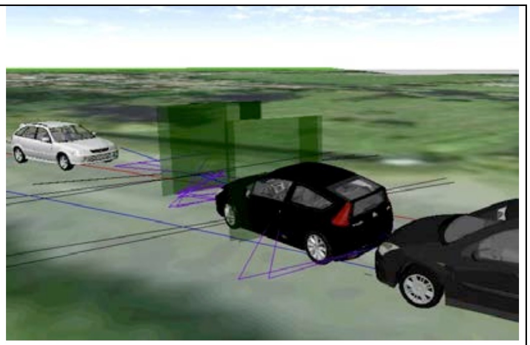
[GP]: The evidence from the RTA Investigation showed that The Citroen vehicle had received a multiple impacts to the front and rear. The front driver's and passenger's airbags had deployed. Inspection of the rear nearside brake light bulbs indicated a level of distortion to the filament. This would indicate that the brake lights were illuminated at the moment of impact.

[GP]: The Ford vehicle had received a single impact to the front bumper and bonnet. The front driver's and passenger's airbags had deployed. It appears that the Ford Focus would have had a clear view of the scene of the collision for 250m before the approaching the scene of the incident. The Mazda vehicle had received a single impact to the front bumper and bonnet. The front driver's airbag had deployed. The vehicles in this case demonstrate how a clear road with no obvious hazards can form a multi-vehicle collision, caused by a simple maneuver.

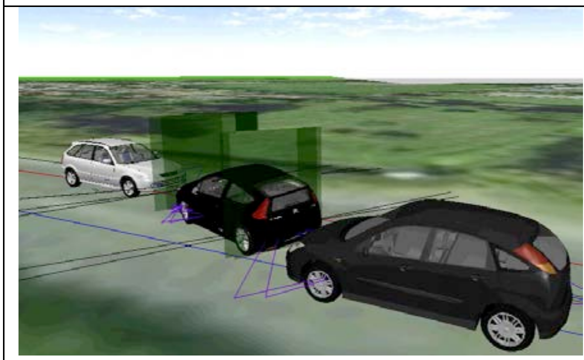
RTA6 Slideshow I

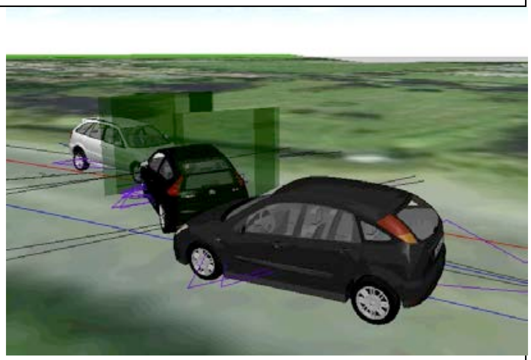
Figure 5.6 (vi-xi): Usk Multi-Vehicle Crash [SJU]



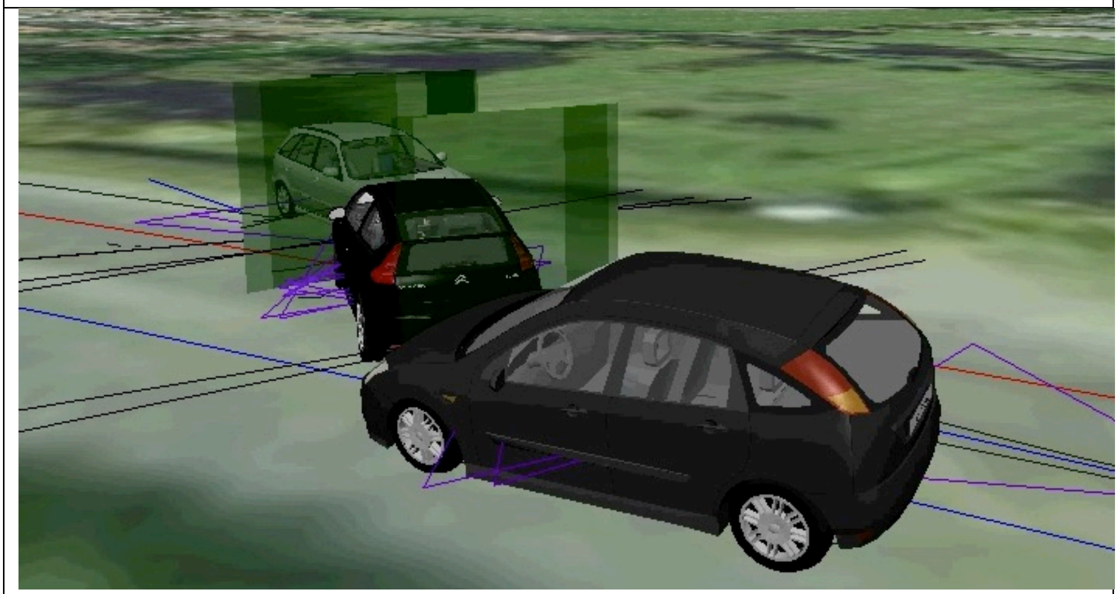


Imminently before the collision, the Citroen is slowing to a halt to turn right across the road. As this vehicle comes to a stop with some right steering lock, the other two cars approach front the rear and front respectively.





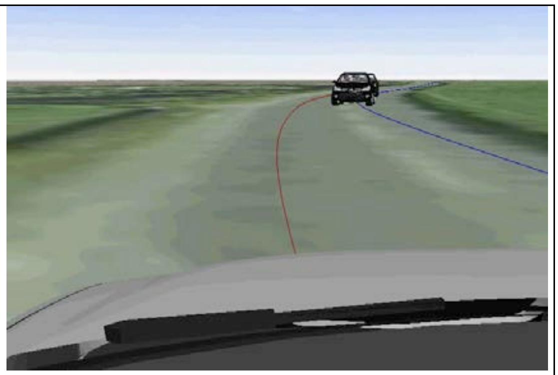
The Focus, directly behind the Citroen, makes contact with the bumper. This impact pushes the Citroen forward and onto the opposite carriageway. The oncoming Mazda in the other side of the road is now in the path of the Citroen. Contact is made when the Citroen is at a 40 degree angle to the median road line.



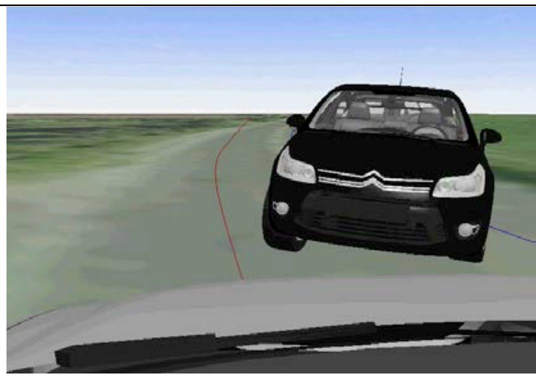
At the end of the impact, all vehicles are in contact. The Citroen is shunted further forward, and thus pushed the Mazda back into the grass verge. Past this point, all vehicles come to a rest but remain within contact with each other.

RTA6 Slideshow II

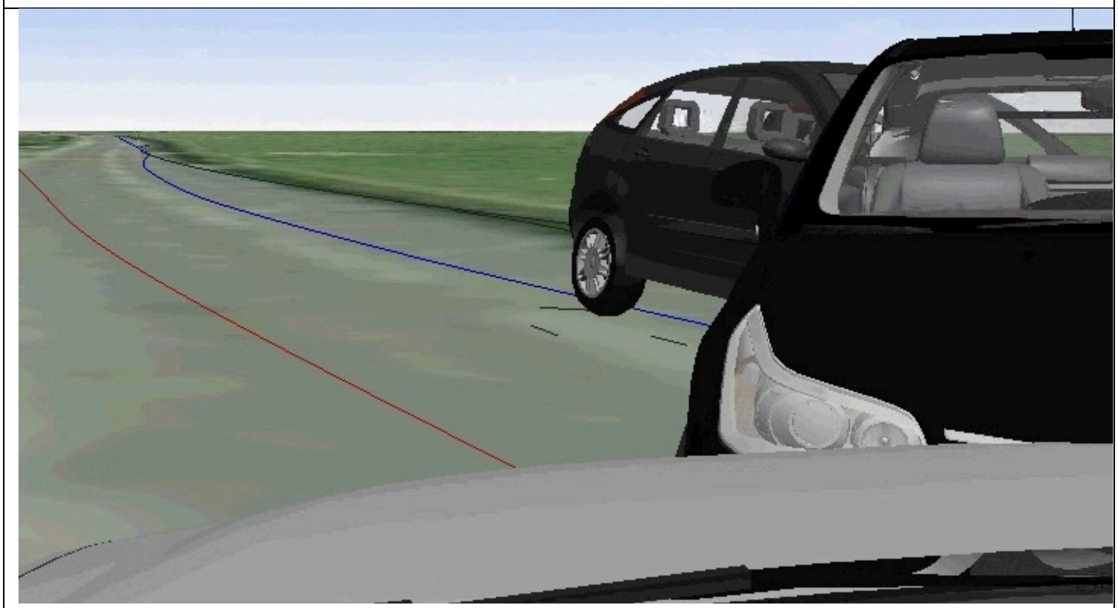
Figure 5.6 (xii-xvii): Usk Multi-Vehicle Crash [SJU]

From the point of view of the Mazda in the oncoming lane: Imminently before the collision, there is no reason to suspect an accident is about to occur. As the distance between the cars decreases, it becomes evident that the Focus will not halt or evade impact with the Citroen.

The Citroen can now be seen to be proceeding across the median point of the road, with some right steering lock. Note that the rear impact from the Focus moves the Citroen’s suspension down at the front passenger side.



As contact is made with the front bumper of the Mazda and Citroen, the Mazda spins round from the angle of contact of the two vehicles and the sudden deceleration. Note that at this point in the impact, the suspension of the Focus has caused it to yaw to the passenger side.

5.7 RTA7: M4 Coldra Junction, Medium-Speed Fatality

Study: To illustrate the trajectory of a vehicle with no apparent driver control on a downhill section of road, with focus on a head-on lamppost impact.

- 1 Vehicle
- Motorway junction, Daytime, Dry Weather
- 1 Fatality
- Scene attended by RTA Investigator

Scenario [GP]: A driver of a small van/car hybrid lost control of the vehicle while exiting the M48 via a sliproad at the Coldra junction. The vehicle hit barriers on both side of the sliproad before being stopped by a head-on impact with a roadsign pole. Footage of the event was captured by a CCTV camera.

Figure 5.7(i): Coldra Junction Crash [GP]

The evidence from the PC Goddard [GP] outlined three separate points of impact from the scene. On the nearside crash barrier was an impact mark with scrapes and similar blue paint to that of the Renault. Approximately 90m from this point, blue paint and scrape marks were seen on the junction wall at a height of ½ metre. From this point, tyre tracks lead away from the wall towards the carriageway and left the verge after a further 23.2 metres.

[GP]: The grass within the tyre mark was inspected and it was formed by being simply laid flat. The grass indicated that the wheels were rolling and not braking, as there were no plucked or torn grass stems within the mark. The vehicle came to rest at the centre post of a roadsign located at the end of the slip road. The post had been dislodged by the impact and was bent over to an angle of approximately 30º to the ground.

Figure 5.7(ii): Exit Sliproad of Coldra Junction Crash [GP]

Figure 5.7(iii): Blue paint on crash barrier of Coldra Junction [GP]

Figure 5.7(iv): Rest position of vehicle and pole damage to front [GP]

Outcome [SJU]:

- Vehicle 1: Renault Kangoo, medium speed
- V = 40 mph, Deformation = 26cm

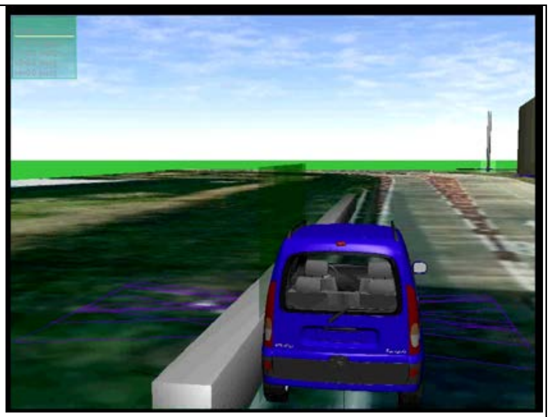
The RTA evidence [GP] reported that 3 passengers were in the vehicle, the driver and passenger, whom were wearing seat belts, and a passenger in the rear seat who was not. The first collision with the nearside crash barrier at the top of the exit slip road for the junction could be described as a glancing blow where the nearside of the car contacted the crash barrier, causing relatively minor damage. This impact deflected the car away from the barrier and across the sliproad.

[GP]: The car continued across the road and onto the offside verge and into a concrete wall, again causing minor damage to the bodywork. After this contact with the wall, the vehicle struck the centre post of a roadsign and came to rest.

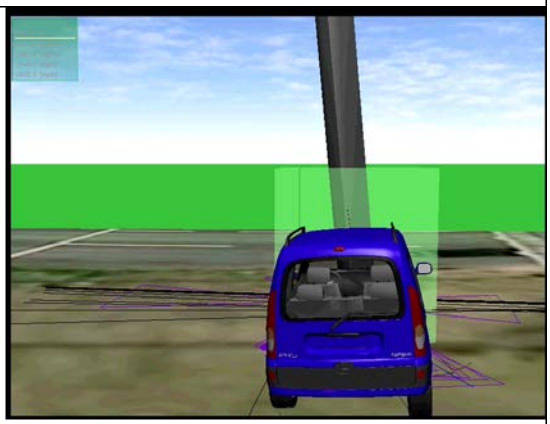
[SJU]: The vehicle in this case demonstrates how a lack of steering and braking on a downhill section of road can cause the vehicle to ricochet off roadside barriers and walls. The software concept of modelling roadside features as solid objects with a large mass is representative in this respect.

RTA7 Slideshow

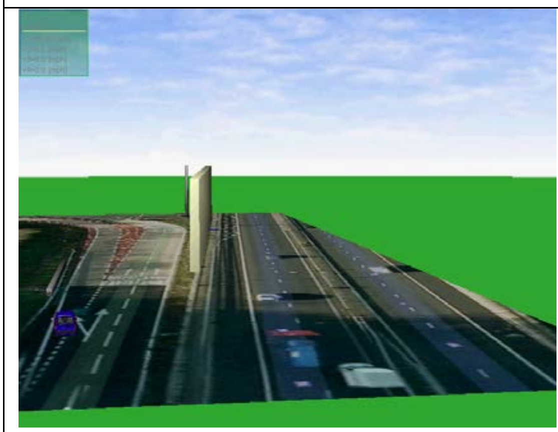
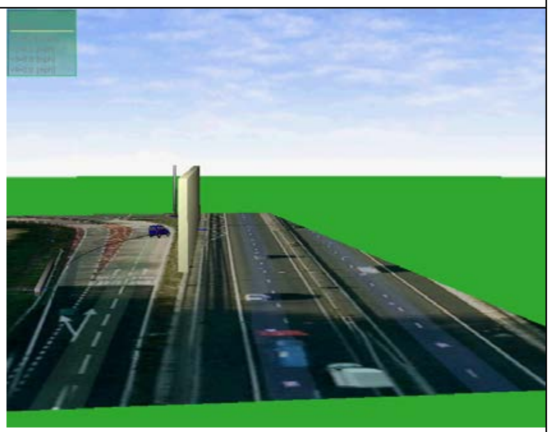
Figure 5.7 (v-xi): Coldra Junction Crash [SJU]

The vehicle exits the sliproad from the motorway, but for unknown reasons veers from the normal left-hand exit lane into the roadside barrier. Contact is made with the roadside barrier at a known point, measured by the RTA Investigator. This is modelled as 3 short sideswipe impacts. The vehicle then rebounds from the barrier to the right.

The vehicle now veers right across two lanes towards the concrete wall of the overhead motorway. Again, no evidence of braking or steering was recorded by the RTA. At contact with the wall the software reconstructs this collision as 3 short sideswipes. The vehicle then rebounds to the left again, heading towards the main junction roundabout. Before the vehicle can reach the roundabout, a frontal impact with a pole occurs, stopping the vehicle suddenly and dislodging the pole.

As part of the case file was CCTV footage taken from a motorway camera mounted high above the carriageway, two viewpoints from this camera position are given. On the left, the vehicle is shown heading towards the first impact with the side barrier. On the right, the subsequent rebound towards the junction wall is given.

5.8 RTA8: M48 Rogliet, Head-on Collision with Emergency Barrier

Study: A case demonstrating the reconstruction of a small vehicle striking a roadside barrier head-on. The complex barrier geometry has been represented by a series of blocks with mass and friction to model deceleration of the vehicle.

- 1 Vehicle impacted with object
- Motorway, Daytime, 2012
- No serious injuries, subsequent fatality following incident
- Scene attended by RTA Investigator

Scenario [GP]: A driver was travelling along the M48 motorway in clear light. At some point the vehicle drifted to the left hand side of the carriageway, onto the grass verge and impacted with the initial section of the roadside barrier (yellow/black stripe). No obstacles or collisions with other vehicles were noted or suspected. The barrier absorbed the momentum of the vehicle and brought the car to rest in a clump of trees to the left of the verge.

Figure 5.8(i): Rogliet Barrier Collision [GP]

Figure 5.8(ii): Compressed Roadside Barrier [GP]

Figure 5.8(iii): Rest position of vehicle [GP]

Figure 5.8(iv): Res position of vehicle from side view [GP]

Figure 5.8(v): Compressed Roadside Barrier [GP]

Outcome [SJU]**:**

- Vehicle 1: Suzuki Swift, medium speed
- V = 60 mph, Deformation = 22cm

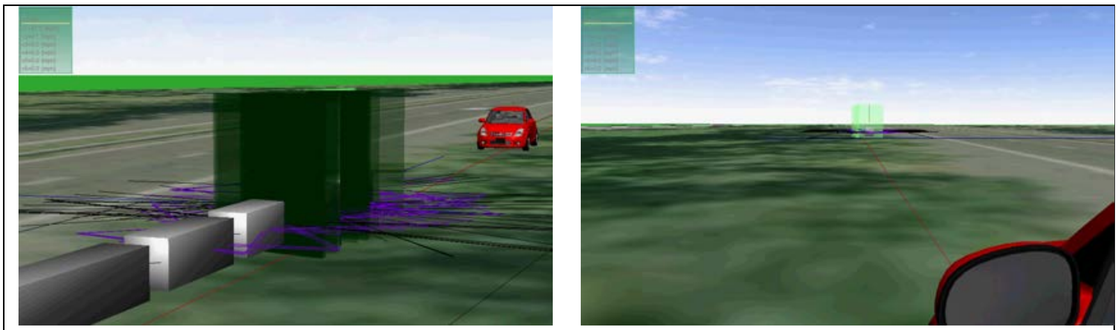
[SJU]: Evidence from the RTA report does not give a definite reason for this collision, although loss of consciousness of the driver is suggested as a possibility. The head-on impact with the barrier was a fortunate event, as the resulting deceleration of the car allowed it to stop safely and out of the path of other motorway vehicles.

The simulations demonstrate the effect of the deceleration on the vehicle body, which can be clearly seen in the reactions of the car suspension, its subsequent deceleration and the ‘twist’ of the car body to the left hand side of the grass verge. There is some travel in the modelled barrier objects that represents the compression of the real-life barrier and its sliding effect during the impact.

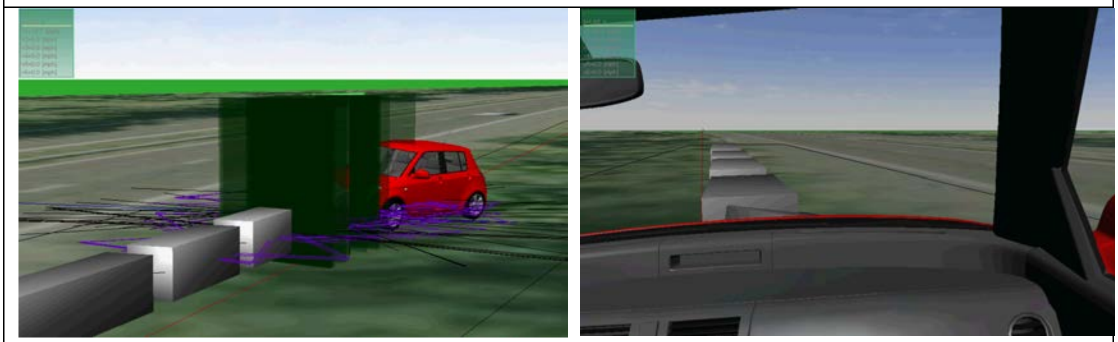
[SJU]: The physical models in this case demonstrates how an interaction between a compressible body with a linear stiffness (the vehicle) meets a series of uncompressible, massively weighted blocks with friction. Naturally this is constructed using several assumptions to model the ‘concertina’ effect that hitting an emergency barrier head-on. It should be noted that the case photos give a textbook example of how such a barrier *should* react in an incident of this manner; in this example the vehicle was stopped within 10m, without immediate harm to the driver who was able to walk away from the vehicle once it had come to rest in the trees.

RTA8 Slideshow

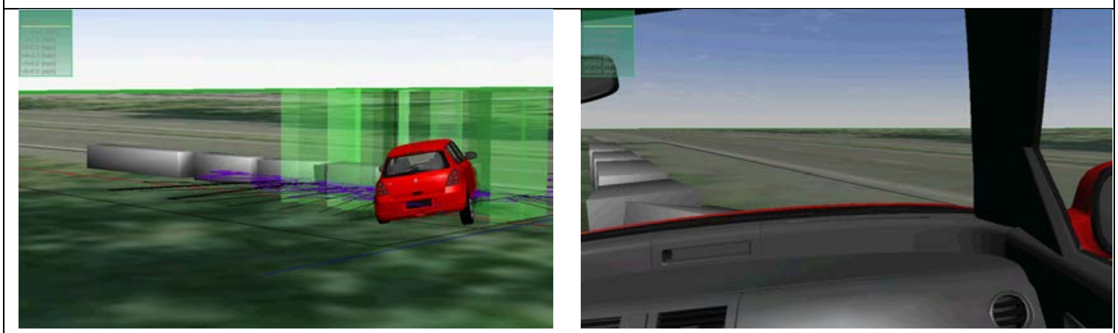
Figure 5.8 (vi-xii): Rogliet Barrier Collision [SJU]



The vehicle drifts from the motorway onto the grass verge area for unknown reasons. At this point the vehicle is heading straight-on to the end section of the barrier. No braking or evasive maneuver takes place. Note that the series of POIs between the first block sections and the vehicle form a ‘wall’ of contact planes.



The vehicle now hits the first barrier section at a point in front of the driver’s seat. The impact dislodges the first block, with the corresponding deceleration force slowing the vehicle down and causing the vehicle to twist to the left hand side of the barrier. This is of course due to the position of the COG of the vehicle, positioned directly in the middle of its geometry and 0.5m from the ground.



The vehicle continues to decelerate and twist to the left, dislodging the second in the series of barrier blocks. The movement causes significant yaw to the vehicle, the effect of which can be seen in the raised rear right wheel arches which react with standard suspension. After this point the vehicle comes to rest.

5.9 RTA9: A48 Coedkernew, Vehicle Rollover

Study: A case demonstrating the physics involved in modelling a vehicle rollover without any interaction from other vehicles or roadside objects.

- 1 Vehicle
- Dual Carriageway, Daytime, 2013
- No serious injuries
- Scene attended by RTA Investigator

Scenario [GP]: A driver travelling along the A48 was travelling at excessive speed when approaching a roundabout. The resultant steering around the curvature of the road caused the vehicle to yaw excessively, such that the vehicle rolled over through 360 degrees. No other contact with any roadside objects or vehicles occurred.

Figure 5.9(i): Coedkernew Rollover [GP]

Figure 5.9(ii): Approach to Roundabout [GP]

Figure 5.9(iii): Rest position of vehicle after rollover [GP]

Figure 5.9(iv): Interior of vehicle after rollover [GP]

Figure 5.9(v): Rest position of vehicle from rear [GP]

Outcome [GP]**:**

- Vehicle 1: Nissan Qashqai, Excessive speed
- V = 56 mph, Deformation = N/A

[GP]: The evidence showed that as the Nissan entered the left hand bend on the entrance to the Roundabout, it was travelling at a speed of 56 mph, losing control. The driver then attempted to steer the car leftwards to avoid the roundabout, causing the vehicle to spin in a clockwise direction.

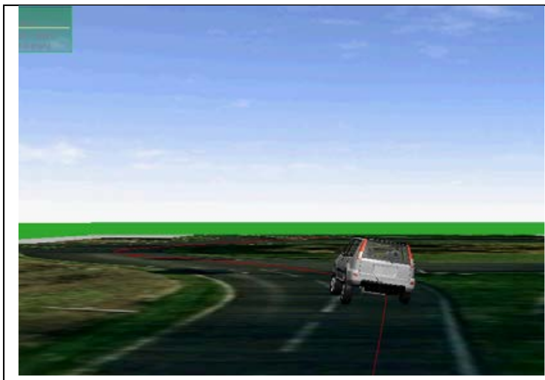
[GP]: The driver has again attempted to correct the 'over steer' when heading towards the eastern exit onto the A48, causing the car to yaw rapidly and spin in a anticlockwise direction. The resultant forces on the tyres were sufficient to cause the alloy wheels to make contact with the road surface, marking the road. Past this point the momentum and yaw of the car caused it to overturn onto its roof, then coming to rest in the middle of the eastbound lane.

The evidence shows that the distance from leaving the first skid mark to the point where the car overturned was over 98 metres. A car travelling at 50 mph could stop in 26 metres, hence the speed of this vehicle was excessive.

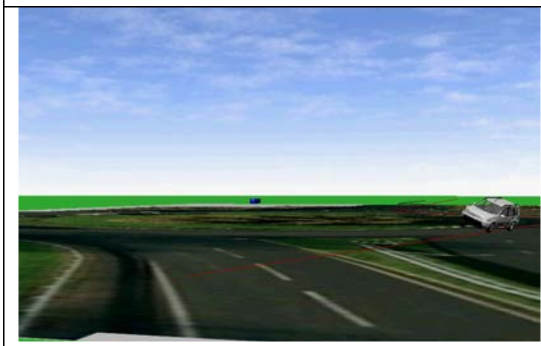
[SJU]: This case demonstrates that the physical forces involved in a non-contact incident can be accurately represented. Attributes such as COG and suspension stiffness are vital in giving a meaningful interpretation of the incident.

RTA9 Slideshow

Figure 5.9 (vi-xii): Coedkernew Rollover [SJU]



The vehicle approaches the roundabout at an excessive speed for the dual carriageway. Near to the roundabout section, the vehicle steers sharply to the left, causing the car to lean to the right. As the car goes round the road section this steering is reversed, causing the vehicle to yaw excessively to the left.



The view from the exit point of the roundabout shows the point at which the vehicle is then travelling on two wheels. As travel continues, the steering and momentum of the vehicle are enough to tip over the COG and therefore the whole vehicle onto its passenger side. After this point the momentum is still of enough magnitude to continue the movement, rolling the vehicle back onto its four wheels to rest.

The interior view shows the yaw to the left after steering towards the roundabout exit point. As the yaw angle increases, the vehicle rotates from resting on its passenger side to an oblique angle where the roof is about to contact the road.

5.10 RTA10: A467 Aberbeeg, Bus and Car Collision

Study: A case demonstrating the difficulty in bringing several less common factors into a reconstruction, namely: ice, disproportionate vehicle size, extreme vehicle crush, plus oblique impact.

- 2 Vehicles
- A-road, Daytime
- 1 Fatality
- Scene attended by RTA Investigator

Scenario [GP]: A car travelling along an icy road lost control and skidded, subsequently heading veered into the path of an oncoming bus. The severe vehicle crush caused a dramatic impact and the fatality of the car driver.

Figure 5.10(i): Aberbeeg Bus & Car Collision [GP]

Figure 5.10(ii): Aberbeeg Bus & Car Collision [GP]

Figure 5.10(iii): Rear view and frosted road [GP]

Figure 5.10(iv): Severe vehicle crush of Bus & Car bodies [GP]

Figure 5.10(v): Side view, severe vehicle crush of Bus & Car bodies [GP]

Outcome [SJU]**:**

- Vehicle 1: Rover 216
- V = 35 mph, Deformation = 34cm
- Vehicle 2: Dennis Single-Level Passenger Bus
- V = 39 mph, Deformation = 11cm

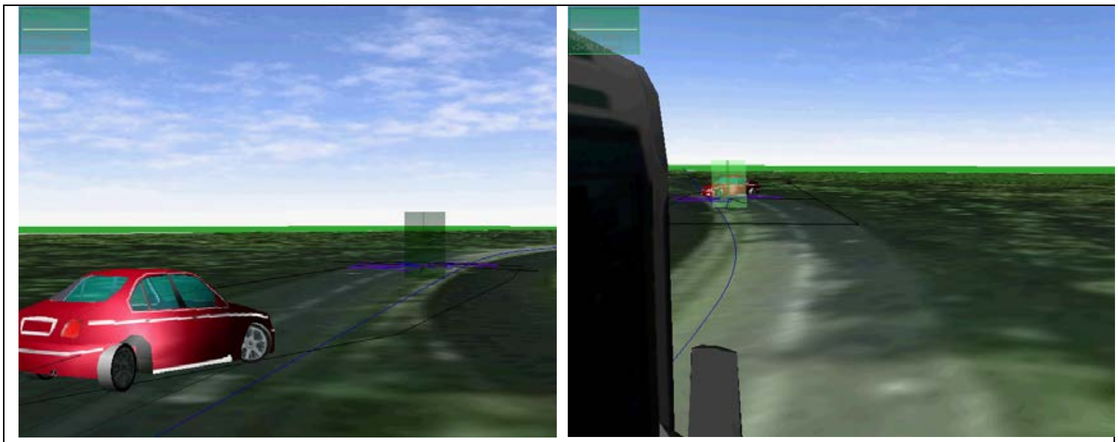
[SJU]: The environment surrounding this incident was highly influential in the action of the drivers and the trajectory of the vehicles involved, as it was a very cold and dry day. [GP] The road temperature was measured at between -7°C and -9°C, and black ice was present on the road surface.

[GP]: The driver of the Rover was travelling on the A467 in a northerly direction, and appeared to be wearing their seat belt at the time of the collision. On a right hand bend it lost control and started to spin in a clockwise direction, crossing the centre white line and rotating to a broad angle to oncoming traffic.

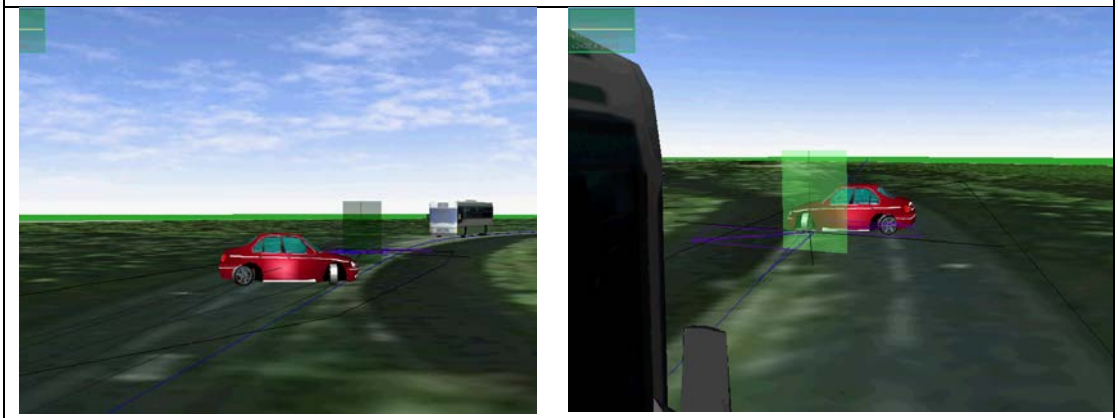
[GP]: The Bus operated by Stagecoach was travelling in the opposite direction. The car had skidded for 33 metres before impacting into the front offside corner of the bus. After this impact, the vehicle bodies of the bus and Rover were interlocked and took 21 metres to come to rest near the left-hand side of the road.

RTA10 Slideshow I

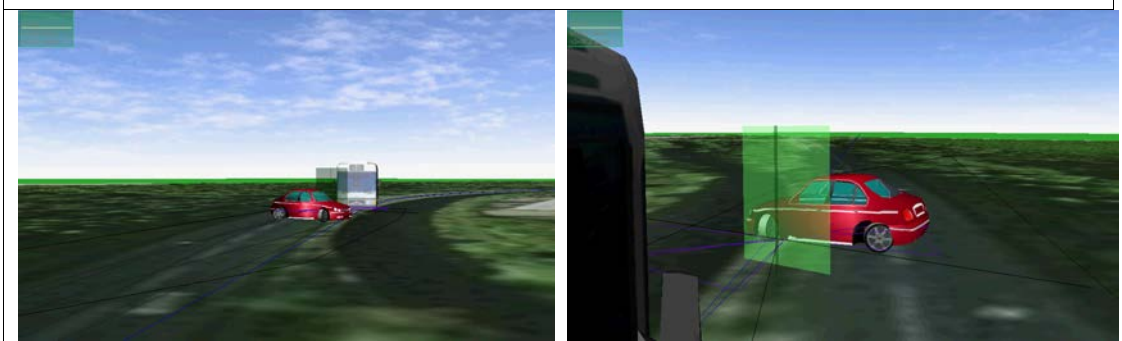
Figure 5.10(vi-xii): Aberbeeg Bus & Car Collision [SJU]



The car is travelling round the curve of the road and begins to lose control, with right lock being applied to the steering. At this point all four wheels have made contact with the low-friction portion of the road designated as ice. This portion can be seen as a black-lined polygon. From the opposing point of view of the bus driver, the car is now becoming visible.



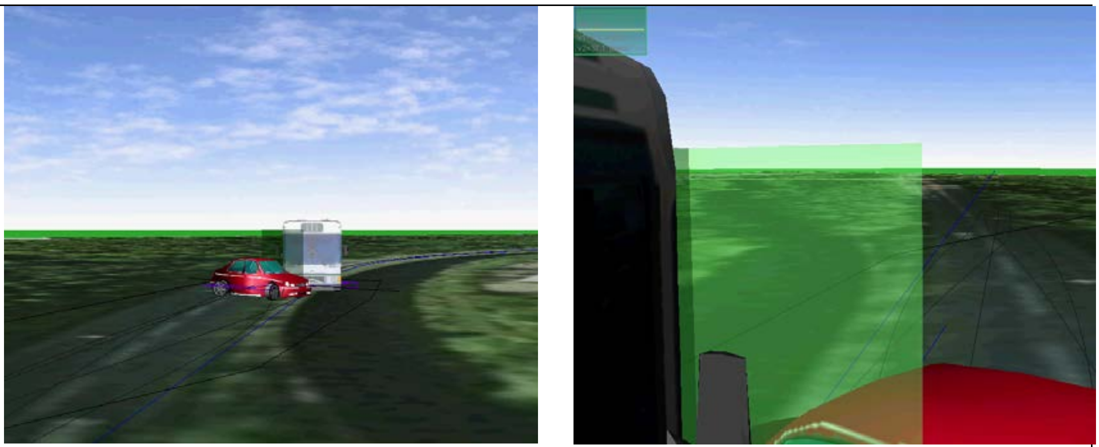
The momentum of the car continues as further right wheel lock and full braking is applied. The car is now out of control and continues to skid across the ice over to the right-hand side of the road. This point now represents the image of the bus CCTV footage included in the appendix. The exact reaction point of the bus driver is not known but this position would be a reasonable estimate.



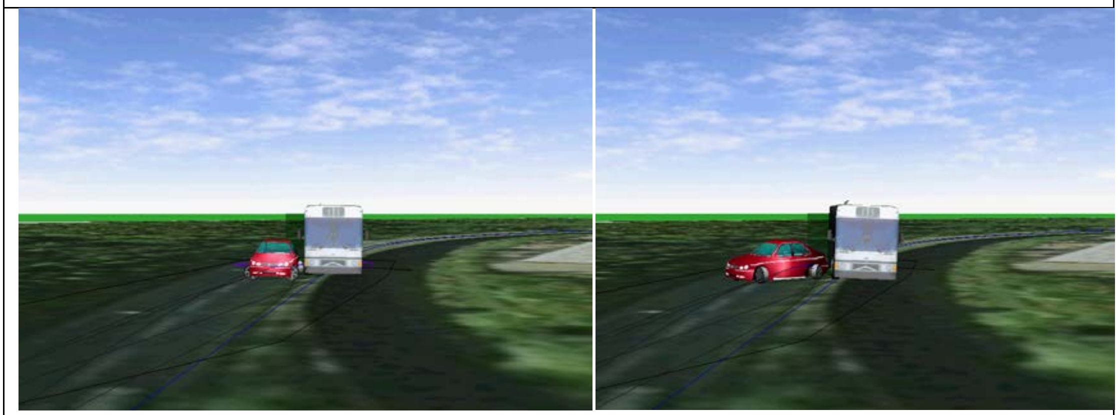
The car continues along its trajectory, rotating clockwise as it does. Imminently before the collision the car is about to contact the opposing grass verge. Note that the contact plane at the POI is almost parallel to the car body.

RTA10 Slideshow II

Figure 5.10 (xiii-ix): Aberbeeg Bus & Car Collision [SJU]



At the POI, the bus impacts the car at the area of the passenger side door, with an angle of impact approximately 30 degrees to the longitudinal axis of the car body. Full steering lock and braking is still applied to the car at the point. The bus driver would have a view above the impact area.



Immediately after the impact, there are no modelled forces to represent the interlocking of the vehicle bodies. The rotation of the car body continues against the bus, with the low friction of the ice underneath encouraging further skidding. This modelled situation allows the car body to separate from the bus. The bus then drifts to the left, hitting the grass verge.

The car continues to skid and rotate, heading away from the bus. The minimal friction on the ice allows it to stop on the right hand side of the road. The bus is now in contact with the grass verge (designated as a high-friction area) and comes to a stop.

[SJU]: The incident here details how several factors are particularly difficult to model in a manner that represents a real-life case. One aspect is that a very large, heavy vehicle has collided with a normal size car at an oblique angle. This means the software automatically assumes a 'sideswipe' impact for each crash at each point of impact, although this can be modified. The next subsequent challenge is the severe crush damage to the car body, which can be graphically represented but not physically changed whilst the crash is being continuously modelled. Factors such as wheel position, COG, mass and locked wheel friction may be used to compensate for this, however.

[SJU]: The factor of ice on the road is easy to program into the scene as a low coefficient of friction (typically 0.1-0.3), but is hard to apply in a pragmatic sense, as the reconstruction quickly becomes too much of an 'ice rink' without consideration to how a driver would normally react to controlling a vehicle on such a road surface. Finally, the large ratio of mass between the two vehicles makes it very difficult to consider a means to interlock the vehicle bodies after the impact has taken place.

These combined factors make it hard to represent the interlocked position and interaction of the two vehicles, hence, the rest position of the car in this case is inaccurate.

6. Discussion of Results & Professional Feedback

The caseload of simulated RTA Incidents were then presented back to PC Goddard at Gwent Police. The officer was shown the scenes in the form of several 2D and 3D reconstructions, and asked to give direct and critical feedback regarding the suitability and accuracy of the software for collision modelling. The table below shows the RTA caseload given and areas which were said to require modification in order to be accurate and meaningful to the incident.

RTA	Location	Modification was Requested to the Following Parameters:				
		Vehicle & Settings	Speed	Layout & Environment	Collision/ POI	Friction, Restitution
1	Example	No	No	No	No	No
2	Plymouth	No	No	No	No	No
3	Warnham	No	Yes	No	No	No
4	Danbury	No	No	No	Yes	No
5	Usk A449	Yes	No	Yes	No	No
6	Usk A472	Yes	No	No	Yes	No
7	Coldra M4	No	No	Yes	No	No
8	M48 Barrier	No	Yes	Yes	No	No
9	Coedkernew	Yes	No	No	No	Yes
10	Aberbeeg	Yes	No	Yes	No	Yes

Table 6.1: Modifications requested to reconstructions in caseload.

The comments of the officer [CG] are given in an edited form that extracts most of the conversational element of the feedback. The most pertinent points to the reconstructions have been underlined; some reflection [SJU] is given to each of these points, as well as other commentary from PC Goddard.

6.1 RTA1 Example

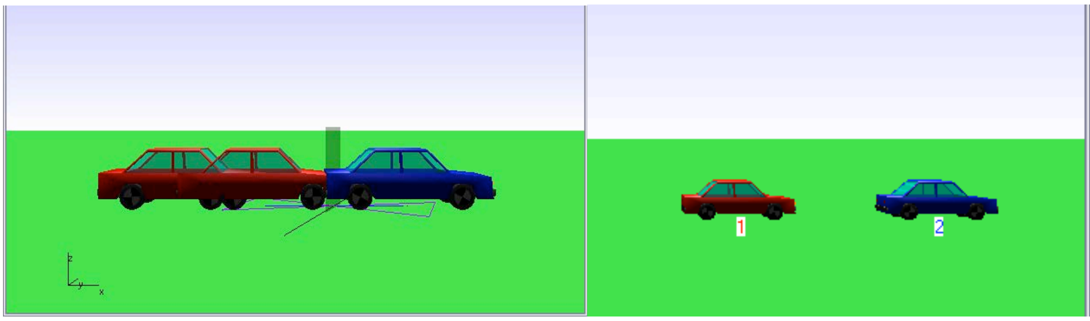


Figure 6.1: RTA1, Example

[CG]: This is a very simple example so it is difficult to comment. It isn't a real case so it simply appears that the impact is just that. There is <u>movement in the car suspension</u> which is appropriate, but there is not really more to add.

[SJU]: This is indeed an 'example case'. The note of vehicle suspension is worth commentary as this is one of the advantages of the PC-Crash software, given that suspension is modelled realistically and may be adjusted widely.

6.2 RTA2 Plymouth

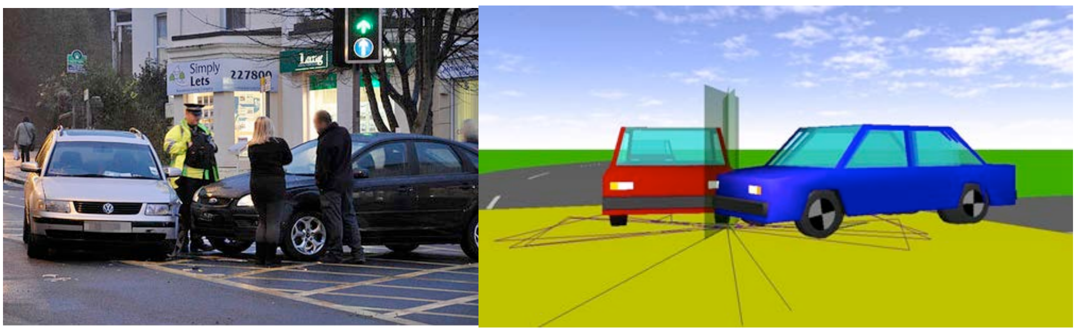


Figure 6.2: RTA2, Plymouth Low-Velocity Collision

[CG]: It would be beneficial to know if there was any displacement of the red vehicle (the stationary car on the left). A lot of the impact at low speed will be absorbed by the suspension alone. It appears that the red car has not moved at all with a very small rebound from the blue car. This would be expected in a normal low-speed collision.

[SJU]: There was no information on post-impact displacment available from the public domain source. Commentary above demonstrates that the potential investigating low-speed crashes is very limited, due to the small amount of damage to vehicle bodies, lack of tyres marks, debris, and so forth. This type of incident still remains less popular among Forensic Investigators, although dashcams have become widespread in use as a means of recording such impacts.

6.3 RTA3 Warnham

Figure 6.3: RTA3, Warnham High-Velocity Collision

[CG]: A staged incident set up for controlled crash research resembled this case very closely. The staged incident here used a Peugeot 206 with an Astra in a perpendicular T-bone impact. In this incident, the force of the impact tilted the impacted car significantly. Looking at the Golf (in Figure 5.3ii) the damage is appears comparable, which suggests the speeds are relative; 50mph in the setup test and 60mph in the RTA3 case. The suspension of the impacted car would have moved sharply on impact, absorbing a little of the kinetic energy.

Here the simulated case does not appear very different from the real vehicle-to-vehicle interactions.

[SJU]: The integration of vehicle suspension features to the program is given some more validation here. More interestingly, this case outlines a general type of crash (the t-bone, common at junctions) that appears to have been modelled well with regard to simulating this scenario accurately. There is an advantage to this case in that both vehicles are approximately the same mass and dimensions. The accuracy of the modelling could well diminish if this was not the case (requires further research).

6.4 RTA4 Danbury

Figure 6.4: RTA4, Danbury Multi-Vehicle Collision

[CG]: There are various collision points (POIs). Unless these points are made clear, judgement is difficult. Four vehicles are involved with the Aygo contacting all 3 other vehicle. It is necessary to establish the POIs for all of these, and this could be done quite easily by speaking to the RTA Investigator involved. This would help considerably; even if there are no tyre marks it should be ascertainable. Perhaps the debris field could indicate this. There are chevron signs at the bend, which means they are a necessary warning. The view going round the bend is restricted due to the curvature of the road.

Regarding the officers driving the pursuit car, the impact of this vehicle would have resulted in whiplash in the least. The car has absorbed the impact damage quite well, but more severe damage is evident in the front tyre has been pushed right back by the collision.

The source of damage to the passenger side of the Aygo is unclear, as it is unlikely to have been caused by the Beetle car. The sill has been ruptured on the Aygo, plus it appears some oil spill has been splattered up the side. There is a severe impact on the Aygo overall, which is only a small car.

Given the prescence of a turning lane in the road, the cars should be 3m apart when travelling on opposite sides of the roads. Debris fields are not a very accurate means of measurement, but this may prove what side of the road a car was on. The photos of vehicle damage could yield more information. There does seem to be an awful lot of debris in the oncoming lane by the junction which I would is likely to originate from the Aygo.

On a side note, the punctured tyre of the Stilo appears to be a run-flat tyre, although the picture is not detailed enough to confirm this. When drivers leave them on the car after a puncture, handling problems result from the tyre being smaller and holding much higher air pressure, say up to 60psi. As a result, it has little resilience and loses grip when used. Failure or puncture then can be more dramatic in comparison to normal tyres.

[SJU]: Several requests for more information were made to Essex police, but no data was forthcoming. The commentary demonstrates that POIs are one of the crucial points of reconstructing a scene, although not absolutely

necessary. Other commentary demonstrates that retrieving crush information from a severely damaged small car can be problematic. The damage to the police car, in comparison, is easily measured and can be compared with damage to the tyres to reach a firmer conclusion. This demonstrates that the common and traditional method of damage analysis may not always be viable in certain incidents.

Further comment on tyre use provides some interest. The front tyre of the Stilo may have been the root cause of the accident, if indeed this was a run-flat tyre that was pushed beyond recommended use, i.e in hard cornering and high speed. Police files on the vehicle should be able to confirm this, however, there exists no feature in the PC-Crash program for modelling tyre pressure (only geometry). This could be an aspect for future development.

6.5 RTA5 Usk A449

Figure 6.5 (i): RTA5, Usk High-Speed Collision [GP]

[CG] The reconstruction shows some ‘wobble’ in the path of the BMW *(flickering in the modelled steering)* as it approaches the van. This is not realistic and it is more likely that this car was travelling up the carriageway in a very straight path.

The different points of view (camera angles) of the modelling help to give a good description of the scene. Particularly useful is the interior view from the van, looking backwards, although it's a shame this can't be shown in nighttime view. The impact of the vehicles seems quite accurate and the movement in the suspension of both cars at the time of impact that is representative of an impact like this; the front of the BMW is shifted down into the road, creating a divot in the road surface (See *Fig. 6.5ii)*, and the van is shunted forwards and leftwards, eventually making contact with the barrier.

The emergency barrier on the left is incorrect in height, typically this would be around 0.6-0.7m high. In the reconstruction it is set at 0.4m and should be raised to reflect this.

Figure 6.5(ii): RTA5, Divot left in surface at POI by BMW chassis [GP]

One thing that stands out is that the model shows that the van 'flattens' the roadside barrier when it makes contact with it. In reality the van bent and distorted the front part of the roadside barrier, the effect of which can be seen in the scene photos. Past this point it travels over the barrier and into the far roadsign, coming to an abrupt halt. Obviously then the van comes to a rest in the section of trees to the far left, but this is not shown in the model. The van can be seen to be rolling back here which is not what happened. It may be better to insert a cluster of trees and use that as the rest point.

[SJU]: The BMW path had been not been inserted into the program as a straight line, taking the form of several connected points. Minor angles were present between the points, and once corrected the steering 'flicker' was not present. More support is given to the suspension modelling implemented which seems to represent the vertical displacement of a rear shunt.

Problems with environmental objects are noted. The roadside barrier is easily corrected for height, but its action as a solid body is not realistic. The investigator points out that the van comes to rest in a patch of trees, but this is not possible with the current program. This results in an unsatisfactory rest position for one of the vehicles, one of the key outputs of incident modelling.

6.6 RTA6 Usk A472

Figure 6.6: RTA6, Usk Multi-Vehicle Crash [GP]

[CG]: All the vehicles here are in contact, which is very unusual. The reaction of the furthest car with the grass verge may have something to do with this – the rear part of the Mazda is on contact with the grass but has not yet contacted the hedge. This side window of the Mazda has also broken.

Part of this modelling rests on whether the brake lights of the Citroen were illuminated. The Citroen driver's lights were examined and found to have a bowed filament (extended in a semicircular shape). As the tungsten filament was bowed, it must have been hot, ductile, and therefore illuminated at the moment of impact. This should be confidently integrated into the modelling; the examination of the lights was not in any doubt.. As the braking in the reconstruction is only light, the brake factor should be increased.

The bumper impact towards the Citroen seems be lacking in momentum. There was 15% overlap between the Mazda and Citroen, perhaps integrate this to the model some more for a more accurate picture.

[SJU]: The brake factor of the vehicles in question was increased, and the path of the Citroen was compensated for a slight overlap. This caused the rest positions of all 3 vehicles to move slightly. Movement was minor but resembled the scene photographs more accurately, supporting CG's suggestions.

The comments demonstrate that braking factors are important in modelling the momentum transferred during a crash. The integration of this feature to the program is given as a number, which has to be tested and trialled with regard to the animations. This process introduces variability to the reconstruction process, which could be be implemented more precisely.

6.7 RTA7 M4 Coldra

Figure 6.7: RTA6, Coldra Junction Crash [GP]

[CG] The more unusual aspect of this case is that the car was modified to have one pedal used for acceleration and braking only for driving via a disabled person. It is unknown if there was a problem with driver reaction or the lack of braking being a disability issue with the modified controls.

The reconstruction seems to be a reasonable picture of the events that occurred at scene. There is some CCTV images from the case but these are taken from a camera high above the main carriageway and have a limited view of the Renault striking objects on its exit down the sliproad. The steering of the vehicle between impacts was perfectly straight – this could be seen from tyre marks and tracks left in the grass. The reconstruction could do to take this into account.

The measurements between the POIs on the barrier and junction wall were obtained with robust measurement and seem to be accurate with the modelling shown here. The final impact with the pole is around the right place, but the pole doesn't fall and hit the ground (*as shown in the simulation*). At the scene it was left poking from the sign at around a 30 degree angle. Nevertheless this was the rest position of the car and its trajectory to this point is realistic.

Another complexity to this case is that occupants of the car were thought to be suffering from delirium after the crash, making statements unreliable. The death of one of passengers in the case made the relatives of this passenger, one of whom was driving, very reluctant to give further statements after the incident.

[SJU]: Most of this reconstruction appears satisfactory. The modelling of a single vehicle with an immovable barrier (in this case, the carriageway wall) has been well represented – but only because of using an exaggerated mass value for this feature. Other nearby features such as the pole could benefit from more realistic integration to the software. Again, the point of rest of the vehicle is under discussion and this highlights an area for further development.

The comments on witness statements demonstrate the difficulty in using this data for reconstruction. It is suggested, as in the methodology, that these are disregarded for the modelling process.

6.8 RTA8 M48 Barrier Collision

Figure 6.8: RTA8, Barrier Collision [GP]

[CG]: <u>The roadside emergency barrier here has been modelled as a series of blocks, which may not be the best way to consider a barrier that concertinas under force from a vehicle</u>. A suggestion is to contact MIRA, enquiring about a P4 Terminal collision. This organisation has crash test data for the decelleration rates and forces for such a crash into a roadside barrier just like the one in this case. This would be most helpful for reconstruction.

The scene photos show that the whole barrier section has been pushed back 10m, 8.6m to be exact, with around four barrier leg supports being snapped off. These would be made of mild steel and designed to break off. The result would be a very uniform decelleration.

The 50mph set for the vehicle is reasonable but the case file yields an estimate of 70-80mph for a similar vehicle seen on CCTV before the crash, so perhaps increase the speed of the vehicle.

The rest position of the Suzuki is around 90 degrees to the original position of the barrier. What is very remarkable is that this was a small car, without an airbag, without a particularly good NCAP rating, and yet it has survived a high-speed impact very well, with the driver being able to walk away from the vehicle. <u>It would be very interesting to integrate the decelleration forces from MIRA and see how this assists the reconstruction</u>.

[SJU]: The comments show that an impact causing uniform decelleration with a crash barrier has been modelled well. Otherwise, regarding the request for data, Dr. Tony Payne (NCAP) was contacted. After a conversation, an agreement was made to release force/displacment data from a P4 crash involving a Suzuki Swift. Unfortunately this data took around 18 months to arrive, and on receipt, proved impossible to integrate to the software. Given

the rate of crash testing that NCAP perform (which is every commericial vehicle produced in the UK), it could surely be highly beneficial to investigators to look at means of importing this data to the software.

6.9 RTA9 Coedkernew SUV

Figure 6.9: Coedkernew Rollover [GP]

[CG]: One source of information is how a windscreen breaks; In this incident it can be seen how the glass on the SUV has broken. It's possible to cut through broken glass with scissors to get out of the car is such a case as this, as the plastic laminate is easy to cut through.

Looking at the reconstruction from above, the car has left the designated path and gone wide of the skidmarks around the roundabout. There was ABS on the car but it appeared the driver did not brake at the roundabout, rather more just kept on steering, therefore, disable modelling of the brakes.

The first set of skidmarks are from the driver's side wheels. The vehicle navigates around the kerb, after this full steering lock is applied in the opposite direction. The second marks are just the passenger side tyres as the car starts to spin sideways, after the driver puts maximum lock on.

The driver's reactions here were very abrupt, but not as sharp as the red vehicle path that has been plotted. If the red path for vehicle trajectory is the path of the centre of mass, the first set of marks should be modelled by offsetting the vehicle by half the wheelbase. The majority of vehicle mass would be applied to the skidmarks on the road, hence this is a more realistic approach to modelling the scene. The same process should be applied to the second set of skidmarks, which should be offset by half the wheelbase in the opposite direction. This will smooth out the cornering in the reconstruction so there isn't such an abrupt change in direction.

As the car travels round the bend it is out with its direction of travel, spinning around. The physics of the car resemble a 'pendulum' movement, bouncing from right to left to right again, finally resulting in a motion that cause the car to overturn. The third marks are the driver's side wheels again, which have divotted into the road surface, causing a rollover.

There was also a 'gouge' in the road from the final set of skidmarks (*note: not visible from police photos)*. This is the wheel rim contacting the road after the tyre shape has become heavily deformed. This seems particularly tricky to model as the tyre tread is not in contact with the road, rather the sidewall section of the tyre. When the rim 'digs' into the road, it creates a momentarily high value of friction which is similar to being tripped up by a kerb, rather than a surface-to-surface interaction. This may be very difficult to model.

It is recommended that the value of 0.5m for COG height needs to be increased to 0.7-0.8m. A standard car COG height is 0.55m. The most striking thing about this case is that the rollover motion is realistic, but the change of direction needs to be reconsidered be offsetting the COG by half a wheelbase for the sets of marks in the case.

If the friction of the road is set at 0.8, this may need adjusting. The case report used a value of 1.0 from a mean of two tests of 1.01 and 0.99. This test involved a 57-plate Ford S-Max, but the comparison should be realistic enough.

[SJU]: Recommended adjustments were made for COG, friction, braking and path of the vehicle. This did not result in a simulation that resembled the incident; the vehicle did rollover, but at the first application of steering rather than at the exit to the roundabout. Nevertheless, the motion of the SUV was more realistic - presumably owing to the more accurate variables. This highlights the importance of using values from experience, rather than by a general reference to 'template' situations.

What could not be modelled was the 'divot' caused by wheel edges contacting the road. An attempt was made with small road area of high friction, but in general there was no suitable workaround for this process and the simulation could not be improved. There is agreement that aspects of the software cannot represent some physical situations of an incident. In such a case a this, the result may be the incident not being investigated at all by a researcher using this software.

6.10 RTA10 Aberbeeg

Figure 6.10: RTA10, Aberbeeg Bus & Car Collision [GP]

[CG]: This was a case with severe vehicle crush. Individually, what is reconstructed up to the POI is very accurate, and is exactly what has happened in this RTA case.

Past this point, the action of the modelled Rover causes the car to bounce off the Bus after the impact, which is not what resulted in the case.

Once the impact and deformation has occurred, it would be beneficial to find a means to make the Bus ‘capture’ the body of the Rover, as the vehicle bodies have become mechanically locked together.

It seems that applying a field of ice to the whole road and both vehicles is a good way to model the scene. A low value of friction should be applied – there would have been some variation over the road but it wasn’t possible to predict where variations would be. It certainly was a bitterly cold day – when the fire brigade arrived, drips of water from the engine froze into stalagmites on the ground immediately.

The whole car was pushed backwards, but didn’t rebound off the Bus as shown in the model. Evidently after the impact, the car has wrapped around the front of the bus. Here restitution doesn't apply as the vehicle body has been completed captured by the bus. The issue comes as after the momentum of impact, the Rover body becomes instantly plastic and all the kinetic energy is absorbed. It is suggested to <u>increase the value of restitution in the program, perhaps to 0.5.</u>

If the program models the car as a separate object, it will naturally rebound from the impact, and also spin around after impact when it hits the kerb section to the left of the road. Instead of setting the friction for the grass at a high value of 0.9, set it at 0.3 as the verge section here was cold and partially covered in snow and ice.

Vehicle-to-vehicle friction could be increased as well, given that when the Bus impacts the Rover, all the energy is converted into vehicle damage. When the Bus comes to a standstill, there is nothing to make the car rebound or separate.

[SJU]: This case demonstrates how difficult a two-vehicle collision can be. The variables under scrutiny here are surface friction and vehicle restitution. Frictional values were reduced to account for ice, but the movement of all vehicles became unrealistic. This was due to the software modelling each vehicle as a mass travelling in one direction without much resistance; both vehicles did not stick to the programmed trajectories. Whereas the recommended frictional values may be right, they do not represent a road in cold conditions. It is suggested that low friction values are best reserved to model small sections of 'black ice' and similar features.

Restitution variables were also changed for the impact and rebound of the impact, but no setting could model the mechanical locking together of the two *vehicles. Again, this is due to the basic mode of the software. This is unfortunate as many incidents involve severe crush of this manner. This shortfall is certainly in need of further development.*

6.11 Summary of Investigator's Comments

As a means of reconstructing traffic accidents, PC-Crash is successful at an inconsistent rate. Some aspects of an incident are said to be accurate, whereas some are in need of further development. These points are summarised here before more discussion in the following chapter (7.Critique).

Accurately modelled aspects of RTAs

- Collisions between two vehicles of roughly equal mass, in rear or side impacts [RTA3-6]
- Simulation of rear-shunt impacts [RTA6,9]
- Impact of single vehicles with immovable objects [RTA7], or head-on impact with compressible barriers [RTA8]
- Vehicle trajectories between POIs [RTA7]
- Braking factors during car-to-car impacts [RTA6]
- Incidents where vehical suspension is an influential factor [RTA3-6,9]

Inaccurately modelled aspects of RTAs

- Low-velocity collisions [RTA2]
- Incidents with unconfirmed POIs [RTA4]

- Non-standard tyres or severe tyre deformation, or incidents with tyre rim to road contact [RTA4,9]
- Impacts with natural environmental objects or artificial objects mounted on poles (signs, roadside barriers) [RTA5,7]
- Low friction road surfaces, or surface covered with large proportions of ice [RTA10]
- Incidents where two or more vehicles interlock due to impact damage [RTA10]

7. Critique

The overall aim of this project was to study the suitability of PC-Crash as a tool for modelling vehicle collisions. Additional commentary on aims and outcomes of the project follows after a technical focus on specific aspects of the project methodology and the crash reconstruction process.

7.1 Investigators

It is not unreasonable to state that the feedback from the police officer is the most helpful in terms of assessing the suitability and success of the project. This research was assisted greatly by one officer in general, as cases, information and advice were plentiful enough for the caseload from one source. The viability of this arrangement was only possible due to a long-held working relationship between Prof. Alan Smith and Gwent Police, which saw fit to enable the sharing of data and further collaboration.

Other investigators were continually contacted throughout the research, but no useful data was ever forthcoming, for example, Sussex Police [RTA3], NCAP [RTA8], and Essex Police [RTA4]. Partial data was eventually received, but not in the detail required to simulate cases. It is suggested that due to the senstive nature of the data regarding incidents, working relationships need to be set up in order for this to take place. Accreditation and trust would help to encourage the sharing of data for research purposes; it is noted that this process cannot be rushed in time for project deadlines.

7.2 Capabilities of PC-Crash Software

It is recognised that the virtual environment created by this software has several limitations. Some discussion is given here to these points and how such limitations can restrict the accuracy of incident reconstruction

7.2.1 Vehicles

First of all, some consideration should be given to the accuracy of which the software integrates vehicles into the modelling environment. There are multiple settings, parameters and features that enable many vehicle parameters to be simulated, however, for the purposes of this critique, features pertinent to the caseload are discussed.

Vehicle Library

The software includes a somewhat expansive library of vehicles from the past 30 years of auto manufacture, inclusive of cars, trucks, HGVs and buses. However not all the requires models were available for the cases in this study. For example, in RTA4, 17 models of Fiat Stilo were available, but not an estate model as was present in this case. The matter was easily overcome by modifying the length, wheelbase and other features of the car (such as weight), but this can easily lead to inaccuracy in the reconstruction.

The library of vehicles integrated to the program was generally sufficient for all the cases, as was the extent of applicable changes to the caseload.

A more troublesome example is the Dennis Bus used in RTA10; a few basic models of common buses were available, but none from this manufacturer. This was overcome by looking up the specific model of bus impacted at the scene, finding the entire geometry, weight, wheelbase, axel positions, wheel sizes, suspension stiffness, centre of gravity, etc. and applying these values to a standard bus. The process could easily result in errors in the reconstruction due to inaccurate vehicle assumptions.

One parameter than clearly needed adjusting was the COG of vehicles in a few cases. Although this can be a difficult measure to obtain, especially without knowledge of occupant weight or cargo, for cases such as RTA8 this parameter is critical to modelling a case accurately.

7.2.2 Layout and Environment

The use of OS and Google maps into the software has meant that the modelling process can accurately represent a road layout with a good degree of accuracy. Most of the feedback given pertains to the modelling of road surfaces, roadside objects and barriers, which is given some discussion here.

The software normally considers a crash scene as a flat plain with a constant coefficient of friction. As most incidents occur on road surfaces, it is straightforward to model slope and curvature of road with an appropriate coefficient of friction, but natural features are a strong limitation.

Grassy surfaces can be modelled with a coefficient of friction of 0.4-0.5, but if braking occurs the grass blades ‘snap’ due to tyre friction and the effect is highly variable depending on conditions. Verges, mud and damp are also not possible to integrate to the reconstruction for the same reasons.

Natural Objects

Trees, hedges and other natural roadside barriers may be included graphically (for 3D detail) but there is currently no method to model these objects physically. These limitations can be obstructive to many cases in which vehicles drift from the carriageway and into the side of the road [RTA5,8]. This is a clear disadvantage when using the software.

Artificial Objects

The modelling of roadside objects is strictly limited to polygonal features with a mass, centre of gravity, and linear stiffness. In some cases where immovable, or entrenched barriers are present this is somewhat helpful. In RTA7, the left-hand motorway impact barrier was hit with a sideswipe impact. This barrier was modelled with a mass of 20T and a centre of gravity at 0.1m height to represent the embedding posts, which due to the small amount of deflection of the barrier was suitable for the impact. Likewise, the concrete wall of the junction opposite was modelled in the same way but with a 100T mass.

However, the point of rest came at an impact with a 15m high sign post. Modelling this post with the correct geometry and an assumed weight of 10T resulted in the post simply 'falling over' on impact with the vehicle. In reality, the post was entrenched and moved to a 30 degree angle from vertical on impact, but there is no existing method to model such features. This is a somewhat significant drawback in the program as all barriers and most roadside objects are embedded in the ground to some extent.

When considering normal roadside "W" or "Bar" barriers, these tend to act as a solid mass with constant geometry. Measurements and barrier height should be given accurately as this is quite influential to the reconstruction, as discussed with the barrier impact in RTA5. The impact with a “P4” barrier is modelled in RTA7 which represents a problem in need of more research; for this case it appears that using a series of massive, regular, rectangular blocks is sufficient for impact but only for decelleration that results from a head-on impact and the concertina compression of this barrier type.

It is foreseeable that the entrenchment of objects could be achieved by allowing a centre of gravity that is below the road surface, i.e. -100m. This may allow a more realistic integration of roadside objects.

Variable light

The default mode of the software is to set all lighting conditions to clear daylight. There is no option to include nighttime, dusk or dawn at any level. This means that although nighttime incidents may be reconstructed with physical accuracy [RTA5], the representation may be seen as unrealistic. There is an option to adjust the position of the virtual ‘sun in the sky’ according to the time of day, but this does not affect light or shading. An updated graphics engine could be integrated into the software to overcome this limitation.

7.2.3 Frictional Forces

Given that vehicles are often braking before or after most incidents, the frictional forces on the road between tyres, and forces between vehicle bodies are critical to representing the scene accurately. The two main ‘categories’ of friction for surfaces have been given thought to here as “high friction”, between 0.8-1.0 for tyre-road contact, and “low friction”, between 0.1-0.3 for slippery or icy roads. The feedback given demonstrates that these values are reasonable but require adjustments for certain cases. In addition to this, good judgement should be applied to give an accurate representation, as shown in the RTA10 case.

Particularly suitable was the brake model, which allowed wheels to be given variable braking force or to be locked completely; an extra feature of which leaves modelled tyre marks in 2D view which can then be compared to scene photographs for accuracy.

Vehicle-to-vehicle friction is another parameter that has been effectively used in most of these case, but also requires adjustment for particular scenarios. The strong mechanical interlocking of the vehicle bodies in RTA10 demonstrated that a higher value of this parameter, or a different means of integration, should be used in order to represent the scene accurately.

7.2.4 Vehicle Crush

The physical behaviour of the vehicles is explained in some length elsewhere (Steffan, 2011), but the methods used to similar a vehicle body are given some focus here. Whereas features like tyre models and vehicle suspension in PC-Crash were considered to be accurate methods in reconstruction, the process employed to model impacts to vehicle bodies considers each vehicle as a homogenous solid. This limitation is due to (a) the lack of publication of manufacturer's crash test data (b) the computational demand on the program.

The software has a built-in library of vehicle stiffness measurements that are easily integrated to each model. However, these exist only as a linear (Hookean) value that applies to the entire car body. This is quite a limitation as the resistance of any vehicle body to an impact force is a complex measurement. In addition, vehicle body stiffness is much stronger for frontal impacts due to the heavy engine compartment being present; typically rear and side impacts have 50% or more damage due to reduced stiffness. The presence of side-impact bars complicated this matter further. Therefore, the modelling of an impact with a single vehicle stiffness value is a leading cause of inaccuracy in many case reconstructions. This is not insurmountable, however, as with the presence of reliable stiffness data from a specific crash direction (i.e. NCAP tests) a linear correlation can be calculated to give a specific stiffness value for front, side and rear impacts. The limitation then becomes finding and acquiring this data. If appropriate data could be acquired, this limitation would not be such a severe influence on modelling vehicle-to-vehicle impacts.

7.3 Suggestions for Overcoming Software Limitations

From use of the PC-Crash software it appears that the platform has been developed based on a kinematics/kinetics model, initially used to impact solid-body objects with restitution. This causes problems when immovable objects of natural features are involved. The large mass of roadside objects such as barriers, together with the lack of means of embedding features in the ground, causes deflection in such barriers and a transfer of momentum to the vehicle impacting such a feature; overall not a realistic representation of an impact. Here it suggested that if not ‘entrenchment’ could not be integrated to the software, another suitable means could be a restraint on some part of an object’s co-ordinates. This is a means often employed in

FEA programs, where an edge or surface of an item is set to be immovable. This would allow objects such as roadside barriers to be fixed in position, or objects such as poles to be fixed in the ground, yet remain flexible above this point when impacted.

A comparable problem is that of natural barriers, such as trees and hedges. These are included graphically to the software, but not physically in any sense. Given the non-extinct status of such natural features in the UK and Europe, this is as perplexing as it is frustrating, although a proposed suggestion is to include some measure of kinetic energy absorption. For a hedge, the area, depth and height of the feature could be easily measured and constructed in the program as a rectangular polygon. Rather than use deflection of this polygon, a measure of the maximum mass and speed the object could absorb before fracturing would be a more realistic means of modelling its impact with a vehicle. This would also integrate well to the software's contact/POI computation.

Impact with trees may be more complex, but worthy of some consideration. These features could be modelled as a pole or post if minor branches are ignored and trunks of >0.1m are included. Stiffness values of wood supports could function as an estimate (although treated wood yields less deflection than green wood), which then enables impacts to be modelled. To be used with any meaningfulness, however, the trunk of the tree needs to be embedded in the ground or have some displacement restrictions.

7.4 3D Reconstruction

It is here that the software used in this project is considered in terms of its end product, a 3D Animation. In most RTA cases, investigation takes place after the incident and then attempts to build up a picture of the preceding events using the evidence gathered. This will commonly focus on the speed and direction of the vehicles present. Turning this information into a clear picture of the collision is the main aim of an RTA Investigator, as witness statements may not always be truthful after a collision.

The feedback given demonstrates that the software is a powerful tool in providing several viewpoints of the same incident. A comparison of several driver's views, for example, may demonstrate low visibility or the lack of available foresight when travelling on a specific road layout. Overhead views simulate how aerial photography may have seen the incident occur. The possibility of slow-motion in the reconstructions adds to this.

This, however, is an aspect that could benefit from further improvement: night-time views are not currently possible with the software setup and this is a limiting factor. Where 3D models of the specific vehicles in a case are available, this is most helpful, but if not some degree of reality is lost in the reconstructions that gives the models an unwanted touch of artifice. These improvements, it should be stated, are easy to overcome with further software packs and devoting time to constructing vehicle DXF models.

Some thought should be given to the increase in popularity of dashcams (small, digital camera recorders commonly mounted on a car dashboard or vehicle rear-view mirror). This equipment is cheap, becoming common, and exceptionally useful in specific circumstances due to the tracking of speed and time as well as capturing footage from the driver's point of view. It seems inevitable that an increase in dashcams would lead to a decrease in the importance of 3D modelling, however, it is important to remember that only a single point of view is captured. This is a firm limitation, as any accident from a fixed point of view appears shocking despite whatever driver has caused it. The feature that dashcams lack is the ability to see different angles in the incident, plus the means to vary the trajectory and speed of vehicles to assess where the true cause of the accident lies.

7.5 Suitability for Legal Proceedings

The reconstruction process discussed here is also used in several stages of legal proceedings in the UK. The application of the software depends on which stage and kind of process is being followed with regard to a RTA case; some discussion is given here to its suitability.

Use of the PC-Crash software among police staff for prosecution is somewhat rare in the UK. The first instance in which a RTA case would be reconstructed in this manner would commonly begin with a third party forensic investigator, i.e. a private company contracted by a legal or insurance body. All evidence pertaining to the incident in question would be supplied to the forensic investigator, who may obtain further information by their own means. The full body of information would then be used to construct a virtual accident scene in a similar manner to the process described in this thesis.

The reconstruction may then be used in several ways. Normally, the forensic investigator would prepare a report with their considered conclusions, combining the gathered evidence and software-generated content as needed. This method would form the professional decision for the insurer or legal body, and would not reach court unless challenged in some context.

Less commonly, the investigator would be asked to attend court to present evidence. In this eventuality, all information pertaining to the case could be brought as evidence, such as scene photos, physical vehicle parts, GPS data, as well as the computer-generated reconstruction.

7.6 Suitability/Unsuitability for Court

The visual content of the computer-generated reconstruction can, naturally, be used for and against the case. On the supporting side, the reconstruction demonstrated how the accident may have occurred from several viewpoints; in this employment the software and investigator create an 'virtual witness' out of the available information. The court would question the accuracy and potential oversights of the reconstruction, which would be a routine task for an experienced forensic investigator. In a straightforward accident case trying to establish liability, for example, the investigator may say in summing up "it is my professional opinion that this reconstruction fully represents the events of this incident", thus resting their findings on skill and reputation. At this point, the prosecution or defence may try and establish weak points in the reconstruction. These are inevitable in any RTA case and it is the forensic investigator's responsibility to answer accordingly.

In this respect, the reconstruction process helps to fill a gap in the evidence. In many accidents, the only witness statements recorded are given by drivers, who may not be honest after an incident has occurred. The reconstruction can function very well in this respect when variables such as speed, weather, vehicle conditions and driver reactions can be established; with such information clearly defined, the case can be brought down to a level of physics, albeit with some assumptions. An example would be a case involving a car hitting a roadside object that resulted in dramatic damage to the front of the vehicle. If this damage was consistent with an impact of 60mph or thereabouts, this can be shown to contradict an existing driver, or other witness statement that "I was driving well below the 30 mph speed limit". Other reconstruction findings such as rest positions, damage to barriers, etc. can be used to support this and demonstrate the validity of the investigator's assumptions.

In a different respect, an investigator may be questioned in a manner that is aimed to undermine the reconstruction. For example, some questions to establish doubt in the findings could be posed: *"Did you visit the accident scene? Have you inspected any of the vehicles?".* Despite the established reconstruction process and the reputation of an investigator, it can be easy to instill doubt in technology and sway a jury, if this was the intention. A more technical line of questioning could be very disruptive to an investigator, for example: *"How can you be sure about the weight of each vehicle? Did you measure this, or assume it? Isn't this critical to measuring the rest position of that car?".* In these matters a high degree of expertise, both technical and legatorial, is needed to defend the opinion of the investigator in court.

It is for these reasons that use of PC-Crash is not common in UK Police prosecutions. Although the reconstruction process is useful and can be established with a reasonable degree of accuracy, it is hard to defend unless an expert witness with robust technical knowledge of the software can be employed. Training to expert stage is a long and costly process, hence it is more straightforward for a Police Investigator to use their experience as a basis for establishing their credibility. It also worth mentioning that should any software employed by the public sector be used in a court case and fail to establish a conviction, the software immediately becomes highly and publicly vunerable to legal criticism.

8. Conclusions & Further Work

With regard to the original objectives of the project, these have been met to a somewhat satisfactory degree. Discussion is given here to these aims and potential further improvements to the research and software.

8.1 Project Objectives

1. "To program and demonstrate a series of reconstructed accident scenarios (or "cases") that clearly demonstrate a range of common traffic accidents. Redacted case files will be obtained from a voluntary agreement with a UK police department."

The objective to "demonstrate a series of reconstructed accident scenarios (or "cases") that clearly demonstrate a range of common traffic accidents" has been achieved. In most instances the reconstruction gives an appropriate representation of the accident scene, in some it does not. The reasons for an inaccuracy in each case have been discussed, mainly with respect to the capabilities of the software used.

2. "Specify the speed and damage occurring to each vehicle in each case, quantifying the extent of the damage and how this is dependent on the specific vehicle, scene or environmental variable being considered."

The specification of speed and damage has been specified to each vehicle as listed in the objectives, although detail relating to vehicle structure was not readily available throughout the process. There was, however, suitable discussion of the incident environment and roadside objects, and how these contributed to vehicle damage. With further information on vehicle body stiffness, more detailed comparisons could be made in each respect.

3. ”Use the findings gathered to form a critique of the existing method of investigation and reconstruction, such that the decisions made from this aspect of the accident reconstruction process may be made with less error. Priority should be given to any cases that can benefit accident prevention.”

The findings gathered have been critiqued, although to a brief and conversational extent. Nevertheless, several shortcomings and limitations of the software have been clearly identified. Some of these limitations are form quite a restriction on the capabilities of the software and are in need of development

4. “If the research and investigations were sufficiently in-depth, the findings and feedback could then be brought to the software manufacturer and discussed, with the aim of improving the limitations of the reconstruction program.”

Regarding this additional objective, a summary of findings is being prepared for presentation in an academic paper.

8.2 Suggested Improvements

It has become clear throughout the project that feedback from professional investigators is vital to spotting oversights in the modelling process and therefore improving the accuracy of the reconstructions. Areas in each RTA case have been assessed and judged, with a provision of helpful feedback that allows improvement in most cases. The timings, costings and progress of the research have been followed with care and have not caused any notable problems throughout. A small matter persists in that extra data regarding the barrier section in RTA8 would have been most helpful if it could have been integrated before the end of this study.

Software Improvements

The software studied in this thesis is clearly capable in many respects of producing reconstructions of an RTA incident. The limitations and accuracy of how this can be achieved are a little less established, however. Some discussion is given to the practical application of this process and what shortfalls currently exist.

1. Overall graphical reconstruction using the software is to an appropriate standard for presentation in several fields, i.e. legal, private, academic. The range of available vehicles assists this ability, however, simple aspects such as the lack of night-time views make it easy to criticise the modelling process. This places the person using and presenting the software, i.e. a forensic investigator, in a difficult position should such criticism occur. He or she is not responsible for the limitations of the software, but would have to defend using the software despite knowing the presence of these limitations.

2. The software is best suited to cases where the points of impact and pre-crash vehicle trajectories can be known within reasonable accuracy. As the main mechanism for modelling collisions is momentum based, the reconstruction is heavily dependent on basic accuracy in these incident events.

3. Difficulties in reconstructing the cases presented here have resulted mainly from roadside objects. There needs to be much better integration of natural and artificial roadside barriers and signs, almost to the point that this seems to be an oversight by the software developer.

4. Vehicle stiffness measurements still remain at a basic standard. This feature is mainly a result of the lack of availability of crash test data, but nevertheless there could easily be a more efficient means of integrating vehicle body stiffness to the program

8.3 Future Developments

What is apparent in this research is that there is ample scope for further research in these cases. Three suggested areas are given below.

The first area proposed for future work is in the development of a measurement of vehicle body stiffness. It is hoped a suitable, accurate measurement of this property can be acquired from manufacturer or forensic research associations and integrated to the crash modelling software. This would result in greater accuracy in the process and firmer conclusions for all users modelling RTA incidents when using this method.

The second area for future development lies in presenting the limitations of the PC-Crash software to the manufacturer and developers. The critique of the software has demonstrated several major shortcomings in the program that are common to RTA incidents. It is suggested that a discussion be set up with a focus on research and potential developments, as there may be workarounds to these shortcomings that have (a) been in development (b) are accessible in one form or another.

The third area for future development is proposed to focus on the vehicles not covered in this study: motorbikes, HGVs, and so forth. There is scope for taking on incidents involving these vehicles, as an additional module is available for PC-Crash that includes vehicle occupants, i.e. a motorcycle rider. In such instances the focus of the case could move from the vehicle post-impact path, to the rider post-impact path.

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Appendix I

3D Reconstruction Data

Due to the visual nature of the simulations demonstrated in this work, it is advised to view the video files of the RTA cases. These files are currently stored in an online folder, which will remain available until end 2014. Below is one example from RTA4, as the case is in the public domain. Please contact the author to obtain the hyperlinks to the other cases.

https://dl.dropboxusercontent.com/u/76621798/RTA/1C-4%20Danbury%20Crash%20video%20joint.mp4

If you require more information on the reconstructions or have trouble accessing the files, please contact the author of this thesis for further information on these simulations on simon.urquhart@gmail.com.

Appendix II

Project Timeline, Appointments & Visits

A summary of the progress of this investigation is given below, inclusive of contact with RTA Investigators and other experts. Important meetings and conversations that have influenced or directed the work are also given.

Item	*Contact, Location*	*Date*	*Summary of Progress*
Start of Research. Commencement of Mphil.	Dr. Syed Hasan (SH), SHU	1.Oct.2011	First meeting with Project Supervisor (SH) outlines scope of project. Initial task is to find appropriate crash modelling software.
Enquiry: Crash Software.	DSD, Austria	19.Oct.2011	Contact with software provider. Arrangement for UK rep Ian White to visit SHU.
Review of Crash Software. Demonstration of PC-Crash v10.	SH, Ian White (United Assessors), SHU	25.Oct.2011	Demo of software and discussion of capabilities, cost, licensing.
Purchase & Use of Software.	SJU	23.Feb.2012	Purchase of PC-Crash under educational license. Start of case modelling, beginning from RTA1.
Caseload collection begins. Public info used.	SJU	26.Feb.2012	Selection of RTAs from public domain sources, i.e. news reports, papers. Collection based on those with high-quality images and retrievable locations.
Meeting. Project Supervisor.	SH, SJU (SHU)	10.Apr.2012	Bi-weekly meeting with SH results in decision to use real RTA caseload. Idea of meeting with HoD (AJS) to discuss contacts.
Meeting. Contact with Head of Dept. Prof. Alan J. Smith.	SH, SJU, AJS (SHU)	19.Apr.2012	Outline of project research to HoD. Request for method to retrieve RTA caseload, using AJS's Accident Investigation contacts.
Caseload modelling. Public info used.	SJU	May-Aug.2012	Cases RTA1-4 reconstructed from public domain sources. Impacts, rest positions and damage calculated. Animations extracted.
Meeting. Follow-up with HoD.	SH, SJU, AJS (SHU)	24.Aug.2012	Demo of RTA1-4 and discussion. Meeting results in AJS agreeing to arrange a police RTA investigator

			as main project contact.
Contact with Police Investigator.	SJU, (SHU)	10.Sep.2012	Project contact PC Chris Goddard (Crash Investigator, Gwent Police) agrees to assist research with RTA Research. Discussion of cases required and issues to resolve.
Email Conversation. PC C. Goddard.	SJU, CG	18.Sep.2012	PC Chris Goddard confirms clearance to release caseload data for research use. Request for further cases requested.
Email Conversation. PC C. Goddard.	SJU, CG	2.Oct.2012	Update: CG preparing files and redacting sensitive data.
Delivery of Cases. Private domain RTAs.	SJU, CG	20.Nov.2012	Delivery of various RTA casefiles from Gwent police. Files include 30+ incidents from 2011-2012. Modelling of private domain cases begins.
Phone Conversation. PC C. Goddard.	SJU, CG	9.Dec.2012	Discussion of details of ongoing reconstructions. Advice on HGV/Bike cases. Propose next meeting to review in person.
Guest Lecture. From CG.	SJU, CG (SHU)	20.Dec.2012	First meeting with CG, at guest lecture on forensic investigation held at SHU. Lunch meeting and agreement to continue sharing data.

Phone Conversation. Dr. Tony Payne, NCAP.	SJU, TP (SHU)	13.Jan.2013	Discussion with Technical Director Tony Payne, at NCAP UK Crash Test centre. Advice given on modelling RTAs and safety features of modern vehicles.
Reconstructions. RTA cases 1-5.	SJU	25.Feb.2013	Initial reconstructions complete on RTA cases 1-5.
Meeting. PC C. Goddard.	SJU, CG, (Cwbran Constabulary, Gwent)	1.Mar.2013	Meeting to review RTA1-5. Critique and advice given. Collection of further private domain data from 2012-2013 for further incident simulation.
Presentation. SHU Industry Day	SH, AJS, SJU (SHU)	4.Mar.2013	Presentation and demonstration of RTA1-5 for conference. Projection of incident animations in conference hall. Enquiries received for feedback, further development and improvement.
Reconstructions. RTA cases 1-5.	SJU	20.Apr.2013	Revised reconstructions complete on RTA cases 1-5.

CPD Course. Forensic Engineering.	AJS, SJU (SHU)	5.May.2013	Attendance of course for post-impact analysis of vehicle lights. Presentation of existing caseload for the group; feedback and interest collected.
Reconstructions. RTA cases 6-10.	SJU	May-Sep.2013	Initial reconstructions for RTA cases 6-10 ongoing.
Meeting. PC C. Goddard.	SJU, CG, (Newport HQ, Gwent)	5.Sep.2013	Meeting to review initial reconstructions of RTA6-10. Final review before thesis writeup.
Reconstructions. RTA cases 6-10.	SJU	Sep-Dec.2013	Revised reconstructions for RTA cases 6-10 ongoing.
Thesis Submitted.	SJU	17.Dec.2013	Final version of thesis submitted.
MPhil Viva. With Ian Tranter (SHU), Jasper Graham-Jones (Univ. Plymouth).	IT, JGJ, SJU (SHU)	10.Jan.2014	MPhil viva and discussion of caseload, methodology and writeup.

Project Safety Plan 2011/2 **Date:** 20.10.2012 (*project start date or first planning meeting with DoS*)

DESK BASED STUDENTS only

STUDENT NAME	URQUHART, Simon	**DoS NAME**	Syed T. Hasan
Project Title	Vehicle Collision Modelling		
Short Summary of project activities	Computer modelling of road traffic accidents (project involves desk work only).		
SHU Health & Safety Policy for students	https://staff.shu.ac.uk/healthandsafety/documents/UHSP-2.0-Aug07.pdf	Date:20.10.2012 Signature:	

Safety training for first month including Induction		**Date:**	**DoS Signature:**	Student Signature:
	Attended University Induction Session	**21.11.2011**		S. Urquhart
	Attended MERI Induction Programme	**02.11.2011**		
	Attended Fire Awareness Training session	**05.12.2011**		

You must know :
Where your Fire Evacuation Assembly Point is: you can find this on the blue wall signs
Who the First-Aiders in your area are: you can find this on the green wall signs

In case of an emergency you must ring X888 and explain the problem and give your location