Developing the Research Applications for High-Resolution Real-World Collision Data

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Developing the Research Applications for High-Resolution Real-World Collision Data

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Executive summary

The Developing the Research Applications for High-resolution Real-World Collision Data study was undertaken as part of the TRL re-investment programme to promote internal research.

The aim of the study was to explore the usefulness of the Incident Data Recorder data which is routinely collected by the Metropolitan Police from its vehicle fleet, in the context of improving road safety research and exploring the effectiveness of theoretical incident reconstruction techniques.

TRL have long recognised the potential of this data to provide a new high-resolution collision data set of real-world incidents. This study has concentrated on the detailed investigation of anonymised data from a small number of incidents to assist in developing research applications for the high-resolution data generated by Metropolitan Police vehicles fitted with an IDR. There are many areas of research, including vehicle safety, occupant injury, accident research, collision investigation and driver behaviour where new high resolution pre-event and collision data from real-world collisions would prove valuable.

Since 2006 the Investigations Group (SSR) has worked with the Metropolitan Police to gain access to high resolution real-world collision data which has been generated during collisions suffered by Metropolitan Police vehicles fitted with the Kienzle Unfall-Daten-Speicher (UDS), a form of in-vehicle data recorder (IVDR) specifically designed to capture data in the event of a vehicle incident.

To date a database containing about 200 incidents has been compiled, containing information about the circumstances of the collision, the participants involved, photographs, UDS data files and numerous data fields relating to shift patterns, injury level etc.

A number of research areas across TRL were chosen where it was believed access to this high-resolution real world data would enhance both the understanding of vehicle motion leading to a loss of control and an understanding of the collision and its effect on occupant injury. The four research areas were biomechanics, crash analysis, vehicle safety systems and behavioural change. Each research area was provided with a sample of four incidents that covered a range of their research interests.

Having provided this information to the research groups, detailed discussions were then undertaken with experts in these fields to determine the potential benefits of the data, their current concerns with the data, solutions to these problems and potential research applications.

There was a positive response from each research group, highlighting the potential that this data has on improving the current understanding of injury biomechanics, vehicle crashworthiness and the intervention of vehicle active safety systems. However, while UDS devices have been fitted to Metropolitan Police vehicles for a considerable time, there appears to be little information and research relating to the actual accuracy of the devices in the measured acceleration and the ability to calculate accurate changes in velocity, or delta v’s.

The various research areas identified concerns with the data, such as whether or not the 256Hz high resolution recording frequency, which is less than the 1800Hz defined for crash testing, would be sufficient for detailed injury causation research, and also whether or not the lower resolution, 16Hz data, would be sufficient to determine the movement and driver inputs leading up to a collision.

The data gathered to date, and compiled in the TRL database, would be insufficient for a number of potential research applications. Access to the vehicles involved, the injury data of occupants (through appropriate channels with the Metropolitan Police and the Police Federation) and details of the safety systems fitted to the vehicles would all complement the existing data and enhance its potential usefulness. Other useful
information was identified as being of assistance, but in the context of the current study and UDS system adopted by the Metropolitan Police, such further information would not be possible.

In addition to exploring the various research applications for this data, accident reconstruction was identified as being a particular area of benefit to this data. Part of this study was to obtain sufficient information relating to a collision for a reconstruction expert to apply theoretical reconstruction techniques to identify factors such as vehicle approach speed, impact speed and change in velocity. These reconstructions were undertaken without any knowledge of the data recorded on the IDR.

Five incidents were selected from the database, and the detailed reconstructions can be found in Appendices A.1 to A.5. These incidents included two car to pedestrian collisions, a low velocity rear impact, a side impact and a frontal impact.

The theoretical techniques often rely on the expert determining appropriate and reasonable ranges for some of the unknown factors in a collision. Such an approach clearly leads to a range of potential speeds being calculated. In this study, the ranges of approach and impact speeds, together with changes in velocity, encompassed the actual values recorded by the IDR. However, with the IDR data, it was possible to determine much more accurately the appropriate values to use for the unknown factors in a collision. When comparisons of these more precise values were made with the previously estimated ranges, it was found that they did not always lie within the estimated range.

There were a number of recommendations made in this study, which take the form of both gaining a better understanding of the accuracy of the IDR data and also potential future research applications, such as investigating the increased risk of thoracic injury at sub-NCAP test speeds and validation of software packages such as CRASH3.
Abstract

Since 2006 TRL’s Incident Investigation and Reconstruction Group has worked with the Metropolitan Police to gain access to high resolution real-world collision data which has been generated during collisions suffered by Metropolitan Police vehicles fitted with the Kienzle Unfall-Daten-Speicher (UDS), a form of in-vehicle data recorder (IVDR) specifically designed to capture data in the event of a vehicle incident. It was considered that this data offers opportunities for new and innovative research in the field of road safety. To date, in excess of 200 incidents have been complied into a database and appended with details relating to the collision, including background information, photographs and the collision data.

There were two main themes to this project, these being to: assess the feasibility of using IDR data to enhance or develop new avenues of research across TRL, including vehicle safety, occupant injury, and driver behaviour; and to compare theoretical accident reconstruction methods with the incident data captured by the IDR device in order to identify the potential for enhancing theoretical collision reconstruction techniques.

A sample of incidents was provided to a number of research areas across TRL and their views on the potential benefits, technical issues and research opportunities were sought. In addition, five separate incidents were selected and reconstructed in detail to determine the effectiveness of various theoretical accident reconstruction techniques.

Four research groups at TRL provided positive feedback on the data, with several potential areas of future work being indentified; however, some of these would first require a better understanding of the accuracy of the data and access to more information about the incident, the vehicles and the injuries to occupants.

It was found that the theoretical techniques provided a range of possible speeds for a vehicle, with the speeds recorded by the IDR device being encompassed by these ranges in each of the reconstructions.
1 Introduction

Since 2006 the Investigations Group (SSR) has worked with the Metropolitan Police to gain access to high resolution real-world collision data which has been generated during collisions suffered by Metropolitan Police vehicles fitted with the Kienzle Unfall-Daten-Speicher (UDS), a form of in-vehicle data recorder (IVDR) specifically designed to capture data in the event of an vehicle incident. Since the installation of these devices within the Metropolitan Police vehicle fleet, the UDS has been referred to within the force as an Incident Data Recorder (IDR). The Metropolitan Police currently has over 3000 of its vehicles equipped with a UDS ‘Black Box’ incident data recorders.

TRL have long recognised the potential of this data to provide a new high-resolution collision data set of real-world incidents. This study has concentrated on the detailed investigation of anonymised data from a small number of incidents to assist in developing research applications for the high-resolution data generated by Metropolitan Police vehicles fitted with an IDR. There are many areas of research, including vehicle safety, occupant injury, accident research, collision investigation and driver behaviour where new high resolution pre-event and collision data from real-world collisions would prove valuable.

Such real-world collision data is rarely available to researchers, and thus it is considered that many of the incidents for which high resolution collision data will become available have the potential to provide new insights which could benefit the quality and depth of road safety research and assist in the refinement of methods and techniques in accident investigation.

Five incidents that contained enough information to allowed detailed incident reconstructions to be undertaken using theoretical techniques were selected from the database. The results of the in-depth investigations can be found in Appendices A.1 to A.5. Many accident reconstruction methods are well understood and validated, however there are others that would benefit from additional research.

To support this research, additional, anonymised data, collected by Metropolitan Police Collision Investigators at the scenes of incidents involving IDR equipped vehicles (specifically photographs and incident scene plans), was obtained. This additional information provided details of the physical evidence created during the incident, upon which theoretical collision investigation would rely, allowing comparisons to be made between IDR records and reconstruction calculations.

Four research areas at TRL were identified as potentially benefitting from the high resolution real-world data in addition to collision investigation. These were (the information in bracket relates to more specific area of interest):

- **Collision Investigation** – (pedestrian accident investigation, low velocity collisions, computer simulation validation, CRASH 3 validation)
- **Biomechanics** – (real world crash pulses, low velocity rear collisions and vehicle crash performance).
- **Crash Analysis** – (occupant protection, CRASH3 validation, collision investigation, pedestrian injuries)
- **Vehicle Safety Systems** – (effect of active safety systems such as ESC and BAS).
- **Behaviour Change** – (detection and monitoring of driving styles, driver attitude and risk factors)
2 Background

Over the last few decades the electronic systems within passenger cars have become more advanced. With the development of on-board electronic systems has come the ability to record and preserve high resolution data which is pertinent to a road traffic collision; such devices are a class of in-vehicle data recorder (IVDR).

IVDRs of several different types are increasingly being installed in vehicles across a range of different types of vehicle fleets, and for varying reasons. IVDRs provide a wide range of functionality to car drivers and fleet managers; typically such devices are designed to:

- record and preserve the before and after data relating to specific road traffic incidents;
- record data relating to entire journeys;
- analyse vehicle usage and fuel efficiency;
- monitor driving style and performance;
- preserve data relating to the activation of a safety system within a vehicle (such as an airbag).

For the purpose of this report electronic devices that are designed to record high resolution data relating to a road traffic collision are referred to as incident data recorders (IDRs), although it is recognised that the term event data recorder (EDR) is often used in respect of such devices, particularly where event data is recorded automatically within a vehicle following activation of a safety system in response to an incident (such as an airbag activation). Other types of IVDR include video event data recorders (VEDRs), journey data recorders (JDRs) and a variety of telematics devices which can monitor factors associated with vehicle usage, location and driver actions, for example.

Over the last decade retrofit IDRs have been installed within several large vehicle fleets for the purpose of capturing high resolution data in the moments before, during and after a collision. An IDR typically incorporates a set of accelerometers, gyroscope and internal recording capability, and provides input capabilities to record vehicle generated speed signals, and number of other inputs from the vehicle or other retrofit devices (such as blue lights and siren in a police car). In addition to providing high quality evidence relating to the circumstances of an incident, for the purpose of resolving liability in relation to a road traffic incident, research (Rau et al. 1997) had identified a significant reduction in the collision involvement of vehicles fitted with IDR devices. This drop in accident involvement was attributed to increased levels of driver care due to the presence of the IDR (the data from which could be used to demonstrate a driver’s contribution to a road traffic collision, for example).

In the same period the increasing sophistication of on-board electronic systems within passenger vehicles has led to the heightened potential for data relating to a road traffic incident to be captured within the electronic systems of a vehicle in the case of a driving event causing the activation of a primary or secondary safety system.

An IDR is generally found within the Sensory and Diagnostic Module (SDM), which has the primary role of determining when seat belt petitioners and airbags should be fired. An IDR piggy backs on to this system by allowing data from the SDM to be captured and stored in an event involving accelerations which are above a pre-determined threshold or
which exhibit particular characteristics. This quantity and quality of data stored by IDRs can be highly manufacturer specific, but can include detailed information on vehicle speed and acceleration, as measured from the onboard sensors at the time of an incident.

In general therefore IVDRs perform many functions such as providing information on journey times, vehicle speed, driver behaviour and driving style, vehicle usage, fuel economy, crash data preservation, safety system activation data and video recordings. This project looks at the opportunities available to safety researchers and collision investigators to utilise the high resolution data which has been generated over several years by the Metropolitan Police vehicle fleet. It is considered that the findings from this study could be applied to data obtained from other vehicle fleets equipped with equivalent or similar IVDR systems.

**Development of Incident Data Recorders in the United States**

In the United States the National Highway Traffic Safety Administration (NHTSA) started a Special Crash Investigations Program in 1972 where data was collected from real-life crashes (NHTSA 2009). Later, in 1998, they set up a working group to look at the state of the art with respect to IDRs (typically referred to as Event Data Recorders, EDRs in the US), and concentrating on the information stored within an IDR from real world collision and crash tests.

As a result of this work, NHTSA produced a set of standards for the minimum requirements for IDRs. An IDR is not mandatory in the US; however, if fitted to a vehicle, it must conform to the following (Table I reproduced from 49 CFR Part 563, www.nhtas.dot.gov):

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Recording Interval / Time (Relative to time zero)</th>
<th>Data Sample Rate Samples per Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta-v, longitudinal</td>
<td>0 to 250 ms</td>
<td>100</td>
</tr>
<tr>
<td>Maximum delta-v, longitudinal</td>
<td>0-300 ms</td>
<td>n.a.</td>
</tr>
<tr>
<td>Time, maximum delta-v</td>
<td>0-300 ms</td>
<td>n.a.</td>
</tr>
<tr>
<td>Speed, vehicle indicated</td>
<td>-5.0 to 0 sec</td>
<td>2</td>
</tr>
<tr>
<td>Engine throttle, % full (or accelerator pedal, % full)</td>
<td>-5.0 to 0 sec</td>
<td>2</td>
</tr>
<tr>
<td>Service brake, on/off</td>
<td>-5.0 to 0 sec</td>
<td>2</td>
</tr>
<tr>
<td>Ignition cycle, crash</td>
<td>-1.0 sec</td>
<td>n.a.</td>
</tr>
<tr>
<td>Ignition cycle, download</td>
<td>At time of download</td>
<td>n.a.</td>
</tr>
<tr>
<td>Safety belt status, driver</td>
<td>-1.0 sec</td>
<td>n.a.</td>
</tr>
<tr>
<td>Frontal air bag warning lamp, on/off</td>
<td>-1.0 sec</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
Frontal air bag deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag, driver | Event | n.a.
---|---|---
Frontal air bag deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag, right front passenger | Event | n.a.
Multi-event, number of events (1,2) | Event | n.a.
Time from event 1 to 2 | As needed | n.a.
Complete file recorded (yes, no) | Following other data | n.a.

The standard also provides details for the recording of an additional 30 elements, should a manufacturer opt to record these. These elements can include engine rpm, ABS activity and steering wheel angle.

The data stored within an IDR has many applications, not only for manufacturers but also for Collision Investigators. However, it can be notoriously difficult to get manufacturers to extract the data after a collision, which may be due to concerns over product liability (Zeidler 2004), cost and due to the IDR being part of secondary equipment manufactured by a supplier.

Bosch Diagnostics have produced a commercially available Crash Data Retrieval System tool that allows investigators to gain access to IDR data that could be stored on passenger cars, light trucks and sports utility vehicles. In the US it is believed that more than 80 million such vehicles can be accessed to retrieve the data stored in either the airbag control module (ACM) and or the powertrain control module (PCM).

**Development of Incident Data Recorders in Europe**

Routine access to IDR data in Europe is much less widespread, and although many vehicles have IDR capabilities the data it is not accessible in a similar manner to the US. Access to IDR data in Europe is requires the cooperation of a manufacturer and often a referral to secondary equipment suppliers to access the data on the investigator’s behalf. This process can be convoluted and time consuming, such that it discourages the use of such data by collision investigators.

There are, however, a small number of vehicles on the roads in the UK and Europe that have similar IDR technology to that used in the US and, with the correct equipment, can permit access to event data, as and when stored within these vehicles.

Currently IVDR technology for use in collision investigation in Europe is mainly limited to IDR devices fitted aftermarket to vehicle fleets, such as the UDS system fitted to the Metropolitan Police vehicles.

To address the absence of routinely downloadable IDR data from European vehicles the EU has funded two projects, Veronica and Veronica II. The latter of these projects was designed to determine the optimum IDR or EDR system to implement in vehicles across Europe, should the EU put such legislation in place, and also to define the data that should be captured. More information of these projects can be found in Appendix A.6.
Limitation of IDRs and their Application in Collision Investigation

The IDR technology has been in vehicles in the US for many years, and accident reconstructionists have analysed the data and have identified issues relating to its interpretation. It can be very easy to arrive at an incorrect conclusion if the reconstructionist does not fully understand how the IDR operates within that specific make and model of vehicle. As well as being careful with analysing the data, it is also extremely important to continue to examine the vehicles and investigate the circumstances of the accident as would have been done previously without access to the data. Since the UDS system is standard across the Metropolitan Police vehicle fleet, some of these issues are less critical; however, there is need for an understanding of the level of accuracy of such systems.

One of the main research areas with the IDR data concerns the accuracy of the values recorded. Reust (2004) assessed ECM’s on commercial vehicles and found that speed measurement accuracy altered depending on whether the vehicle was accelerating, braking or changing gear. For passenger cars, Barbara et al. (2006) investigated the limitations with the (SDM) in General Motors and Ford vehicles, finding a pre-impact speed accuracy of ±4%, of ±5% for throttle position and a change in velocity accuracy (delta v) of ±10%.

Further work by Reust et al. (2008) investigated the speed accuracy from the Power Control Module (PCM) of Ford vehicles. It was found that there were slight differences in speed for steady state movement and low and harsh acceleration. However, when braking heavily or steering violently, the speed estimates could be underestimated by about 5%, while violent steering and ABS braking at the same time could result in an underestimate of 14%.

In a series of crash tests, Wilkinson et al. (2007) compared the delta v from the SDM with onboard accelerometers, and found that the onboard system could overestimate by as little as 1.5% and underestimate by as much as 13.3%. The authors found that in some tests the IDR did not record the entire crash pulse, sometimes missing 10 to 50 ms of the pulse. Other issues noted were related to the location of the SDM, which could result in the SDM seeing a lower effective acceleration or speed change and also that, in the tests analysed, the SDM only measured longitudinal acceleration.

German et al. (2001) compared the delta v from the IDR with that calculated by an investigator using a theoretical method, a similar methodology to that adopted in this study. The study by German et al. reported on staged collisions at a known test speed with the vehicles fitted with an IDR. The theoretical delta v calculation was undertaken using the damage sustained by the vehicle and its stiffness characteristics. One comparison undertaken, from a side impact test, resulted in a theoretical delta v of 25 km/h, compared to the IDR data of 22 km/h. It is interesting that the authors provided a single value for the delta v based on the damage assessment, and perhaps using a range for the many unknowns may have resulted in a delta v range encompassing the IDR delta v. If the theoretical technique results in a delta v greater than that which occurred in the incident, then care must be taken when applying that value.

As well as using traditional damage assessment techniques, computer programs can also be used to provide a better delta v assessment based on more complex measurements of the vehicle damage. Hampton et al. (2004) assessed incidents from the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) Database, where both delta v from the IDR and a WinSmash run were recorded. They found that the WinSmash program underestimated the IDR delta V by about 20%, although they also noted restrictions with the IDR not recording the full crash pulse.
The error in WinSmash is further compounded by the error between the true delta v and the IDR delta v. Neihoff et al. (2006) compared the results from 37 laboratory tests with the values recorded by the IDR. They found that in nearly all tests, the IDR delta v was less than the true delta v, with the error being about 6% for a frontal collision. As with other authors, they found a limitation in the amount of the crash pulse that was recorded (in about one-third of the tests) and also problems with the position of the sensors.

Much of the work in the US relates to IDRs that are based on data already recorded by the vehicles. In Europe it appears more likely that a separate device may be fitted to vehicles to increase the data capture frequency and resolution, and therefore similar research into their accuracy may be required before the data is used in detailed research projects or for criminal and civil court proceedings.
3 Metropolitan Police Data

3.1 The Kienzle Unfall-Daten-Speicher (UDS) System

Before analysing the data it is useful to gain an understanding of the system fitted to the Metropolitan Police vehicle fleet, the information it records and the accuracy of that information.

The Kienzle Unfall-Daten-Speicher (UDS), type II, Incident Data Recorder, is a device that records the motion of the vehicle to which it is fitted so that, in the event of an incident, the movement of the vehicle and, therefore, the manner in which it was being driven can be determined with a high degree of confidence. The device can be likened to an aircraft black box flight recorder, albeit that the IDR records only a selected number of data streams, and that it does not record cabin conversations.

The device constantly monitors the following data streams:

i) longitudinal acceleration (acceleration and braking);

ii) transverse acceleration (cornering);

iii) direction (compass heading);

iv) wheel (vehicle) speed.

In addition the device also monitors a number of status signals in relation to the use of the vehicle equipment, including the ignition, brake light activation, left and right direction indicators, lighting (including side, dipped and main beam lights) and the use of emergency equipment (such as blue lights and siren).

The system consists of the device itself and a manual button (for manual activation) that incorporates a warning light and a speaker through which audible signals are emitted. The button is typically located on the centre console adjacent to the gear lever/selector. It is common practice to fit a second (repeater) warning light on top of the steering column housing, in the direct line of sight of the driver.

The device is triggered to retain the data in a number of ways:-

- if the driving results in pre-defined triggering conditions being met, i.e. a piece of driving is unusual, the device will automatically store the data for up to 30 seconds prior to the incident and about 15 seconds after, and also over the next 100 metres of travel;
- by use of the manual storage button, the previous 45 seconds of data and the subsequent 100 metres of movement are recorded;
- if the vehicle becomes stationary, with no IDR input, for more than 5 seconds, the previous 45 seconds of data and subsequent 100 metres of movement is recorded.
3.2 TRL IDR Database

Before commencing this study, TRL had collected about 100 IDR activation cases from the Metropolitan Police, based on an agreed set of incident criteria, these being:

1. Vehicle to vehicle impacts or vehicle to roadside furniture impacts where there is significant damage to the police vehicle (with the potential to cause serious personal injury)
2. Rollover incidents
3. Low severity rear end collisions (where the police vehicle is either the struck or the striking vehicle)
4. Pedestrian collisions
5. Motorcycle collisions

Of these incidents, the following list provides a further filter:

i. Incidents where IDR data is recorded at high frequency at the time of the collision
ii. Incidents where there are photographs to show the damage in detail
iii. Incidents where there is a brief description of the incident to assist in understanding the circumstances
iv. Incidents that were attended by the Collision Investigation Unit and that are likely to have additional information and photographs of the damage

To enable researchers to make use of these incidents, a database was created within Excel, containing pertinent information about the incident. During this study, additional incidents were obtained, growing the database to almost 200 cases.

The earlier incidents received were accompanied by a ‘Briefing Report’, which was compiled by the investigating Police Officer and gave brief circumstances of the incident, together with several speeds associated with the Police vehicle. However, changes to the Metropolitan Police procedures resulted in additional and personal information being included in their briefing reports and it was no longer possible for them to be provided. Instead, a new system was developed with Metropolitan Police IT support, to allow the supplementary information, useful for research purposes, to be exported. This was appended to the previously compiled database.

The database was designed to give the user a brief understanding of the collision type, vehicles involved and, where calculated, impact speeds and changes in velocity. Each incident record is linked to the additional data provided by the Metropolitan Police, including descriptions of the incident, occupants of the vehicle, damage and brief injury codes.

By using appropriate filters, users can select cases based on several parameters, including participants (car, pedestrian, etc.), impact type (frontal, side, etc.), impact speed (impact speed range) and also degree of overlap.

A small section of the database is provided below for illustrative purposes (Figure 1).
<table>
<thead>
<tr>
<th>Accident Date</th>
<th>Accident Time</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
<th>Impact Type</th>
<th>Collision Configuration</th>
<th>Collision Configuration on Vehicle 1 Containing Black Box Data</th>
<th>Impact Configuration on Vehicle 2 Containing Black Box Data</th>
<th>Overlap Estimate on Vehicle 1 Containing Black Box Data (%)</th>
<th>Overlap Estimate on Vehicle 2 Containing Black Box Data (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/01/2004</td>
<td>08:45:00</td>
<td>Police Car (Astra)</td>
<td>Street furniture</td>
<td>Car v Other</td>
<td>Frontal</td>
<td>Frontal</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/03/2004</td>
<td>11:02:00</td>
<td>Police Car (Astra)</td>
<td>VW Golf</td>
<td>Car v Car</td>
<td>Frontal</td>
<td>Frontal</td>
<td>NA</td>
<td>20</td>
<td>NA</td>
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<td></td>
<td>Police Car (Ford Fiesta)</td>
<td>Pedestrian</td>
<td>Car v Pedestrian</td>
<td>Frontal</td>
<td>Frontal</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>18/04/2005</td>
<td></td>
<td>Police Car (Vauxhall Astra)</td>
<td>Honda Accord</td>
<td>Car v Car</td>
<td>Frontal</td>
<td>Frontal</td>
<td>NA</td>
<td>80</td>
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<tr>
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<td>04:30:00</td>
<td>Police Car (Vauxhall Astra)</td>
<td>Single Vehicle</td>
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<td>Police Car (Vauxhall Astra)</td>
<td>Peugeot 306</td>
<td>Front-Engaged</td>
<td>Multiple Vehicle</td>
<td>Side</td>
<td>80</td>
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<tr>
<td>08/06/2005</td>
<td>12:15:00</td>
<td>Police Van (Mercedes Vito)</td>
<td>Vauxhall Astra</td>
<td>VW Golf</td>
<td>Multiple Vehicle</td>
<td>Side</td>
<td>Frontal</td>
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<td>NA</td>
<td></td>
</tr>
<tr>
<td>28/06/2005</td>
<td></td>
<td>Police Car (Vauxhall Astra)</td>
<td>Mercedes Sprinter Van</td>
<td>Car v Van</td>
<td>Frontal</td>
<td>NA</td>
<td>30</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>09/07/2005</td>
<td>00:45:00</td>
<td>Police Van (Mercedes Sprinter Van)</td>
<td>Toyota Estima</td>
<td>Van v Car</td>
<td>Side</td>
<td>Side</td>
<td>NA</td>
<td>NA</td>
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</tr>
<tr>
<td>09/08/2005</td>
<td></td>
<td>Police Car</td>
<td>Bus</td>
<td>Car v Car</td>
<td>Frontal</td>
<td>NA</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17/09/2005</td>
<td>02:00:00</td>
<td>Police Car (Vauxhall Astra)</td>
<td>VW Polo</td>
<td>Car v Car</td>
<td>Frontal</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/11/2005</td>
<td></td>
<td>Police Car (Vauxhall Astra)</td>
<td>Citroen Relay Van</td>
<td>Car v Van</td>
<td>Side</td>
<td>Side</td>
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</tr>
</tbody>
</table>

**Figure 1 – Database sample**
4  Selected Cases for Research Review

4.1  Introduction

One of the objectives of this research study was to demonstrate how IDR data can contribute to road safety research by providing high resolution, real-world incident data to researchers. It is considered that this data has the potential to enable new directions of research through the interpretation of detailed vehicle speed, acceleration and rotational data from on-road incidents (rather than staged test collisions) in areas such as vehicle safety, occupant injury, and driver behaviour.

The work is also intended to identify avenues for developing the techniques associated with in-depth road traffic accident investigation and reconstruction which could assist in refining the methods used by researchers, police and other organisations concerned with the accurate interpretation of road traffic collision evidence.

It is recognised that since the number of incidents to be reviewed in this project is small, observations in respect of currently practiced collision investigation methods should be regarded as demonstrating the potential accuracy of these methods, rather than offering a validation of their accuracy or otherwise, although clearly the potential to undertake more extensive, and potentially statistically valid research in these areas would be possible through the development of focussed projects in around these issues.

4.2  Format of Data Provided

The IDR data collected from the Metropolitan Police vehicles was in a format that could only be read by the UDS “UDScience” software. Therefore the data was converted into a CSV file to enable it to be opened in a spreadsheet program such as Excel. An automated system was developed which took the raw CSV data for any incident and converted it into a multipage spreadsheet containing useful information on the incident. The spreadsheet front page shows the circumstances of the collision, see Figure 2.

![Figure 2 – Example front page of spreadsheet.](image-url)
The second page of the spreadsheet, Figure 3 illustrates the longitudinal and lateral acceleration, the vehicle movement and the speed, as recorded by the UDS software. These figures are automatically generated from the database for a selected case and allow easy transfer between research groups who do not have access to the UDScience software.

![Figure 3: Automatically generated acceleration, speed and movement plots](image)

**Figure 3 – Automatically generated acceleration, speed and movement plots**

The final page in the spreadsheet is the raw data which will allow other researchers to carry out further analysis.

This data, together with photographs and a brief incident description, enables the investigator to understand the circumstances of the accident and have the data and vehicle damage to assess the physics of the incident.

Case studies were taken from the database and passed to a number of research groups across TRL. Each group were given four incidents to view, and their feedback on the IDR data was sought in relation to its usefulness in their research areas, its ease of use in an Excel format and any further information that the researchers felt would be needed to enhance the database.

A number of issues were identified in the process of extracting the data from UDScience into a format to be viewed in Excel. On occasion, the high resolution (256Hz) data did not get exported, and a suitable check should be carried out to ensure the detailed acceleration pulse is output in its entirety. The second issue related to the vehicle speeds, both v-spline and v-tacho. When viewed in UDScience, the speeds are given in km/h; however, when exported into Excel, the speeds are in m/s.

Since providing the data to the various research areas, the automated case creation program was altered to overlay the v-spline speed data onto the v-tacho speed to allow the researcher to identify areas of uncertainty in the speed traces caused by braking.
4.3 Selected Incidents

For each of the four main areas of research interest, four incidents were selected that best highlighted the potential benefits of the IDR data.

In the sections below, details of these incidents are presented, together with samples of the data provided to the research areas.

4.3.1 Incident 1

The incident occurred at a crossroads, where the Police vehicle was impacted on its offside by a Black Cab, forcing the Police vehicle sideways, up onto a footpath and partially demolishing a wall, Figure 4. The vehicle striking the Police car did not have an IDR fitted and it was therefore not possible to assess directly the speed of the collision. Note that this incident is reconstructed at Appendix A.4.

Figure 4 – Incident 1 Photograph

![Figure 4 – Incident 1 Photograph](image)

Figure 5 – Incident 1 Lateral Acceleration (overview)

![Figure 5 – Incident 1 Lateral Acceleration (overview)](image)
4.3.2 Incident 2

A Police vehicle was travelling straight ahead when it struck the rear offside corner of a SUV that turned right ahead of it. The Police vehicle was travelling at about 40 mph, and there was about a 40% overlap of damage to the front of the Police vehicle.
4.3.3 Incident 3

Two unmarked Police vehicles were travelling in convoy. Approaching a junction, the lead vehicle braked for traffic but the following vehicle was not able to stop in time, running into the rear of the lead vehicle. Note that this incident has been reconstructed in detail at Reconstruction 2 in Appendix A.2.

Figure 10 – Incident 3 Photograph of Damage to Vehicle 1

Figure 11 – Incident 3 Longitudinal Acceleration, Police Vehicle 1 (overview)
Figure 12 – Incident 3 Longitudinal Acceleration, Police Vehicle 1 (expanded)

Figure 13 – Incident 3 Photograph of Damage to Vehicle 2

Figure 14 – Incident 3 Longitudinal Acceleration, Police Vehicle 2 (overview)
4.3.4 Incident 4

Two Police vehicles were responding to an incident. The lead Police vehicle braked, as did the following Police vehicle. A third party vehicle collided with the rear of the second Police vehicle, pushing it forwards into a minor collision with the lead Police vehicle. The data recorder on the Police vehicle hit by the third party failed (as is shown below), and the data presented here related to the low velocity collision (about 4 mph) between the two Police vehicles.
Two marked police Vauxhall Astras were travelling west along the same road towards a roundabout junction. The first vehicle entered the roundabout, intending to turn through 180 degrees and travel east, back along the same road. The second vehicle did not correctly negotiate the roundabout but travelled the wrong way around it, colliding head on with the other police vehicle. This incident is reconstruction in Reconstruction 5, in Appendix A5.
4.3.6 Incident 6

This was a low velocity pedestrian collision. The Police vehicle had attempted to travel onto the opposite side of the road at a pedestrian crossing facility and stuck a pedestrian causing limited damage to the Police car.

Figure 22 – Incident 6 Photograph

Figure 23 – Incident 6 Longitudinal Acceleration (overview)
4.3.7 Incident 7

This was a higher velocity pedestrian collision. As with Incident 6, the Police vehicle had attempted to travel onto the opposite side of the road at a pedestrian crossing facility, striking a pedestrian causing more damage to the Police car than in the preceding incident.

Figure 25 – Incident 7 Photograph

Figure 26 – Incident 7 Longitudinal Acceleration (overview)
4.3.8 Incident 8

A Police vehicle was travelling at speed along a high speed road. When approaching an exit slip road the driver attempted to steer onto the slip road and misjudged the manoeuvre, resulting in it hitting kerbed median and overturning.
4.3.9 Incident 9

A Police vehicle responding to an emergency was approaching a mini roundabout. On the approach to the roundabout the Police vehicle moved onto the opposite side of the road and to the right of two keep left bollards. Whilst on the opposite side of the road the vehicle contacted the offside kerb and lost control. The vehicle then contacted a central reservation before mounting the footpath and colliding with a sign post, garden wall and several vehicles.

Figure 31 – Incident 9 Photograph

Figure 32 – Incident 9 Longitudinal Acceleration (overview)
4.3.10 Incident 10

As the Police vehicle was travelling at about 75 mph, a vehicle pulled out of a side road ahead of it. The Police driver steered to avoid this car, first right then left to avoid an oncoming lorry. Whilst steering back to the left the Police car collided with the rear of a parked people carrier, which deflected the Police vehicle back into the opposing carriageway where a collision occurred between the car and an HGV. The Police car then mounted the pavement and knocked over a lamppost and in doing so flipped onto its roof, trapping the driver and injuring the other two passengers.
Figure 35 – Incident 10 Longitudinal Acceleration (expanded)

Figure 36 – Incident 10 Lateral Acceleration (expanded)

4.3.11 Incident 11

A Police car responding to an emergency call approached a sharp right hand bend at a speed of about 60mph. The Police driver moved to the nearside for better vision around the bend. On the apex of the bend there was an access road to an industrial unit, and the edge of the road was covered in gravel and possibly a small amount of spilt diesel. As the car negotiated the bend it drifted wide onto the gravel. The driver then lost control of the car and it slid further onto the gravel. The driver then braked but could not avoid a collision. The car collided with a telegraph pole causing extensive damage to the car and pole. Both occupants of the Police car suffered minor injuries. It is difficult to determine further information relating to this incident, shown in Figure 37, and when incidents occur at night, detailed photographs are not always available.
4.3.12 Incident 12

This incident involved two Police vehicles attending an emergency. A marked Police car turned right into the path of an unmarked Police car resulting in the marked car sustaining a heavy rear impact. The marked car triggered its UDS box three times in the
few minutes before the incident itself, while the unmarked Police vehicle triggered the UDS once before the incident, plus during the incident itself.

Figure 40 – Incident 12 Photograph

Figure 41 – Incident 12 Longitudinal Acceleration, Vehicle 1 (expanded)

Figure 42 – Incident 12 Longitudinal Acceleration, Vehicle 2 (expanded)

4.3.13 Incident 13

A Police vehicle was travelling south approaching a junction. A private vehicle was travelling east along the main road. The Police believe that their traffic light was red,
but a vehicle travelling west on the main road stopped to let them through. Believing his route to be clear, the Police Office continued into the junction where a collision occurred. This incident did not have any other activations of the UDS box before the collision.

Figure 43 – Incident 13 Photograph

![Figure 43 – Incident 13 Photograph](image)

Figure 44 – Incident 13 Longitudinal Acceleration (expanded)

![Figure 44 – Incident 13 Longitudinal Acceleration (expanded)](image)

Figure 45 – Incident 13 Lateral Acceleration (expanded)

![Figure 45 – Incident 13 Lateral Acceleration (expanded)](image)
5  Review of Research Opportunities

5.1  Biomechanics

5.1.1  Research Interests

This research group has a particular interest in the injuries sustained by occupants in side impact collisions, rear impacts and also collisions which have the same configurations as used in EuroNCAP testing.

5.1.1.1  Real World Crash Pulse Data

Currently it is difficult to know whether full scale crash tests accurately reflect the accelerations experienced by vehicles and occupants during real collisions. IDR data from collisions which closely match test configurations could thus be of significant interest to researchers concerned with the interpretation of crash test data and the development of crash test standards.

5.1.1.2  Low Velocity Collisions

The mechanisms by which injuries are sustained in low velocity collisions are not fully understood. In low velocity collisions one of the main issues that researchers face is determining the speed of a vehicle at impact. Using damage assessment alone is not sufficiently accurate to identify impact severity: access to detailed, high resolution data regarding real-world collisions would be used to link structural/component damage to impact severity and to identify the nature of the acceleration pulse sustained during a collision.

5.1.1.3  Vehicle Crash Performance

Vehicle safety researchers are typically limited to full scale crash tests when seeking to link impact severity to the structural performance of a vehicle. Such tests are expensive and thus test programmes examine a very limited number of impact configurations and speeds. High resolution collision data from real accidents offers researchers access to a much wider range of collision types and, critically, access to high resolution data describing the vehicle motion before, during and after the collision. This data can be used to better understand the structural performance of vehicles in real-world incidents and to calibrate full scale impact tests.

5.1.2  Feedback

The Biomechanics research group was provided with the information relating to incidents numbers 1, 2, 3 and 4. In general, these incidents covered frontal, side and low velocity rear collisions to provide a general overview of the possible crash pulses.

Feedback was received in relation of the quality of the IDR data for research purposes, opportunities for exploring the usability of IDR data, the need for additional information relating to injury and potential research applications.
5.1.2.1 Potential Benefits

IDR data could assist the investigation of low speed impacts and injuries. Information on real world collision pulses is limited and that which is available can be limited in itself (such as the data collected by the Swedish insurer, Folksam, whose device, despite providing real world collision pulse data, does not record the initial part of the collision pulse). This limitation restricts the ability of researchers to draw conclusions around the significance of the initial portion of the acceleration pulse. It is possible that an IDR will capture this initial acceleration in low speed incidents, and hence has the potential to provide a very useful source of acceleration pulse and delta-v data to researchers, with the potential to link to injury information.

By comparison, a major German whiplash accident investigation project estimates the delta-v of the collision by analysing the photographs of the damage to the struck vehicle. TRL researchers have long argued that the accuracy of this method would be poor. This is demonstrated by Incident 3 involving a low velocity rear collision between two police vehicles which shows markedly different damage to the two vehicles, and it is believed unlikely that any researcher would estimate a delta-v of around 12 km/h for one of the vehicles.

The value of using the images of the damage to the vehicles, together with measured delta-v’s, was highlighted as being particularly important, and views were expressed of its immediate usefulness. Such images, together with acceleration data could provide useful reference data for researchers.

In Whiplash Associated Disorder (WAD) research, information relating to whether an injury was sustained in a low velocity collision is of paramount importance. Injury data from vehicle occupants involved in low speed collisions could potentially be extremely valuable if linked to IDR data. It is envisaged that with the agreement of the Metropolitan Police and the Police Federation, individual officers involved in such collisions could be approached to contribute to such research on a voluntary basis.

Injury information for all occupants in an involved vehicle would allow comparative assessment of the influence of the acceleration experienced by the occupants and allow user diversity issues to be assessed.

5.1.2.2 Technical Issues and Solutions

In injury biomechanics, it can be both the change in velocity of the vehicle and its acceleration that are of interest. The issue raised was with the resolution at which the data was captured, which would have a greater influence on the detailed acceleration pulse than on the change in velocity.

It was noted that the highest sampling rate of the IDR device was 256 Hz (filtered from 512 Hz), and that this was captured at the time of the collision. However, it was noted that even at the filtered 256 Hz resolution the IDR data was significantly less than specifications laid out by both SAE J211 and ISO for determining change in velocity in instrumented crash tests. These standards specify that a channel filter class (CFC) 180 filter should be used; this filter delivers data filtered from at least 1800 Hz. This frequency of data acquisition allows the acceleration pulse to be measured accurately for a number of impact configurations.

An example of the 256 Hz IDR data is presented below. In Incident 3, the longitudinal acceleration data was expanded (Figure 46) between 29.41 and 29.49s (80ms interval), where there are around 20 data points. At the SAE and ISO CHC_180 standard, there would be 144 data points over the same period. Figure 47 shows an example of the higher resolution for the acceleration response that is often used when the shape of the collision pulse is deemed to be important.
In order to utilise the IDR data it is first necessary to consider the accuracy of the 256 Hz acceleration data against that delivered by the CFC_180 standard. This could be done by sampling data from previous crash tests (with 180 CFC data) at the required rates, firstly at 512 Hz, and then filtering to 256 Hz. The variability of results could be examined both in respect of the sampling method and through comparison/characterisation of the IDR equivalent and CFC_180 acceleration pulses.

This work would provide a clearer understanding of the potential value of the IDR data, and could guide its use to the most appropriate areas. For example, it was noted in the DfT and EC ‘Thorax’ study that more vehicle occupants received thorax injuries in frontal collisions at half the EuroNCAP test speed than at the 64 km/h test speed itself. Linking accurate delta-v and collision pulse data to occupant characteristics and injury outcome would potentially provide a valuable source of data to better understand the cause of injury in such incidents.
5.1.2.3 **Useful Additional Information**

Access to injury data, including that connected to Stats 19, HES data and/or information from individuals involved in collisions could also provide valuable information on variations in injury outcome due to user diversity (variations in age, height, weight).

Measurements relating to airbag timing, pretensioner activation and load limiter activation (and limit level) would be valuable for more detailed studies of occupant motion and injury, but it is recognised that such information would not be captured with an IDR. Future studies may have to incorporate high speed video and additional vehicle data channels to capture such detailed information.

5.1.2.4 **Summary**

In summary, the examination of IDR data by biomechanics experts within TRL’s vehicle engineering group indicated the potential for IDR data to provide valuable input to research projects in the following areas:

- Evaluating the quality of IDR collision pulse and delta-v data against known CFC_180 crash tests;
- Examining increased thorax injury risk in sub-NCAP energy collisions;
- Examining user diversity injury patterns and issues;
- Compiling IDR collision pulse data on real world low speed impact cases to compare with Folksam data;
- To provide reference data and photographs for delta-v estimation
- To link collision pulse data to occupant injury to better understand the characteristics of low speed injury incidents, including collision pulse and user diversity issues.
- An IDR device could be acquired by TRL and fitted to test various test equipment to provide benchmark comparisons between high resolution ‘research’ collision data and real world IDR data.

5.2 **Crash Analysis Group**

5.2.1 **Research Interests**

This research group has a particular interest in gathering real world accident data and undertaking analysis to determine trends between impact severity and injury, including the accurate and repeatable calculations for collision severity measures, and accident reconstruction.

5.2.1.1 **Occupant Protection**

TRL run the Co-operative Injury Study (CCIS) on behalf of the Department for Transport (DfT) and is currently the single largest safety research programme funded by the DfT. The CCIS project seeks to understand the mechanisms of occupant injury and to promote vehicle design which reduces or eliminates repeated injury patterns. However, a limitation of the study, which links the injuries sustained by occupants to vehicle structures and collision severity, is the accuracy of collision severity assessments.
The key method of assessing collision severity in the CCIS project is the use of the CRASH3 algorithm to calculate collision speed from vehicle damage. This method relies on vehicle crush measurement and the calculation of collision energy and collision severity using generic sets of stiffness coefficients. The availability of IDR data would represent a significant opportunity to validate or calibrate collision severity indicators provided by CRASH3 and could potentially add significant value to the programme.

The ‘On The Spot’ (OTS) in-depth accident research project examines the factors which have contributed to accidents of all severities, and involves the attendance of a research team at live accident scenes. The project seeks to gather sufficient data to reconstruct collisions with a view to understanding the causal and contributory factors in terms of accident occurrence and road user injury. The project relies heavily on the application of traffic accident reconstruction techniques, hence this project or similar studies would benefit from any development of collision reconstruction techniques through the use of IDR data.

5.2.1.2 Vehicle Crash Performance

Full scale crash tests have traditionally been the only method for vehicle safety researchers to link impact severity and the structural performance of a vehicle during a collision. However, such tests are expensive and test programmes can only examine a very limited number of impact configurations and speeds. The high resolutions IDR data would. Such tests provide an important means of calibrating the findings of in-depth research and collision reconstruction to the results of a known, controlled collision.

5.2.2 Feedback

5.2.2.1 Potential Benefits

The presence of vehicle fleets equipped with IDR systems opens the possibility for the conduct of high resolution in-depth accident and injury studies. Taking the Metropolitan Police fleet as an example, highly accurate, detailed collision severity indicators from IDR devices, combined with vehicle inspections and access to injury data from injured persons could provide data to investigate more precisely the linkages between collision severity and occupant injury. Such a study could provide detailed case studies for occupant injury mechanisms and the performance of safety systems. The resulting data would potentially improve the information available to researchers to understand and eliminate injury mechanisms.

For example, rollover incidents are traditionally difficult to interpret in terms of the motion of a vehicle before and during the rollover, and of the mechanism of the roll itself. Whilst not providing 3 dimensional (vertical accelerations), IDR data would provide good information relating to the pre-roll motion of the vehicle, including the number of impacts and rolls suffered. Since this information is traditionally difficult to ascertain, our current understanding of occupant injury mechanisms in real world rollover incidents could be improved through the study of IDR incidents involving rollover.

With the encouragement of walking and cycling in response to concerns around public health, traffic congestion, air quality and CO₂ emissions, the protection of vulnerable road users is a significant concern in road safety. Consequently it is of increasing importance to develop a better understanding of pedestrian and cyclist injury accidents and how to prevent or mitigate injury mechanisms. IDR data from such incidents would provide an opportunity to reconstruct very precisely the circumstances of vulnerable road user incidents, with particular reference to the speed of a vehicle at the point of
collision and possible influence of pre-impact safety systems such as a Brake Assist System (BAS). Such cases, with high resolution data relating to the collision event, could allow researchers to compile vulnerable road user specific case studies in parallel with existing or future in-depth accident research projects. Reviews of such cases would allow researchers to more effectively establish relationships between impact speed, damage and head impact location.

As discussed above, a key method of assessing collision severity in existing in-depth accident research projects is the use of the CRASH3 algorithm to calculate collision speed from vehicle damage. Current methods for this rely on vehicle crush measurement and the calculation of collision energy and collision severity using generic sets of stiffness coefficients. The use of IDR data represents a significant opportunity to validate or calibrate collision severity indicators provided by CRASH3.

Accident reconstruction methods are generally based on sound theory or the results of physical testing. They stand up well to validation; however, because of uncertainties in the many parameters which influence the motion of vehicles, pedestrians and other elements involved in road traffic collisions, these techniques are restricted in the degree to which they can establish precise vehicle speeds during the key phases of an incident. With the development of active vehicle safety systems such as antilock braking (ABS), electronic stability control (ESC) and brake assist (BAS) both the evidence necessary for effective collision investigation (using tyre marks, for example) and the reliability of traditional assumptions relating to braking characteristics have been eroded.

Hence, it is necessary to continually assess the effectiveness and refine the accuracy of established methods. IDR data could be used to develop and refine collision investigation methods, from critical speed yaw-mark calculations to pre-tyre mark speed loss under emergency braking, pedestrian throw calculations and the validation/calibration of the CRASH3 algorithm. Such work would be of benefit to both the accuracy of in-depth research (and hence the quality of research findings) and would be of significant benefit to all UK police forces in the investigation of serious and fatal collisions.

Vehicle safety researchers are typically limited to full scale crash tests when seeking to link impact severity to the structural performance of a vehicle. Such tests are expensive and thus test programmes examine a very limited number of impact configurations and speeds. High resolution collision data from real accidents offers researchers access to a much wider range of collision types and, critically, access to high resolution data describing the vehicle motion before, during and after the collision. This data can be used to better understand the nature of the collision suffered by a vehicle and hence to relate this to the structural performance vehicles in real-world incidents.

5.2.2.2 Technical Issues and Solutions

The level of information currently available in relation to the Metropolitan Police investigation of these incidents would be insufficient to assess all relevant damage to the vehicle, and in particular the vehicle interior. For example, in injury causation analysis, knowledge of whether or not the seatbelt was being worn, and whether or not airbags triggered during an incident would be valuable, but this data in not recorded by the IDR. Hence, access to the vehicles shortly after an incident to obtain further information, such as crush measurements and contact marks would be essential for the use of this information in in-depth accident research/occupant injury study, or for use in the validate computer programs such as CRASH3.

In addition, a procedure for accessing injury information for involved persons would be required. It is understood that the Police Federation would, in principle, be supportive of
facilitating contact between researchers and police officers (on a voluntary basis and under strict ethical guidelines) in order to promote the potential benefits of this safety research.

The UDS data provides details of vehicle speed and acceleration, from which the change in velocity due to the collision can be determined, and which would be of considerable use to this area of research. However, further information on Equivalent Energy Speed (EES) or Equivalent Test Speed (ETS) would also provide useful data and it should be explored whether this information can be reliably determined from the UDS data and incident information.

5.2.2.3 Summary

In summary, the examination of IDR data by crash analysis experts within TRL’s safety group indicated the potential for IDR data to provide valuable input to research projects in the following areas:

- IDR data offers the opportunity to undertake highly detailed investigations into real world road traffic incidents involving personal injury. Such in-depth investigations, utilising the high resolution driving and collision data has the potential enhance our understanding of injury mechanisms through a more precise understanding of the circumstances of crashes.
- IDR data could have particular applications in the assessment and understanding of rollover incidents and hence mechanisms of occupant injury.
- The comparison of vehicle crush measurement as a technique for crash severity calculation can be compared to and validated against IDR data in order to gain a better understanding of the accuracy of CRASH3 delta v calculations, and the accuracy of various approaches to the use of stiffness coefficients.
- IDR data offers the potential for researchers to further develop collision reconstruction methods, which would benefit the investigation of cases in which vehicles are not equipped with IDR devices, including the reconstruction of cases for in-depth research and litigation.

5.3 Vehicle Safety Systems

5.3.1 Research Interest

This research group has interests in both primary and active safety systems, and their benefits in assisting drivers to avoid collisions, or protecting them when they occur. Several cases were provided for assessment, and these included incidents where a loss of control occurred at speed prior to a collision.

5.3.1.1 Effect of Active Safety Systems

Vehicles in the UK are increasingly equipped with safety systems such as electronic stability control (ESC), electronic brake assist (BAS) and brake force distribution. To understand the wider safety benefits of such systems, researchers require detailed information as to how these systems operate in the real world, and their influence on collision avoidance or mitigation. IDR data could provide indications of the effectiveness of such systems in extreme driving situations (particularly when compared with the performance of vehicles without such systems), and could also provide practical examples and guidance to the Metropolitan Police, policy makers and industry as to the benefits of certain active safety systems.
5.3.2 Feedback

5.3.2.1 Potential Benefits

IDR pre-impact data was seen to be useful to show how a loss of control might start and how it develops during an incident, together with providing understanding of the effectiveness of active systems when they intervene to assist the driver. The time, acceleration and heading data could be used to determine the path taken by a vehicle during a loss of control sequence. Further work could be undertaken to establish whether or not the 16 Hz data (the lower resolution data leading up to a collision) would allow detailed analysis of the vehicle movement. This analysis could be undertaken using existing vehicle data held at TRL from previous vehicle handling studies.

In particular, the investigation and analysis of loss of control mechanisms involving stability control equipped and non-equipped vehicles could provide a clearer understanding of the implications of stability control activation, particularly whether the presence of stability control changes accident patterns in terms of the nature of a collision experienced by the equipped vehicle. This, in turn, would yield detailed case study data on the effectiveness of stability control, and its influence on accident scenarios.

In the case of primary safety systems such as BAS (brake assist), IDR data could be employed to consider larger numbers of incidents involving vehicles both equipped with and without BAS. Such a data set would allow researchers to examine deceleration rates of BAS and non-BAS equipped vehicles in real-world incidents over a given period of pre-impact heavy braking. The accurate pre-braking speed and subsequent acceleration data would allow the likely influence of BAS to be assessed over a range of cases. Such information could be particularly relevant to policy decisions around the adoption of BAS as a means of reducing injuries to vulnerable road users (as opposed to alternative means of vulnerable road user protection, such as the provision of active frontal structures to absorb impact energy).

5.3.2.2 Technical Issues and Solutions

It was noted that knowledge of the safety systems fitted to an incident involved vehicle would be needed in order to assess how a system (or combination of systems) performed in during an incident. This question is not always easy to answer, and thus preliminary discussions would be required with the Metropolitan Police and/or vehicle manufacturers in order to determine what information is available with respect of primary safety equipment. However, the Metropolitan Police vehicle fleet does largely consist of vehicles from a small number of manufacturers.

Knowledge of whether any of the safety systems within the vehicle were turned on or were activated either before or during the collision, would be of assistance. Systems such as Electronic Stability Control (ESC) constantly monitor the movement of the vehicle and the driver input, and this information can be accessed from the vehicle. A method of connecting the data from this system to the UDS box could provide valuable information. To have information on the activation of these systems would enable the effectiveness of them to be established and whether the systems are as efficient during an emergency avoidance manoeuvre.

Whilst the current speed and acceleration data recorded by the IDR allows researchers to understand the movement of the vehicle, it does not allow the severity of driver actions to be assessed (such as rate of steering application, brake application, etc.). Therefore,
in addition to the speed and acceleration data provided by the IDR, a number of additional data channels were identified as being of potential value to researchers. In this respect, data relating to the position and movement of the driver controls would be very useful in order to determine whether and how the driver attempted to make an avoidance manoeuvre immediately prior to the collision.

However, whilst the value of IDR data could be significantly increased through the addition of additional channels of data relating to driver actions (such as %throttle, %brake and degree of steering application), in practice it is recognised that it is currently impractical to capture such data reliably in diverse vehicle fleets. That said, logging and interpretation of CAN bus data can yield high resolution data of this type from most vehicles. A project gathering such information would require an additional data logger to be added to the IDR vehicle and may require manufacturer cooperation to correctly interpret the CAN data.

5.3.2.3 Summary

Overall the data is viewed as potentially beneficial to research studies investigating effectiveness of primary and secondary safety systems.

Additional information relating to the circumstances of the incident and the actions of the driver (in terms of driving inputs such as rates and values of steering, throttle and brake application) would be required to add significant value. Some of this data could be gathered through scene and vehicle inspections following an incident, but data relating to driver inputs would require additional data capture devices to be added to vehicles.

In summary, the examination of IDR data by the vehicle safety system group indicated future research opportunities including:

- Research into whether the 16Hz data provided leading up to a collision would permit detailed analysis of the vehicle movement;
- Assessment of the influence of ESC and BAS systems on incident scenarios, and, through the assessment of a number of case studies, identification of trends in incidents involving vehicles equipped or not equipped with certain safety systems. Such projects would be of value to policy makers in respect of providing independent evidence as to the effectiveness of such safety systems.

5.4 Behavioural Change

5.4.1 Research Interests

TRL’s Behavioural Change group has an interest in the behaviour of a driver in the time before a collision. Researchers in this area seek to understand the factors which influence and the indicators which may point to particular driving styles which correlate to an increased risk of incident involvement.

5.4.1.1 Driving style indicators

A key research area in driver behavioural change is the detection and monitoring of driving styles, and the ability to characterise these driving styles and to detect changes. Any changes in driving style may be correlated to an intervention such as driver training, or feedback on driving performance. Whilst changes in a driver's attitude can be examined through more traditional survey techniques, changes in driving style, other than self reporting, require actual driving characteristics to be monitored, typically by an
electronic device. A driver’s driving style can be closely linked to risk factors such as driving speed and severity of cornering together with many and other manoeuvres, providing risk indicators for a driver in respect of different aspects of their driving.

5.4.2 Feedback

5.4.2.1 Potential Benefits

The accuracy of drivers’ self reports can be assessed by comparing their recollection of the incident with the data collected by the IDR. Incident 12 provides an example of the driver (of the marked police vehicle) providing an account of the moments before the incident that did not match the IDR data. Such events are worthy of further behavioural investigation to establish whether any driver characteristics are correlated with inaccurate self reports (e.g. poor hazard awareness, poor situational judgement) or whether drivers are simply intending to cover an accident that was their fault.

IDR data linked to collision investigations could be categorized in relation to fault and non-fault collisions, in terms of the police vehicle. The profile of drivers deemed to be at fault could be compared to those deemed not to be at fault. These comparisons could yield driving characteristics that are associated with riskier driving and which therefore correlate most closely to ‘at fault’ collisions. Such work could demonstrate links between driving style and accident fault, and thus provide additional insight into driving style indicators relating to risk. It is also envisaged that such information would be of benefit to the police service through feedback into training, and for communication to officers involved in response driving.

In order to characterise drivers according to the data, it would be helpful if the separate IDR cases were entered in a single database and coded by individual vehicle. This would allow metrics to be calculated for each vehicle and then statistical comparisons or regression models to be run to identify metrics that predict certain outcomes (e.g. crash/near-miss; crash severity; crash fault). Some of the questions that could be answered with this dataset might include establishing whether collision events can be separated from near misses using the pre-crash data, whether there are any identifiable trends or extremes of driving/vehicle behaviour, and whether the data indicate the point at which driving becomes risky.

Some of the metrics that have been used in similar research at TRL include:

- Maximum values for accelerations and speed
- Range of values for accelerations and speed
- Statistics for acceleration and speed values (e.g. mean, standard deviation, variance)

Several of these factors have been found to correlate with other factors in previous research, such as fuel consumption. It is possible that patterns within these factors for individual drivers could provide an indication of risk — perhaps even providing an early warning of an imminent collision.

Often with behavioural analysis there are additional data streams available to define personal driver characteristics, from basic demographics to attitudinal data. The factors created from the IDR data could be analysed together with personal data to identify further predictors of certain driving styles or risk factors. Clearly, some amount of information about the driver in terms of demographics would be required to undertake such work, and the availability of this information would be a matter for discussion with the Metropolitan Police.

In addition, as discussed in other sections of this report, there are additional data streams that would be of use alongside the speed and acceleration values. Knowledge of driver inputs would be particularly beneficial: including steering angles, brake pressure,
gear selection would provide further data for characterising driving styles and in particular for identifying risky behaviours. It is quite feasible that drivers will make inputs that do not manifest as extreme changes in acceleration or speed but yet may indicate potentially erratic driving, good hazard awareness, etc. Other data streams of potential value could be extracted, such as engine speed and fuel consumption.

5.4.2.2 Technical Issues and Solutions

High resolution data as collected by the IDR can help characterise driver behaviour. Where the IDR is less useful in this respect is the short duration of data collection and the absence of data that does not precede a crash or near miss (for comparative purposes).

Whilst these cases are typically of police vehicles in emergency situations - and therefore driving at high speed and producing high acceleration - there may be subtle indicators of different driving styles within this high resolution data. Such differences may be more pronounced at lower speeds and during non-response driving, so it is unfortunate that the IDR does not have capacity for storing continuous data (or at least a sample of data) from a period of driving that does not precede an ‘event’. This would provide a helpful base for comparing drivers.

Initially, case photographs help a researcher to understand the events that have taken place and in this respect, video footage would be a helpful addition to the UDS device. The provision of environmental context is of great benefit when assessing driver behaviour, particularly if the driver’s inputs can be observed from in the cab, as well as their view forward.

5.4.2.3 Summary

In summary, the following applications for IDR research were identified:

- Comparing the accuracy of driver and passenger self-reports in relation to the circumstances of incidents.
- Comparisons of incidents involving ‘fault’ and ‘non fault’ driving for the purpose of identifying driver indicators which correlate more strongly to ‘fault’ or ‘non fault’ incidents.
- Development of a database which would allow cross correlation of driving styles between different drivers and vehicles
- The use of demographic data relating to drivers to investigate links between demographics and driving styles.
6 Comparison of IDR data with Theoretical Accident Reconstruction Techniques

6.1 Overview

In the UK and Europe, IDR systems are not routinely installed on private vehicles, and therefore more traditional, or theoretical, accident reconstruction techniques are generally used to investigate collisions for road safety research purposes and court proceedings. In this study, these traditional and theoretical accident reconstruction techniques have been evaluated against the high resolution pre-event and collision data provided by IDRs. While it is envisaged that the IDR data will represent a reasonable degree of accuracy relating to the vehicle involved, without detailed testing of the system it is not possible to establish its true level of accuracy. Therefore, while comparisons are made between the methods, it cannot be concluded that theoretical techniques are limited if the calculations do not precisely match the IDR data.

In many cases, the lack of physical evidence requires an investigator to make wide assumptions and/or rely on sparse research data in calculations relating to vehicle dynamics, speed from tyre marks or other evidence sources (such as the extent of crush damage) or pedestrian throw. The steady advance of automotive technology has enhanced vehicle safety by increasingly allowing vehicles to maintain stability in extreme manoeuvre events. An unfortunate by-product of these developments is the gradual elimination of clear evidence of vehicle motion (such as that provided by tyre marks) at road traffic incident scenes. The following sections below provide a summary of the findings from each reconstruction. The full reconstruction can be found in Appendices A.1 to A.5.

6.2 Reconstruction 1

The first reconstruction involved a Police car on an emergency called involved in a collision with a female pedestrian. Using the available physical evidence, namely the tyre marks associated with ABS braking, the theoretical reconstruction calculated an approach speed of 67 to 79 mph and an impact speed of 47 to 54 mph. The IDR data measured the approach speed as 73 mph and the impact speed as 52 mph.

Pedestrian throw analysis resulted in impact speeds of 35 to 46 mph, using the first point of debris as the impact location. This is somewhat less than the actual speed. However, the IDR data shows that the impact occurred about 8 metres prior to the glass debris, and accounting for this in the pedestrian throw analysis results in impact speeds of 40 to 52 mph being calculated.

The IDR data also showed that the start of braking commenced about 15 metres before the first visible tyre mark.

The speed assessment related to the damage to the vehicle is much less reliable and underestimated the actual impact speed considerably. The two methods utilised resulted in a range of impact speed of 22 to 43 mph. This wide range was in part due to the unknown height of the pedestrian and the cause of the damage to the windscreen.
6.3 Reconstruction 2

This incident involved two unmarked Police vehicles, both with IDR fitted. The following vehicle was unable to brake sufficiently to avoid driving into the rear of the other vehicle.

The theoretical reconstruction techniques utilised were based on conservation of momentum and damage energy assessment.

To calculate the change in velocity of each vehicle, an estimate of the equivalent barrier speed was needed. This is the speed at which each vehicle would need to strike a rigid barrier in order to sustain the same damage.

Undertaking the analysis, ignoring the effect of the external forces associated with the braking forces, resulted in the delta v for the bullet vehicle being 9.2 to 21.9 mph and for the target vehicle, 8.0 to 19.1 mph. When considered the vehicle braking forces, the delta v for the bullet vehicle changed to 10.6 to 23.3 mph if only that vehicle was braking, or 12.2 to 24.9 mph if both vehicles were braking. Similarly, the target vehicle’s delta v was 6.6 to 17.6 mph when only the bullet vehicle was braking and 4.9 to 16.0 mph when both vehicles were braking.

The IDR data measured the delta v for the bullet vehicle of 11.9 mph and for the target vehicle, 7.4 mph.

Therefore, although the delta v ranges for the theoretical reconstructions were wide, they encompassed the actual delta v’s of each vehicle.

Further analysis of the IDR data allowed the actual coefficient of restitution to be calculated, which was higher than the range used in the theoretical reconstruction. When substituting this value into the theoretical calculations, the bullet vehicle delta v was 17.5 to 27.6 mph and the target vehicle delta v was 11.5 to 19.6 mph. These ranges are greater than the actual delta v and are likely to be the result of an overestimate of the equivalent barrier speeds. It appears therefore that the assumed ranges of the two equivalent barrier speeds were too high but, in combination with low restitution values, a reasonable range for the delta v’s was nevertheless fortuitously calculated.

6.4 Reconstruction 3

Reconstruction 3 was another pedestrian struck by a Police car. This time the pedestrian was on a pelican crossing and the Police vehicle was driving along a bus lane on a high friction surface.

Tyre marks from the Police car and an estimate for friction resulting in approach speed of 43 to 51 mph and an impact speed of 25 to 40 mph. This wide range was due to not knowing where between the crossing the pedestrian was struck and also whether or not the tyre marks ceased under the front tyres of the Police vehicle.

Pedestrian throw calculations, using the extremes of the crossing as the impact location, resulted in speeds of 29 to 44 mph.

The impact speed based on damage gave a range of 25 to 34 mph.

The IDR data showed that at the start of braking, the Police car was travelling at 49.5 mph and at impact was travelling at 39.6 mph. The actual speeds fall within the ranges calculated by tyre mark and pedestrian throw analysis, but this was at the upper end of the ranges.

A combination of using a higher average deceleration for the pre-impact braking phase and a braking distance associate with the tyre mark only resulted in a good approximation of the actual vehicle speed. However, the actual average deceleration over the pre-impact braking phase was less than the lower end of the estimate range,
but the effect was negligible as the vehicle braked over a distance greater than the visible tyre mark.

Using the known impact location, both pedestrian throw equations resulted in good estimates of the impact speed.

6.5 Reconstruction 4

This incident involved an unmarked Police car travelling through a cross roads and failing to give way to traffic on the main road. The Police car was struck on its offside by a Black Cab taxi, and was forced across the road and eventually into contact with a boundary wall.

There was little physical evidence recorded in this incident, and therefore momentum calculations were performed to determine the impact speeds required for the vehicles to come to their resultant rest positions. Using a range for the decelerations to rest, and an estimate for the impact location and post impact movement, the speed of the Police vehicle at impact was determined to be in the range of 17 to 30 mph, compared to the IDR data of 23 mph.

The Police vehicle experienced a delta v in both the X and Y directions, calculated from momentum exchange to be 9 to 16 mph and 7 to 11 mph respectively, compared with 19 and 6 mph from the IDR. The total calculated delta v was 20 mph from the IDR and 11 to 20 mph from momentum analysis. While the theoretical method has approximated the actual delta v, this was only at the upper end of the range. This may be due to a combination of inappropriate deceleration and/or any angle change on the Ford Mondeo before impact.

6.6 Reconstruction 5

This incident involved a head-on collision between two Police Vauxhall Astras at a roundabout junction. The collision was relatively minor and, apart from photographs, there was no other evidence recorded.

The theoretical reconstruction techniques utilised for this incident were conservation of momentum and damage energy assessment. To calculate the change in velocity of each vehicle, an estimate of the equivalent barrier speed was needed. This is the speed at which each vehicle would need to strike a rigid barrier in order to sustain the same damage.

The calculations resulted in both vehicles experiencing a delta v of 7.1 to 16.3 mph. This was due to the type and mass of the vehicles being the same. However, for the purposes of the calculations, the collision was assumed to be head-on. The fact that it was not, and the overlaps were slightly less than 100%, and there were slight angles between the vehicles, will lead to the calculated speed range being a slight over-estimate of the actual delta v.

The IDR data measured slightly different changes in velocity for each vehicle, 13 ± 1 mph and 15 ± 1 mph. The slight discrepancy in these results could be due to the lateral accelerations involved, where it was not possible to reasonably calculate the lateral component of the delta v.

Therefore, although the change in velocity ranges for the theoretical reconstructions were wide, they just encompassed the actual velocity changes of each vehicle, albeit at the upper end of the estimated range. With knowledge of the more accurate restitution value of the collision, a refined theoretical change in velocity range of 10 to 16 mph was calculated.
6.7  Computer Visualisation and Simulation

6.7.1  Visualisation
There are several pieces of software available (3D Studio Max as an example) that can take the UDS acceleration and heading data and show the user the vehicle movement. This movement can be overlaid onto an aerial image to show its path in relation to the road environment.

The movement shown would be that recorded by the UDS device, and thus the effect of any interaction with other vehicles would be accounted for. However, it would not be possible to establish the pre-impact movement of the other vehicle.

6.7.2  Simulation
There is software, such as HVE (Human Vehicle Environment) and PC Crash that can also display the movement of the UDS equipped vehicle involved in an incident. However, both of these pieces of simulation software can also be used to provide the initial conditions of the equipped vehicle up to the point of impact, allowing the software’s solver to then calculate the post impact movement. This method would allow the effect of speed and movement of the third party vehicle to be investigated.

The HVE software utilises a number of physics packages, each designed to allow particular aspects of a collision to be assessed. The GATB (Graphical Articulated Total Body) package allows the motion of a vehicle to be controlled by a collision pulse. This collision pulse can take the form of time histories of acceleration, velocity and position.

The positional pulse allows the x, y and z coordinates to be input from a data file, together with the roll, pitch and yaw values. The UDS raw data provides x and y acceleration data, from which x and y positions movement can be determined. The UDS data also includes the heading angle in radians (yaw value). The remaining fields can be left as zero, and the data file should move the vehicle according to the recorded UDS data, allowing the investigator to better understand the vehicle movements.

PC Crash is a collision and trajectory simulation tool that enables the accurate analysis of a wide variety of motor vehicle collisions and other incidents. One of the functions of PC Crash is the ability to use UDS data to apply motion to a vehicle.

By viewing the UDS data in isolation in software such as UDScience, it is difficult to picture the movement of the vehicle. By importing the data into PC-Crash would allow a researcher a better understanding of the pre-impact and post impact movements.

With the assistance of Mr Peter Jennings of TCRI Ltd, who has a licensed copy of PC Crash, an attempt was made to import the UDS data. The authors of the software provided an additional license file to allow the UDS features to work. The UDS data was exported from UDScience as a text file; however, this was not the format required by PC Crash. PC Crash attempted to import this data, but it was apparent that the acceleration data was missing.

While PC Crash would undoubtedly assist with the understanding of UDS data in future research applications, it was not possible on this feasibility study to successfully assess this feature of PC Crash. Although some data preparation would be required to allow a collision pulse to be imported into HVE, this would allow an investigator or researcher to view the motion depicted by the two dimensional acceleration data recorded by the IDR, and to reconstruct occupant motion, or the motion of another vehicle, for example, using HVE simulation modules.
7 Discussion

TRL have long recognised the potential benefits of the high-resolution UDS incident data recorded on the Metropolitan Police vehicles. Such real-world collision data is rarely available to researchers, and thus many of the incidents for which high resolution collision data will become available have the potential to provide new insights which could benefit the quality and depth of road safety research.

The first aim of this study was to investigate the potential benefits for this data within various research areas across TRL. The second aim of the study was to select a sample of incidents where there was sufficient information to allow them to be reconstructed, using theoretical reconstruction techniques and compare the results with the data captured by the UDS system.

The high resolution dataset from real world collisions is not typically available to researchers. Data from selected incidents, was passed to researchers in biomechanics, crash analysis, vehicle safety systems and behavioural change.

The database created for this study was populated with about 200 cases, and additional data was obtained from the Metropolitan Police to append to most of these cases to provide more detail on the incidents. The database is searchable for a variety of collision types, speed range, damage location etc., although it is restricted in the number of particular incident types due to the initial constraints imposed by TRL in requesting the data from the Metropolitan Police. Through work funded in this project, the Metropolitan Police’s own incident database can be more readily accessed by the Police to provide further cases in specified areas of interest, and a short amount of further work would enable this process to be automated. This capability would be of significant benefit to future research work.

Several of the research disciplines identified above have previously had access to data recorded from staged collisions or vehicle handling tests, utilising expensive test apparatus to measure data at a higher resolution than that which is recorded on the UDS system. These staged collisions provide highly detailed information on the injury risk to occupants in relation to the developing crash pulse.

However, staged collisions are expensive and, therefore, are often limited in number or are conducted with older vehicles, which may or may not represent the crash performance of more modern vehicles. The IDR acceleration data from a real-world collisions, together with further information relating to the damage to the vehicles and the injuries sustained by the occupants has the potential to offer a better understanding of a greater proportion of the vehicle and occupant/pedestrian population.

Each research area identified immediate research applications that would benefit from the IDR data and the associated information already held. In the field of biomechanics, a simple comparison of the IDR delta v with the photographs of the damage to the vehicles was seen to be an important information source to challenge methods often used by other EU nations. The variability of visible damage for a similar delta v would highlight the shortcomings of such a methodology.

In crash analysis, research is often undertaken comparing a particular type of injury with the delta v of a vehicle. In order to calculate the delta v, software tools such as CRASH3 are used, where the user inputs information relating to the damage sustained by the vehicles, and the computer program calculates the delta v based on the user inputs and stiffness coefficients. The IDR data, together with access to the damaged vehicles,
would allow the accuracy of the method, and current stiffness coefficients to be established.

With the development of active vehicle safety systems, such as ABS, ESC and BAS, both the evidence necessary for effective collision investigation (using tyre marks, for example) and the reliability of traditional assumptions relating to braking characteristics have been eroded. The IDR data, together with additional information regarding the circumstances of the collision can be used to determine the effectiveness and refine the accuracy of established methods. IDR data could be used to develop new or refine current collision investigation methods, which would be of benefit to both the accuracy of in-depth research (and hence the quality of research findings) and to all UK police forces in the investigation of serious and fatal collisions.

Prior to the collision, the UDS data records about 30 seconds of speed and acceleration data, which together with brake application signal can offer an understanding of how the driver was driving in the moments before the collision. The IDR system does not record the intervention of active safety systems such as ABS and Electronic Stability Control (ESC); however, with some knowledge of whether these systems were fitted or not could allow researchers to assess the potential benefits of a variety of active safety systems.

Initial discussions with the Metropolitan Police and representatives of the Police Federation have been positive in relation to the potential for securing access to additional occupant injury information, subject to the appropriate procedures being implemented. TRL regularly works within strict ethical guidelines to link injuries to collision severity and injury mechanisms in its research programmes, and therefore fully appreciates that provision of any information needs to be on an entirely voluntarily basis, with appropriate protocols and agreements in place between relevant stakeholders.

Accident investigators tend to have to rely on physical evidence, generally in the form of marks on the road surface, participant rest position and damage to reconstruct an incident. Vary rarely will there be any electronic data stored by a vehicle that the investigator can successfully access. With physical evidence, such as tyre marks, becoming less commonplace at incident scenes, investigators often have to rely on less well evaluated methods to try and establish the speed of a vehicle, or find themselves unable to make any determination of speed. In this study, some of these less well established methods were explored.

The theoretical reconstruction assessment demonstrated that provided reasonable ranges were used for the unknown parameters, that it was possible to determine a range of vehicle speeds and/or changes in velocity that encompassed the IDR data values. However, importantly, the IDR data provided actual values (or a means for calculating the values) for some of the unknown parameters that had to be estimated in the theoretical techniques. When this was done it was found that the actual values could fall outside of the range used in the theoretical reconstruction. In one case it was only through a combination of imprecise ranges for more than one of the unknown parameters that a result was calculated that encompassed the IDR values. This occurred, in particular, when an assessment was required for estimating the equivalent barrier speed for the damage sustained by a vehicle and using an appropriate coefficient of restitution.

The comparison of theoretical techniques, and in particular the pedestrian reconstructions, has assisted in evaluating some of the less established techniques, and in this limited assessment it was found that speed estimates from the damage location on the vehicle always underestimated the actual speed of the vehicle, which is in keeping
with the work of Dettinger. It would appear that the current approach to using this data could result in estimated impact speeds being less than the actual impact speed.

Computer visualisation software could provide a useful tool in visualising the vehicle movement up to the point of impact, the collision itself and the vehicle’s post impact motion. However, this would only provide a visualisation of the IDR equipped vehicle. Further simulation would be required to draw conclusions relating to the motion of other involved vehicles. Simulation software would allow the movement (the speed, path and orientation) of the IDR vehicle to be modelled accurately up to the point of impact with the other vehicle. At this point, the model could be run as a simulation, with the IDR vehicle striking the other vehicle. The post impact motion of both vehicles could be assessed in relation to the other evidence (photographs) or the visualisation of the IDR vehicle to rest. The characteristics of the other vehicle (speed, direction, mass etc.) could be varied until the post impact rest positions are consistent.
8 Recommendations

The following lists of recommendations were identified by the four research areas to explore the suitability of the IDR data and potential future research applications:

Biomechanics

- Evaluate the quality of the IDR collision pulse and delta-v data against known CFC_180 crash tests;
- Examine the increased thorax injury risk in sub-NCAP energy collisions;
- Examine user diversity injury patterns and issues;
- Compile IDR collision pulse data on real world low speed impact cases to compare with Folksam data;
- Provide reference data and photographs for delta-v estimation
- Link collision pulse data to occupant injury to better understand the characteristics of low speed injury incidents, including collision pulse and user diversity issues.
- Acquire an IDR device to be fitted to test various test equipment to provide benchmark comparisons between high resolution ‘research’ collision data and real world IDR data.

Crash Analysis

- Undertake highly detailed investigations into real world road traffic incidents involving personal injury. Such in-depth investigations, utilising the high resolution driving and collision data has the potential enhance our understanding of injury mechanisms through a more precise understanding of the circumstances of crashes.
- Application of the IDR data in the assessment and understanding of rollover incidents and hence mechanisms of occupant injury.
- Calculations of delta v from vehicle crush measurement (of the Police and third party vehicle) can be compared to and validated against IDR data in order to gain a better understanding of the accuracy of CRASH3 delta v calculations, and the accuracy of various approaches to the use of stiffness coefficients.
- Develop further collision reconstruction methods, which would benefit the investigation of cases in which vehicles are not equipped with IDR devices, including the reconstruction of cases for in-depth research and litigation.

Vehicle Safety Systems

- Determine whether the 16Hz data provided, leading up to a collision, would permit detailed analysis of the vehicle movement;
- Assess the influence of electronic stability control and brake assist systems on incident scenarios, and through the assessment of a number of case studies, identify trends in incidents involving vehicles equipped or not equipped with certain safety systems. Such projects would be of value to policy makers in respect of providing independent evidence as to the effectiveness of such safety systems.

Behaviour Changes

- Compare the accuracy of driver and passenger self-reports in relation to the circumstances of incidents.
• Compare incidents involving ‘fault’ and ‘non fault’ driving for the purpose of identifying driver indicators which correlate more strongly to ‘fault’ or ‘non fault’ incidents.

• Develop a database which would allow cross correlation of driving styles between different drivers and vehicles

• The use of demographic data relating to drivers to investigate links between demographics and driving styles.
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References


World Wide Web

A.1 Reconstruction 1 – Fatal Incident between a Police Car and Pedestrian

Collision Evidence

The collision happened at a traffic light controlled crossroad junction, and the police vehicle was travelling up hill towards the junction. The collision occurred on the opposite side of the junction on a level section of road. It is understood that the pedestrian may have been standing in the road. It was a clear, dry night, and the road surface was dry. The speed limit was 30 mph.

As a result of the collision, an adult female pedestrian sustained fatal injuries.

The police vehicle was responding to an emergency late at night. At the time of the incident it was operating flashing blue lights and rear red lights; however the siren was not in use.

The photograph below shows the damage sustained by the police vehicle. This was concentrated around the front offside corner. There were some marks across the bonnet leading towards the windscreen. The windscreen had been shattered at what appeared to be two locations, one at its base and the other near the roof line. The damage to the offside door mirror suggests that part of the pedestrian may have moved along the side of the car.

Police Investigation

At the scene of the incident, the police were able to identify tyre marks, collision debris and the rest positions of both the pedestrian and the police car. The locations of these were measured and a scene plan prepared, a section of which is included below.

The scene plan shows there to be tyre marks across the junction which lead to an area of debris. Beyond the debris, the marks cease for a short distance, before the presence
of a single mark, which again ceases prior to the rest position of the car. It is believed that the vehicle involved was equipped with Anti-Lock Brakes (ABS).

Theoretical Reconstruction Methods

In pedestrian-vehicle collisions, there are a number of reconstruction methods that can be used which will provide a speed estimate for the vehicle to varying accuracies. In order of potential accuracy, these are: Speed from tyre marks, speed from pedestrian throw, height of damage on the vehicle, the amount of damage to the vehicle and the injuries sustained by the pedestrian.

The damage to the vehicle in this case suggests that the pedestrian was stationary or had been moving slowly across the path of the vehicle at impact.

Speed from tyre marks

Typically, ABS vehicles not tend to leave clear tyre marks when the vehicle is undergoing emergency braking. However, the tyre marks noted at the scene were undoubtedly related to the police vehicle. If the car braked continuously at an emergency braking level of 0.6 to 0.8g from the start of the tyre mark, through to its rest position, then its speed at the start of the tyre marks would have been about 65 to 75 mph.

A study by Hague and Lambourn\(^1\), using non ABS equipped vehicles, showed that vehicles tended to lose speed before the first instance of visible tyre marks on the road. The results showed that there was some speed dependency, but typically calculations of

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speed loss from skid marks underestimated that actual vehicle speed by about 2 to 4 mph. Therefore, accounting for this, the approach speed range would have been 67 to 79 mph.

If the impact with the pedestrian is assumed to have been at the location of the debris (about 35 metres after the start of the tyre mark), then the impact speed would have been about 47 to 54 mph.

The above calculations would only be valid under the assumption that maximum braking was applied from the start of the tyre marks through to rest.

If the same analysis is performed for just maximum braking over the visible tyre marks, the speeds at the onset of the marks would have been 49 to 57 mph, but the impact speed would have been very low indeed and inconsistent with the other evidence.

Pedestrian Throw Methods

The police did not identify a point of impact on the road between the pedestrian and the car. However, in these collisions the debris tends to move forwards in the direction of the vehicle after impact, coming to rest on the road surface beyond the collision area.

If the start of the debris field was used at the impact location, then the pedestrian would have been thrown 27 metres. For pedestrian throw methods to be valid, the vehicle must be braking heavily at impact, and the collision cannot be a glancing blow. The vehicle was clearly braking heavily prior to the debris field; however, there is the possibility, given the damage to the car, that the pedestrian did not fully wrap around the front end.

There are a number of formulae that can be used to determine the impact speed based on the throw distance of the pedestrian. The methods of Searle\(^2\) and Smith and Evans\(^3\) have been used below.

Searle: This method calculates a range of speed for the pedestrian as they leave the vehicle, and would therefore tend to be less than the actual speed of the vehicle. The speed calculated by this method is in the range of 35 to 43 mph.

Smith and Evans: This method calculates a range of speeds for the car at the point of impact. The speed calculated by this method is in the range of 37 to 46 mph.

Speed from Damage Location

There are a number of studies which assess the location of the head contact of a pedestrian on the vehicle with regards to the speed of the vehicle.

Toor et al.\(^4\) provide a table of vehicle speed ranges together with a description of the head impact location. The descriptions are given based on the relationship between the pedestrian’s centre of gravity and the height of the vehicle front end. The average height of a female person in the UK is about 1.62 metres (in the range of 1.51 to 1.73 for the 5\(^{th}\) to 95\(^{th}\) percentiles). The leading edge of the Police car is about 0.75 metres above the ground. Therefore, the minimum speed for the car based on the head striking the lower edge of the windscreen is about 31 to 37 mph, while for the head strike close to the roof of the vehicle; the speed would be around 37 to 43 mph.

\(^3\) Smith, R and Evans, A, Pedestrian Throw Calculations, IMPACT, Spring 2000.
Dettinger\(^5\) related the standing height of the pedestrian to the wrap around distance to the head contact. The relationship derived was based on impact testing of various vehicles. This relationship ensures that the impact speeds calculated would be less than that found in the testing. Based on the average height of an adult female, the different in height compared to the head impact location would be 0.23 or 0.82 metre. This results in a wide range for the impact speed of around 22 to 41 mph.

**High Resolution Data from the IDR**

The graphs below were downloaded from the data recorder on the vehicle involved.

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**Acceleration Data**

In this incident, the IDR system triggered due to the level of deceleration achieved by the vehicle prior to the collision, capturing the impact with the pedestrian in the high resolution area.

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The vehicle speed trace in this incident was not reliable due to both the activation of the ABS and the nature of the road surface, which caused the wheels to skip. If the wheel speed of the vehicle does not equal the actual vehicle speed, then the speed data in the IDR file cannot be used with certainty. Instead, the acceleration data should be used.

Prior to the onset of emergency braking, the vehicle was travelling at a speed of 73 mph. As defined by the spike in the longitudinal acceleration data, the speed of the vehicle at impact was 52 mph.

The IDR data can also be used to reposition the vehicle at the various points on the approach to the collision. The point of application of emergency braking and the impact location are shown on the figure below.

Comparison of Results

In the theoretical reconstructions, the speed calculated from tyre marks is generally the most reliable. In this incident, emergency braking from the start of the tyre marks to rest indicated an approach speed of 67 to 79 mph, and an impact speed of 47 to 54 mph. These relate well with the IDR data.

These theoretical techniques have to rely on the physical evidence. It can be seen that emergency braking was applied about 15 metres before the tyre marks commences, and the collision occurred about 8 metres prior to the start of the debris field.

The other two methods alone cannot determine the approach speed for the vehicle. However, the estimates for the speed at impact using pedestrian throw are over a wide range, which is less than the actual impact speed. This could be due to the possibility that the collision was partially glancing but it should be remembered that the physical evidence only allows the calculations to use a throw distance which was 8 metres less than shown by the IDR data. Accounting for the additional 8 metres results in a speed range of 40 to 49 mph from Searle, and 42 to 52 mph from Smith and Evans.

In theoretical reconstruction techniques, where there is glass debris on the road, reconstructionists sometime try to estimate the impact location based on an approximate speed for the car and the time it takes for the glass to fall to the road surface. For example, if the glass debris in this incident was from the headlamp unit (about 0.6 metre above the road) it would take about 0.35 second to fall to the road. If the car was travelling at 50 mph the glass would travel about 7.8 metres forward of the impact location. If the glass was from the base of the windscreen (about 1 metre above the road)
ground), it would take 0.45 second to hit the ground and the impact would have been about 8.8 metres before the glass debris.

The speed estimates from damage location appear much less reliable, although they still result in impact speeds less than the actual speed. The range is much greater as well, as the additional unknowns relating to the collision need to be assessed.

The research by Toor et al. does not distinguish between vehicle sizes, and requires knowledge of the pedestrian’s height and centre of gravity. By estimating these, ranges of speeds can be made; however, if the head impact location is not clear, there can be a vast difference in the calculated vehicle impact speed.

The Dettinger study relates the pedestrian height to the vehicle size to give an impact speed. A relationship line drawn on the figure used always gives an impact speed which is less than was found in the testing, and should therefore be an underestimate of the actual speed. However, as with the Toor study, if the height of the pedestrian and head impact location are not known, a very wide speed range is found.

An interesting factor to emerge from the IDR data was the change in the deceleration of the vehicle throughout the incident. Prior to impact, its average deceleration was about 0.75g, then for 1.6 seconds after the collision, this increased to an average of about 0.85g. Following this, the deceleration dropped to an average of about 0.25g until the vehicle stopped. By assessing an average deceleration over the whole distance, the theoretical technique resulted in a reasonable estimate; however, this is due to underestimating part of deceleration and overestimating another. Such a method can generally only be used to determine a maximum speed for the vehicle.

The IDR data also shows some other interesting features. There were two distinctive peaks in the longitudinal acceleration of the data, and given the speed of the vehicle and the timing between the peaks, they most likely represent the initial contact with the pedestrian’s legs and a further contact with the head/shoulders. The timing between these is consistent with simulation work.
A.2 Reconstruction 2 – Low Velocity Rear Impact between two Police Vehicles

Collision Evidence

The two police vehicles were travelling in convoy, utilising blue lights and sirens. They both approached and entered a roundabout; however, there was congestion on the exit to the roundabout, and the leading vehicle braked to avoid other traffic. The following vehicle braked but was unable to stop before coming into contact with the rear of vehicle 1. Both of the vehicles were driven off the roundabout and onto a side road.

It was a clear, dry day, and the road surface was dry. The speed limit at the site of the incident was 40 mph.

The photographs below show the damage sustained by the two unmarked police vehicles.

The Ford Galaxy, which was the lead vehicle, appears to show only a light scratch mark to the rear offside corner of the bumper. The spare wheel is on the ground, but since the vehicle was driven away from the site of the collision and onto a side road, it is not clear if this spare wheel fell at the point of impact and was subsequently moved next to the vehicle, whether it was dragged by the vehicle to this point, or whether it became detached sometime after the incident.

The BMW shows more extensive damage to the front end; however, the majority of this damage is above the level of its bumper, indicating a degree of under-riding. The bonnet, grille and headlights are all weaker structures of a vehicle and will show more damage than if the contact had been with the stiff bumper structure.

Police Investigation

There was no information regarding injuries sustained by any of the occupants of these vehicles and there was no Police Collision Investigation undertaken. The matter was dealt with internally using the data stored on the IDR. There is therefore no further Police information available to assist with a theoretical reconstruction.
Theoretical Reconstruction Methods

In relatively low velocity collisions such as this, the methods often utilised to determine travel speeds and/or the change in velocity in the collision are based on the fundamental laws of physics, and in particular the laws of Conservation of Momentum and Conservation of Energy.

The typical methodology adopted requires evidence of the vehicles’ movements following the collision to allow the immediate post impact speeds of each to be determined. In this instance there is no evidence to allow the post impact speed to be established. Therefore, the theoretical reconstruction method will only allow the change in velocity of each vehicle to be determined.

Equivalent Energy Speed

The first step in an investigation such as this is to make an estimate of the damage energy for each vehicle. This is generally not done based on an assessment of the two vehicles together, but on an assessment of how fast the expert believes the same vehicle would need to be travelling in order to sustain the same level of damage if it struck a rigid barrier. This speed is called the Equivalent Energy Speed (EES), or Equivalent Barrier Speed (EBS).

The images of the vehicles were showed to a number of experts. The consensus was that the EES for the Ford Galaxy would have been about 5 to 10 mph and for the BMW it would have been 10 to 15 mph.

Damage Energy

With knowledge of the masses of the vehicles and their EESs, it is possible to calculate a range of energy that was required to damage the vehicles.

The kerb weight of a Ford Galaxy of this model is 1724 kg and for a BMW 3 series it is 1490 kg. The number of occupants in each vehicle is not known, neither was the amount of equipment being carried. Therefore 100 kg was added to the mass of each vehicle to account for this.

Therefore, the damage energy of the Ford Galaxy is likely to have been in the range of 4.6 kJ to 18.2 kJ. The damage energy of the BMW is likely to have been in the range of 15.9 kJ to 35.7 kJ.

Coefficient of Restitution

The coefficient of restitution is the degree of ‘bounce’ or elasticity in a collision. The coefficient of restitution is the ratio of the separation speed to the closing speed of the two colliding bodies. In a perfectly elastic collision, the value of the coefficient is 1, meaning that the separation speed equals the closing speed.

In a perfectly plastic collision, all of the damage is permanent and the two bodies move together following the collision. In this scenario, the value of the coefficient is zero and so is the separation speed of the bodies.

A real collision lies somewhere between the two, and generally the lower the closing velocity between two vehicles the higher the restitution value.
From impact testing, it has known that for any given closing speed, the value of restitution lies within a range. The range is wider for lower closing speeds and narrower for high closing speeds. Without first knowing the range of closing speeds, it is not possible to identify a suitable range for the coefficient of restitution.

However, based on the circumstances of the incident it is unlikely that that there would have been a closing speed in excess of about 12.5 mph. Therefore values in the range of 0.1 to 0.45 would be reasonable.

The value of restitution is used in the calculations for delta v.

**Change in Velocity due to the Collision – delta v (ΔV)**

In the absence of knowing a closing speed for the vehicles, it is possible to calculate the delta v for each vehicle based on the masses, restitution and damage energy.

\[
\Delta V_1 = \frac{2m_2(E_1 + E_2)(1 + \varepsilon)}{m_1(m_1 + m_2)(1 - \varepsilon)}
\]

\[
\Delta V_2 = \frac{2m_1(E_1 + E_2)(1 + \varepsilon)}{m_2(m_1 + m_2)(1 - \varepsilon)}
\]

where \(\Delta V_1\) is the change in velocity of the BMW, \(\Delta V_2\) is the change in velocity of the Ford Galaxy, \(m_1\) is the mass of the BMW and \(m_2\) the mass of the Ford.

Therefore:

\(\Delta V_1 = 9.2\) to \(21.9\) mph, and \(\Delta V_2 = 8.0\) to \(19.1\) mph

**Effect of Vehicle Braking**

The evidence is that the BMW was braking at impact; however, it is unknown from the physical evidence whether the Galaxy was also braking at impact. In higher speed collisions, external forces acting on a system are generally low compared to the forces of the collision itself, and therefore they are generally negligible. However, in lower speed collisions, tyre forces from emergency braking can no longer be neglected as they can influence the calculation of Delta V.

The braking forces acting over a period of time result in an impulse to the vehicle(s). The law of conservation of linear momentum relates to a closed system whereby the momentum before a collision equals the momentum after the collision. Braking forces by one or more of the vehicles during the collision is external to the closed system.

Therefore, in low velocity collisions where braking is considered, the difference in the momentum before and after the collision is equal to the impulse created by the external tyre forces.

The following two equations account for braking in the delta v analysis.

\[
\Delta V_2 = \frac{2m_2(E_1 + E_2)(1 + \varepsilon)}{m_1(m_1 + m_2)(1 - \varepsilon)} + \left(\frac{\sum F_{braking} \Delta t}{m_2}\right)
\]
The complication in this assessment is that braking can affect the collision duration and therefore the coefficient of restitution. For this analysis, the impact duration has been assumed to be 0.2 seconds and the restitution range remains 0.10 to 0.45.

Using the same data as before, with a braking rate of 0.7g, the delta v’s are:

**BMW only braking:**
\[ \Delta v = 10.6 \text{ to } 23.3 \text{ mph}, \text{ and } \Delta v = 6.6 \text{ to } 17.6 \text{ mph} \]

**Both vehicles braking:**
\[ \Delta v = 12.2 \text{ to } 24.9 \text{ mph}, \text{ and } \Delta v = 4.9 \text{ to } 16.0 \text{ mph} \]

If the collision duration is set higher, \( \Delta v \) increases, while \( t \) decreases. If the maximum restitution is lowered from 0.45, the upper end of the delta v range reduces.

**High Resolution Data from the IDR**

The graphs below were downloaded from the data recorders of the two vehicles.

**BMW 3 Series**

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Ford Galaxy

In this incident, the IDR systems of both vehicles triggered due to the level of
deceleration achieved by the vehicles in the collision, therefore capturing the details of
the impact in the high resolution area.

Analysing the IDR data determined the following:

<table>
<thead>
<tr>
<th></th>
<th>BMW 3-Series</th>
<th>Ford Galaxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Impact Speed (mph)</td>
<td>18.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Pre Impact Braking (g)</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Delta V (mph)</td>
<td>11.9</td>
<td>7.4</td>
</tr>
<tr>
<td>Collision Duration (ms)</td>
<td>176</td>
<td>125</td>
</tr>
<tr>
<td>Post Impact Speed (mph)</td>
<td>6.7</td>
<td>14.1</td>
</tr>
</tbody>
</table>
Comparison of Results

In the theoretical analysis it was not known if both vehicles, or just the BMW, were braking at the point of impact. Therefore, using the range of equivalent barrier speeds for each vehicle for both braking conditions resulted in a range of delta v’s for the BMW as 10.6 to 24.9 mph and for the Ford Galaxy as 4.9 to 17.6 mph. This compares to 11.9 mph and 7.4 mph from the IDR recordings. Therefore the actual speeds fall within the range calculated by theoretical methods, albeit towards the lower end.

The vehicle masses used in the theoretical calculations were based on estimates; however, analysing the momentum equations, with a braking impulse from the BMW, results in a mass ratio \( \frac{m_1}{m_2} \) of about 0.8. The masses used result in ratio of 0.87. To achieve the ratio based on the IDR data either the mass of the Galaxy would need to increase or the BMW to decrease.

With knowledge of the closing velocity and separation velocity, it is also possible to calculate the coefficient of restitution. This was calculated to be 0.56, and somewhat greater than in the theoretical assessment.

Using a known mass ratio, a restitution of 0.56 and the same equivalent barrier speeds as before for the energy, it is possible to re-run the analysis to determine the delta v of each vehicle. These were found to be:

\[ \Delta v_1 = 17.5 \text{ to } 27.6 \text{ mph}, \quad \Delta v_2 = 11.5 \text{ to } 19.6 \text{ mph} \]

These delta v’s are now considerably greater than those of the actual collision. The only unknowns in the equations used are the equivalent barrier speeds that were used to generate the crush energy. It appears therefore that the assumed ranges of the two equivalent barrier speeds were too high but, in combination with low restitution values, a reasonable range for the delta v’s was nevertheless fortuitously calculated. Reducing the estimated values for the equivalent barrier speeds results in calculations of delta v that are more consistent with IDR data from the actual collision.
A.3 Reconstruction 3 – Serious Incident between a Police Car and Pedestrian

Collision Evidence

The collision occurred on a section of dual carriageway with an east to west orientation. Approaching the collision location, which was at or close to the location of a pedestrian crossing, the westbound carriageway was three lanes wide, with the nearside lane a bus lane. Just beyond the pedestrian crossing was a junction to the south with a minor road, and at about this location the two lanes for all traffic filtered into one. The road surface of the bus lane was constructed of a high friction material.

It was a clear, dry night, and the road surface was dry. The speed limit was 30 mph.

It is not known whether the police car went through a red light at the crossing.

As a result of the collision, an adult male pedestrian, in his mid twenties, sustained serious injuries.

The photograph below shows the damage sustained by the police vehicle. This included damage to the leading edge of the bonnet, just to the nearside of the manufacturer’s badge. There were cleaning marks extending rearwards across the bonnet and towards the nearside. The windscreen was smashed approximately a third of the way in from the nearside edge, and about a quarter of the way up from the base of the screen.
Police Investigation

At the scene of the incident, the police were able to identify tyre marks within the bus lane, which commenced before the pedestrian crossing and extended through and beyond the crossing to the rest position of the vehicle. The pedestrian came to rest a short distance further along the road, in the junction mouth of a road to the south. The locations of these were measured and a scene plan prepared, a section of which is included below.

The scene plan shows there to be tyre marks across the pedestrian crossing, which led towards the rest position of the Police car. The pedestrian came to rest a short distance further along the road and to the nearside of the Police car. The vehicle involved was equipped with Anti-Lock Brakes (ABS).

Theoretical Reconstruction Methods

The damage to the vehicle suggests that the pedestrian was moving from the driver’s offside to nearside, and, based on the damage offset and pedestrian rest position, was probably moving quickly.

Speed from tyre marks

Typically, ABS vehicles tend not to leave clear tyre marks when the vehicle is undergoing emergency braking. However, the tyre marks were clear in the Police photographs and can be seen to be related to the police vehicle. They were predominantly on the high friction road surface.

It is not clear whether the tyre marks cease just to the rear of the Police car, or whether they extend to the location of the front tyres. Therefore distances of 21.4 and 25.3 metres have been used to assess the pre-braking speed of the car.

If the car braked continuously at an emergency braking level of 0.7 to 0.9 g from the start of the tyre mark through to its rest position, then its speed at the start of the tyre marks would have been about 41 to 47 mph.

A study by Hague and Lambourn⁶, using non ABS equipped vehicles, showed that vehicles tended to lose speed before the first instance of visible tyre marks on the road. The results showed that there was some speed dependency, but typically calculations of

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speed loss from skid marks under estimated that actual vehicle speed by about 2 to 4 mph. Therefore, accounting for this, the approach speed range would have been **43 to 51 mph**.

If the vehicle only braked over the visible distance of the tyre marks, then its speed at the start of the tyre marks would have been about **38 to 44 mph**.

If the pedestrian involved in the collision was using the pedestrian crossing, then the positions of the pedestrian guardrail fences are likely to have restricted him to the crossing area. Using the two extremes of the pedestrian crossing as the impact point and also the two locations for the end of braking by the police car, gives impact to rest distances of 13 to 17.5 metres based on the rest position of the car, or 9 to 13.5 metres based on the last tyre mark.

This gives impact speed of **30 to 40 mph** if the vehicle braked fully to its rest position, or **25 to 35 mph** if the vehicle braked to the end of the visible tyre marks.

**Pedestrian Throw Methods**

The police did not identify a point of impact on the road between the pedestrian and the car. However, it appears that the pedestrian used the crossing, and therefore the limits of the crossing provide a range of possible impact locations along the road. The width of the crossing was about 4.5 metres and this will result in a wide range of possible speeds for the vehicle.

The pedestrian throw distance would have been in the range of 18.5 metres to 23.0 metres. For pedestrian throw methods to be valid, the vehicle must be braking heavily at impact, and the collision cannot be a glancing blow. The vehicle is clearly braking heavily prior to the collision and the damage to the vehicle suggests it was a fully overlapping collision.

Searle: This method calculates a range of speed for the pedestrian as they leave the vehicle, and would therefore tend to be less than the actual speed of the vehicle. The speed calculated by this method is in the range of **29 to 36 mph** if the pedestrian was struck at the west side of the crossing or **32 to 40 mph** if they were struck to the east side of the crossing.

Smith and Evans: This method calculates a range of speeds for the car at the point of impact. The speed calculated by this method is in the range of **29 to 40 mph** if the pedestrian was struck at the west side of the crossing or **33 to 44 mph** if they were struck to the east side of the crossing.

As expected, since the Smith and Evans formula calculates the speed of the car, the speed ranges are a little greater than those calculated using the Searle equations.

**Speed from Damage Location**

There are a number of studies which assess the location of the head contact of a pedestrian on the vehicle with regards to the speed of the vehicle.
The average height of a male person in the UK is about 1.76 metres (in the range of 1.64 to 1.87 for the 5th to 95th percentiles). The leading edge of the Police car is about 0.75 metre above the ground. Therefore, using the study of Toor et al., the minimum speed for the car based on the head striking the lower edge of the windscreen is about 25 to 34 mph.

Using the Dettinger study, and based on the average height of an adult male, the difference in height compared to the head impact location would be about 0.52 m, resulting an impact speed measured from the graph as 50 km/h, or 31 mph.

**Time and Motion**

Based on the location of the tyre marks, the damage to the vehicle and the post impact rest position of the pedestrian, it appears that the male ran 6.8 metres across the road to impact. The average running speed of 166 males in their twenties was 4.2 m/s. This means that the pedestrian would have been in the road for about 1.6 seconds.

For a Police vehicle travelling through a pedestrian crossing it is reasonable to expect the driver to react in a time of 0.75 to 1.5 seconds and perhaps towards the lower end of this range. This means that some braking should have been possible before the collision.

The speed assessment shows that the vehicle was probably travelling at a speed in the range of 38 to 51 mph. For a vehicle braking at 0.7 to 0.9g, from the start of the tyre marks to the point of impact, this would take between 0.4 and 0.5 second. These times could increase slightly to account for the braking that was applied before the visible tyre marks appeared. The Hague and Lambourn study suggests that a test driver can normally skid a car between 0.10 and 0.15 after applying the brakes, thus increasing the braking time to 0.50 to 0.65 second. It therefore appears that the driver reacted within the expect time range.

If the police car were to have been travelling at 30 mph instead of 38 mph at the onset of braking, it is possible to assess whether the collision may have been avoidable. With

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7 Eubanks, J and Hill PF, Pedestrian Accident Reconstruction and Litigation. 2nd Edition, 1998. Lawyers and Judges Publishing Co. US. Table 3.21
a 1 second reaction time, the police car would have been 24.8 to 29.3 metres from impact when the driver reacted at 38 mph. The braking distance from 30 mph is 13.1 metres with a deceleration of 0.7g. The total stopping distance with a reaction time of 1 second is 26.5 metres. Therefore, had the Police car been travelling at the speed limit it is possible it could have stopped before impact. However, even when it was not possible to stop before reaching the collision location, the time it would take to reach that point from reacting, 2.8 seconds, would allow the pedestrian a further 1.2 seconds to clear the path of the vehicle.

High Resolution Data from the IDR

The graphs below were downloaded from the data recorder on the vehicle involved.

In this incident, the IDR system triggered due to the level of deceleration achieved by the vehicle prior to the collision, capturing the impact with the pedestrian in the high resolution area.

At the point of emergency braking, the police vehicle was travelling at 49.5 mph. The vehicle was braked for 0.64 second before impact, averaging a deceleration of 6.76 m/s² (or 0.69g) including the time to full brake application and a rate of 10.6 m/s² (1.1g) once full braking was achieved.

The vehicle was travelling at a speed of 39.6 mph at impact, and following the collision, braked at an average deceleration of 10.4 m/s² (1.1g) for 1.65 seconds through to its rest position.

A calculation was also undertaken to establish whether it was possible to determine a speed loss on the car due to the impact with the pedestrian. This was calculated to be a little under 1 mph.

Using the above data, the distance that the car moved post impact was 15 metres, and the distance covered braking before impact was 13 metres. The impact point was therefore at about the middle of the crossing.
Comparison of Results

In the theoretical reconstructions, the speed calculated from tyre marks is generally the most reliable. In this incident, emergency braking from the start of the tyre marks to rest indicated an approach speed of 41 to 47 mph, and an impact speed of 30 to 40 mph, assuming the vehicle braked fully to its rest position. Accounting for the speed loss prior to the visible tyre marks, this speed would be in the range of 43 to 51 mph. The IDR data showed these to be 49.5 mph and 39.6 mph respectively. Therefore, the theoretical methods approximate the impact conditions well.

The range of decelerations used was generally towards the low side of what the vehicle achieved, although the average deceleration of the vehicle to the point of impact was less than the lower end of the range considered. However, this average deceleration was over a distance greater than that indicated by the tyre marks. The range utilised in the theoretical reconstruction would have been suitable over the visible tyre mark leading to the point of impact. It would appear though that the vehicle was still approaching peak deceleration when the initial tyre marks were produced.

The impact speed range calculated from the tyre marks and the crossing locations encompassed the actual impact speed; however, this required the impact to have occurred at the eastern extent of the crossing, which was not the case. The reason for the theoretical method’s shortcoming was in the range of deceleration used, which underestimated the actual deceleration, post impact by more than 0.1g.

The pedestrian throw calculations were based on the two extremes of the crossing location and resulted in speeds of 29 to 40 mph (Searle’s estimate of the pedestrian’s speed) and 29 to 44 mph (Smith and Evans). The actual impact speed falls within these ranges, and accounting for Searle’s method giving the speed of the pedestrian and not the car, shows that the theoretical methods provide a suitable range of impact speeds. If the actual impact point is used instead, the equations give impact speeds of 30 to 38 mph (Searle) and 31 to 41 mph (Smith and Evans), again with the Searle equation providing a slight underestimate, in part due to the formula giving the pedestrian’s speed and also the possibility that the pedestrian slid some distance on the high friction surface.

The above speeds were calculated based on decelerations in the range of 0.7 to 0.9g and the impact occurring at either extreme of the pedestrian crossing.

Using the known impact location and the decelerations over the visible tyre marks results in a pre tyre mark speed of 48 mph, which would increase to about 50 to 52 mph to account for speed loss before the visible tyre mark.
The speed estimates from damage location appear much less reliable, although they still result in impact speeds less than the actual speed. The range is much greater as well, as the additional unknowns relating to the collision need to be assessed. The study by Toor et al. tends to generalise the head impact location based on the pedestrian’s centre of mass height above the leading edge of the bonnet, but there is a lot of overlap in the speed ranges.

The Dettinger study relates the difference in pedestrian height to the wrap around distance to the measured head impact location, based on two different shaped front end of car. A relationship line, drawn on the figure used, always gives an impact speed which is less than was found in the testing, and should therefore be an underestimate of the actual speed, although the measured speed of 31 mph is substantially less than the actual speed.

The theoretical calculations show the driver reacted in a reasonable time, braking about 0.5 to 0.65 second before the collision. The IDR data shows that the driver braked for a time that fell within this range.

The IDR data also shows some other interesting features. There were two distinctive peaks in the longitudinal acceleration of the data, and given the speed of the vehicle and the timing between the peaks, they most likely represent the initial contact with the pedestrian’s legs and a further contact with the head/shoulders. The timing between these is consistent with simulation work.
A.4 Reconstruction 4 - Side Impact Collision – Black Cab into offside of Police Car

Collision Evidence

The incident occurred about 02:30 hrs, with the weather being fine and dry and the road surface dry. The speed limit at the site of the incident was 30 mph.

There were two Police Officers travelling in the unmarked Ford Mondeo. The driver of the Mondeo became distracted on the approach to a cross roads junction and continued over the give-way lines onto the main road. A Black Cab travelling along the main road collided with the Mondeo. As a result of the collision, the Mondeo deviated towards the footpath on the opposite side of the junction, rotating and coming to rest against the wall. A small section of the wall was demolished by this impact. The taxi came to rest in contact with the Mondeo at its offside front corner.

The photographs below show the respective rest positions of the vehicles and the damage each sustained.

The Ford Mondeo shows extensive damage along its offside, centred around the B-Pillar. The roof was kinked just above the B-Pillar. There was slight damage to the front bumper close to its nearside corner, and some minor scratching and denting to the front passenger door.
The damage to the taxi was limited to its front, where there appeared to be relatively minor damage, consisting of scratches to the bumper and denting to the front panels. The front bumper was partially detached at both corners.

There appeared to be some intermittent tyre marks on the road surface, which could have indicated heavy braking or tyre scuffing as the vehicle(s) rotated to their respective rest positions.

**Police Investigation**

The injuries sustained by the occupants of the Mondeo and the driver of the taxi were minor, and the matter was dealt with internally using the data stored on the IDR.

**Theoretical Reconstruction Methods**

To assist with the reconstruction, the following scale plan of the incident area and vehicle rest positions has been used.

![Scale Plan of Incident Area and Vehicle Rest Positions](image)

The most useful method to reconstruct this incident is that of the Law of Conservation of Linear Momentum, where the information regarding the approach and departure angles, together with how the vehicles moved to their post impact rest positions, is used to determine their pre-impact speed.

**Conservation of Linear Momentum**

The first step to finding the approach speeds of the vehicles is to determine their post impact velocities. This is done by determining the distance over which each vehicle has moved and then applying an appropriate deceleration rate over that distance.

The photographs appear to show intermittent tyre marks on the road surface which appear to be curved and they are therefore likely to represent the post impact movement of one or both vehicles. Without any more information, it is not possible to determine whether the vehicles underwent emergency braking from impact to rest or whether they simply rotated across the road to rest. The latter of these would represent a lower deceleration.
The taxi does not appear to have rotated to any great degree and it has come to rest against the offside front of the Mondeo. This tends to suggest that the taxi was not slowing at a greater rate than the Mondeo, and may even have been slowed by the Mondeo. In the following analysis, it has been assumed both vehicles decelerated at the same rate, and a range of decelerations of 0.2 to 0.6g have been used.

Using the scale plan and approximate location of the tyre marks, and assuming neither driver attempted to steer to avoid the collision, the vehicles have been positioned at their likely location at impact. Measurements from impact to rest for both vehicles were made, with the Mondeo moving about 8.6 metres and the taxi 6.8 metres.

It is worth noting that the Mondeo partially knocked down a small wall, and therefore would have lost some speed during that contact.

Therefore, accounting for a speed loss due to the impact with the wall of 5 to 10 mph, the post impact speed for the Mondeo would have been 14 to 25 mph, and the post impact speed of the taxi would have been 11 to 20 mph. Once the post impact speed is known, each vehicle’s momentum can be calculated along the path from impact to rest using its mass. Vehicle references indicate that the mass of the Mondeo was about 1300 kg, and if both occupants were about 80 kg, its overall mass would have been about 1460 kg. Similarly, the taxi plus the driver would have been about 1880kg.

To enable momentum calculations to be made, the movement of each vehicle needs to be determined in two directions, at 90 degrees to each other, such as momentum to the north (Y) and momentum to the east (X). Therefore, the departure angles of each vehicle were also measured, these being 42 degrees (θ) for the Mondeo and 26 degrees (α) for the taxi.

Therefore, post impact, the momentum of a vehicle is the product of its mass and velocity in either X or Y directions.

**momentum in X**

\[ P_{\text{Mondeo}} = m_{\text{Mondeo}} \cdot V_{\text{Mondeo}} \cdot \sin \theta \]

\[ P_{\text{Taxi}} = m_{\text{Taxi}} \cdot V_{\text{Taxi}} \cdot \cos \alpha \]
momentum in Y

\[ P_{Y,\text{mondeo}} = m_{\text{mondeo}} \times v_{\text{mondeo},y} \sin \theta \]
\[ P_{Y,\text{taxi}} = m_{\text{taxi}} \times v_{\text{taxi},y} \sin \alpha \]

Using the speeds previously calculated, together with the vehicle masses and departure angles, the momentum can be calculated:

- \( P_{X,\text{mondeo}} = 7858 \text{ to } 12013 \text{ kg m/s} \)
- \( P_{X,\text{mondeo}} = 8728 \text{ to } 13342 \text{ kg m/s} \)
- \( P_{X,\text{taxi}} = 8728 \text{ to } 15118 \text{ kg m/s} \)
- \( P_{X,\text{taxi}} = 4257 \text{ to } 7374 \text{ kg m/s} \)

In a 90 degree collision such as this, all the movement in the X direction would have resulted from the pre impact movement of the taxi. Likewise, all of the movement in the Y direction would be due to the pre impact movement of the Mondeo.

Therefore, conserving momentum in each direction means:

momentum of Mondeo before impact = \( P_{Y,\text{mondeo}} + P_{X,\text{mondeo}} \)

and

momentum of the taxi before impact = \( P_{Y,\text{taxi}} + P_{X,\text{taxi}} \)

Substituting the post impact momentum in each equation and dividing by the mass of either the Mondeo or taxi, results on the pre-impact velocities to be:

- **Taxi** – 18 to 31 mph
- **Police Ford Mondeo** – 17 to 30 mph.

**Change in Velocity**

Both the post and pre impact velocities have been calculated, and it is therefore a simple calculation to determine the change in velocity for each vehicle. Initially the change in velocity is calculated separately for X and Y directions, and then it can be combined to calculate the total change in velocity.

**Taxi**

change in velocity in X = 7 to 13 mph
change in velocity in Y = 5 to 9 mph

**Total Change in velocity = 9 to 16 mph**

**Ford Mondeo**

change in velocity in X = 9 to 16 mph
change in velocity in Y = 7 to 11 mph
Total Change in velocity = 11 to 20 mph

**High Resolution Data from the IDR**

The graphs below were downloaded from the data recorder of the Mondeo.

**Comparison of Results**

Due to the spinning of the Police vehicle after the collision it was not possible to accurately assess its post impact retardation, and it was also not possible to determine the speed loss by the vehicle due to the contact with the wall. However, estimates for these of about 0.6g and 10 mph respectively were made. The speed loss due to the wall contact was twice the speed estimate in the theoretical method while the deceleration of 0.6g was at the upper end of the range.

The IDR data showed that the driver of the Police vehicle braked and steered to the left before the collision, and therefore the post impact movement and angle of each vehicle,
as well as the impact location might have been different to those shown in the reconstruction plan above.

However, using momentum analysis the speed of the Police car at the point of impact was determined to be in the range of 17 to 30 mph. This range was wide to encompass the unknown retardation of the vehicle from impact to rest. The IDR data showed the actual speed to be in this range, at 23 mph.

The change in velocity for the Police car was 9 to 16 mph in the X direction (the direction it was pushed by contact with the Taxi) and 7 to 11 mph in the Y direction, giving a total change in velocity of 11 to 20 mph. This compared with a change in velocity in the X direction of 19 mph in the Y direction of 6 mph and 20 mph overall from the IDR data.

To better understand the Police car movements before the incident, and the effect of the collision with the Taxi, the computer simulation tools which allow the IDR data to be visualised would greatly assist. This would allow the effect of any pre-impact steering by either or both vehicles to be determined and its effect on their post impact movement.
A.5 Reconstruction 5 – Low velocity head-on collision between two police vehicles

Collision Evidence

It is believed that the low velocity head-on collision between the two police vehicles occurred as one police vehicle correctly negotiated a roundabout and the second police vehicle attempted to perform a U-turn without using the roundabout. The driver of the vehicle undertaking the U-turn stated that as the turn was being performed, he lost grip of the steering wheel and continued straight on, thus colliding with the police vehicle coming around the roundabout. The two police vehicles involved in this collision were both Vauxhall Astras. To differentiate the two vehicles in this reconstruction the year of registration will be assigned to the respective vehicles. The vehicle which negotiated the roundabout correctly will be known (for the purposes of this reconstruction) as Astra06 and the vehicle which did not negotiate the roundabout correctly will be known as Astra55.

The sketch below shows the approximate area of the collision between the two vehicles. The two vehicles in the image show the approximate relative impact angle and overlap between the two vehicles; however, their position and orientation on the sketch of the road layout does not necessarily depict their exact position and orientation at impact.

The damage to Astra06 was concentrated around the front offside corner and consisted of damage to the front bumper, offside headlamp, front offside corner of the bonnet and offside corner of the bumper crossbeam. It is not possible to determine from the photographs if the damage to Astra06 comprised any lateral deformation of the lower rails.

The damage to Astra55 was located towards the front, at the nearside of the vehicle, in board of the nearside headlamp unit. The damage noted in the photograph suggests that a degree of overriding occurred during the collision, with Astra06 overriding Astra55. The damage to Astra55 was to the bumper cover, bonnet, headlamp, slam panel and associated components. With both vehicles being of the same make and
model it is surprising that under and overriding occurred as the structures should be aligned, however emergency braking or any change in the vehicle attitude due to the camber of the road on the roundabout could induce a difference in the vehicles’ heights.
Police Investigation

There is no information regarding injuries sustained by any of the occupants of these vehicles, and due to the low severity of the collision it is unlikely that any Police Collision Investigation was undertaken.

Theoretical Reconstruction Methods

The methods used here are based on on the fundamental laws of physics, and in particular the laws of Conservation of Momentum and Conservation of Energy.

The typical methodology adopted requires evidence of the vehicles’ movements following the collision to allow the immediate post impact speeds of each to be determined. In this instance there is no evidence to allow the post impact speeds to be established. Therefore, the theoretical reconstruction method will only allow the change in velocity of each vehicle to be determined.

Equivalent Energy Speed

The photographs of the vehicles were showed to a number of experts and it was determined that an estimate of the EES could be made for each vehicle. For Astra06 it was the consensus that the vehicle would need to have been travelling at a low velocity and thus the EES was estimated as 5mph. For Astra55 it was the consensus that the vehicle would need to travel at a faster speed into a barrier to cause the damage seen and therefore an EES was estimated at 10-15mph.

Damage Energy

With knowledge of the masses of the vehicles and their EES, it is possible to calculate a range of energy that was dissipated during the collision between the two vehicles.

The kerb weight of a Vauxhall Astra of this model type is approximately 1218 kg. It is not known how many occupants were in each vehicle or indeed the amount of equipment being carried. Therefore 150 kg was added to the kerb weight of each vehicle to account for the occupants and equipment.

Therefore, the damage energy of the Astra06 is likely to have been in the range of 0.14 kJ to 3.4 kJ (a speed range of 1-5mph was used for this vehicle). The damage energy of the Astra55 was likely to have been in the range of 13.7 kJ to 30.8 kJ.

Coefficient of Restitution

Based on the circumstances of the incident it is unlikely that that there would have been a closing speed in excess of about 20 to 30 mph. Therefore values for the coefficient of restitution in the range of 0 to 0.36 would be reasonable.

The value of restitution is used in the calculations for delta v.

Change in Velocity due to the Collision – delta v

In the absence of knowing a closing speed for the vehicles, it is possible to calculate the delta v for each vehicle based on the masses, restitution and damage energy. The following equations assumed an aligned impact, which would be the case in a full head-on collision.

\[ \Delta V_1 = \frac{2m_2(E_1 + E_2)(1 + e)}{m_1(m_1 + m_2)(1 - e)} \]

\[ \Delta V_2 = \frac{2m_1(E_1 + E_2)(1 + e)}{m_2(m_1 + m_2)(1 - e)} \]

Where \( \Delta V_1 \) is the change in velocity of the Astra06, \( \Delta V_2 \) is the change in velocity of the Astra55, \( m_1 \) is the mass of the Astra06 and \( m_2 \) the mass of the Astra55.

Therefore:

\( \Delta V_1 = 7.1 \text{ to } 16.3 \text{ mph}, \) and \( \Delta V_2 = 7.1 \text{ to } 16.3 \text{ mph} \)

Due to the masses of the vehicles being the same they cancel and therefore the delta V range is the same.

However, in this collision it appears that there was a partial overlap and also a slight angle between the two vehicles which will have the effect of reducing the changes in velocity calculated above, although both vehicles should still experience the same overall change in velocity.

Simulation software such as WinCrash and AiDamage (both derived from CRASH3) are often used to determine the change in velocity in collisions such as this, by using the damage profile, principal direction of force and vehicle mass and stiffness parameters. Without a detailed assessment of the damage it is difficult to determine the amount by which the change in velocity should be reduced, although the force offset appears to be quite small and therefore the reduction in the change in velocity would also be small.

**High Resolution Data from the IDR**

The graphs below were downloaded from the data recorder of the two vehicles involved. It can be seen that the braking and cornering accelerations of both vehicles before the collision had resulted in their IDRs being triggered and recording in high resolution. The result of this was that the collision itself fell outside the high resolution data, and was therefore only recorded at 16 Hz. This meant that there was limited accuracy when defining the start and end of the impact and also the peak values.

The impact shows that there was a lateral component to the impact for Astra06; however, due to the low sampling rate it was not possible to determine the lateral delta V.

**Astra55**
Analysis of the IDR data determined the following:

<table>
<thead>
<tr>
<th></th>
<th>Astra55</th>
<th>Astra06</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre Impact Speed (mph)</strong></td>
<td>7.7</td>
<td>18.91</td>
</tr>
<tr>
<td><strong>Pre Impact Braking (g)</strong></td>
<td>0.75</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Delta V (mph)</strong></td>
<td>13 ± 1</td>
<td>15 ± 1</td>
</tr>
<tr>
<td><strong>Collision Duration (ms)</strong></td>
<td>188 (± 62.5)</td>
<td>188 (± 62.5)</td>
</tr>
</tbody>
</table>

**Comparison of Results**

In the theoretical analysis no braking was assumed for either of the vehicles, and the IDR data was inconclusive as to whether either vehicle braked during the collision phase. The theoretical analysis determined a change in velocity of both vehicles to be in the
range of 7.1 to 16.3 mph, although it was not possible to determine the factor by which these needed to be reduced to allow for the partial overlap and angled collision. The IDR data showed each vehicle to have a slightly different delta v (13 or 15 mph +/- 1 mph) and within the error band both vehicles could have sustained the same delta V.

In this incident the IDR did not record the collision at high resolution, and therefore there is a limit the accuracy of the measured impact duration and delta V. While it was possible to assess the longitudinal delta V with reasonable confidence it was not possible to determine any lateral delta V. Astra06 had a more significant lateral delta V than Astra55 and this may account for the slight difference in the total delta V for each vehicle.

The IDR measured delta V’s towards the upper end of the theoretical technique range, which could suggest that the restitution in this collision was quite high or that the lower end of the estimation of the equivalent barrier speed was too low. Using the measured approach speeds and the delta V’s, the coefficient of restitution is calculated to be 0.33. This value of restitution, when used in the theoretical calculations, results in a delta V range of 10 to 16 mph.
A.6 Projects Veronica and Veronica II

The Veronica projects were European Union funded studies with the aim of defining guidelines and requirements for the possibility of Incident Data Recorders being fitted to new vehicles. Many uses for the data recorded on such devices were detailed, including assisting the Police and in the area of Road Safety Research. The National Highway Traffic Safety Administration (NHTSA) in the United States had already set some specification requirements for the data collected by IDRs in the US and to some extent Project Veronica was aimed at achieving the same thing for Europe. The specifications cover everything from the technical recording requirements of the IDR to the safety and security implications of the data itself.

The type of system chosen by Veronica consists of a Sensor Data Buffer, which means that it is constantly receiving data but only records when an event is triggered. The recording can commence from a number of different triggers, including airbag deployment, a change in velocity above a certain threshold, ABS activation and many others. The system will also record at standstill. To avoid overwriting critical events, the system ranks each event enabling more serious events to be kept for a longer period of time until downloaded. One of the main requirements of this system would be its ability to detect pedestrian collisions, where the accelerations and changes in velocity of the car are quite low.

The project listed a set of minimum requirements, which would be required by all IDRs fitted by vehicle manufacturers. Some recordings are required to cover a period of 30 seconds before the crash occurred up to 10 seconds after to collision, and record initial speed and speed profile, longitudinal and transverse acceleration, yaw, status signals, user action and monitoring ASD (Active Safety Devises) actions. Some items, however, are only required during the crash sequence itself, for example collision speed, delta v, date and time, any displayed ASD error messages and a higher frequency recording of lateral and longitudinal acceleration. The restraint systems signals are to be recorded 10 seconds prior to the collision and through the crash phase. For each of the recorded fields, an information sheet explaining the resolution, accuracy and frequency requirements is provided. This study also defines the requirements of other data channels, should a manufacturer decide to record them.

There are differences between the requirements set out by NHTSA and Veronica, including the frequency at which the data is recorded and with the additional monitoring of information such as the ASD error messages, which could potentially be very useful in collision investigation.

There are also requirements for those data elements that are not installed in every vehicle, for example, blue lights on emergency vehicles. Another requirement set out by Veronica is when a vehicle is fitted with a recording system already, for example monitoring the steering wheel angle in stability control systems. The steering input is to be recorded between $0^\circ$ to $\pm 270^\circ$, at a resolution of 0.01, at a frequency of 2Hz early pre-crash and 10Hz near pre-crash.

No personal driver data is to be registered for security reasons and the system should stay protected but with simple safety measures. Once the event data is downloaded it is suggested that an authorised expert or organisation should digitally sign the data to seal the record, enabling any tampering with the data to be traced.
A.7 UDS Information

Operation of the UDS type 2 Device

The UDS type 2 device is the second generation of the UDS device, and is the type fitted to the Metropolitan Police vehicles.

The device has the capability to retain the full dataset of up to 12 separate events. Three memory areas are set aside for the storage of manual or stationary events and nine are reserved for automatic events.

Once the vehicle has been stationary for more than five minutes with no IDR input the device switches itself into “parking” mode. During this time the device will record brief details of any “parking jolt”.

The device also has a statistical memory area which retains very brief details of the last 100 evaluated events; the last 200 ignition switch operations; the last 50 vehicle battery voltage drops; the last 50 parking jolts; the last 50 button operations; the last 50 downloads; the last 50 memory deletions and the last 50 self diagnosed faults.

It is important to recognise that this device does not just record collisions; it has been designed to retain data from a period of driving which falls outside a pre-determined value. For instance, the application of emergency braking would probably be sufficient to automatically retain the data, even if the vehicle did not crash or come into contact with anything else.

When the device is triggered by a severe event, usually but not always as the result of an impact, the warning light integral to the manual button is illuminated, as is any repeater warning light.

Evaluated events are retained by order of severity. In order to prevent the memory becoming full with relatively high value events, the event value degrades over time therefore allowing a full dataset of new lower value events to be retained.

In the Metropolitan Police, if the warning light is illuminated, it is normal policy, with the exception of certain circumstances, that the vehicle will not be used until the warning light has been extinguished. Only supervisors and some Collision Investigators are trained and authorised to download and clear the device memory, which extinguishes the warning light.

The IDR is a permanent installation within the vehicle. It is securely attached to the floor pan of the vehicle, although its position on the longitudinal axis can vary; it is correctly aligned with the longitudinal and transverse axes of the vehicle and levelled in all directions.

The device is fitted with an internal battery that provides sufficient power to retain the data if the device is removed from the vehicle or the vehicle power supply is interrupted; the shelf life of this battery is at least five years.

The device wiring harness is permanently connected to the vehicle wiring loom to pick up the various vehicle equipment signals, a power source and a feed from the vehicle speedometer.
After installation a laptop computer with the appropriate software is connected to the device and the various functions are tested via a series of test procedures.

The tests include:

i) the warning lights and audible signal;

ii) status inputs, ignition, lights indicators, etc.;

iii) accelerometers and angle;

iv) generation of speed pulses.

The device is then calibrated to the particular vehicle to which it is fitted. The vehicle is driven over a measured distance and the number of pulses recorded is noted. As a final check the vehicle is should then be driven whilst the various pieces of monitored equipment are used. The data is downloaded and checked to ensure correct operation. This download and a copy of the vehicle passport are then retained with the vehicle maintenance records. The vehicle is now ready for service.

During use the device carries out a self-diagnostic check every time the ignition is switched on and the driver is informed of the result by an acoustic signal (a series of bleeps). One bleep signifies that the device is working correctly, ten bleeps indicates that the device has a fault. (It is usually policy that a vehicle with a faulty IDR will not be removed from the fleet as defective but can continue to be used until there is an appointment for repair.)

If the device has recorded an automatic event the warning lights flash when the ignition is switched off. When switched on the device bleeps once and the warning lights remain continuously illuminated.

**Downloading and Assessing Data**

The data is downloaded onto a laptop programmed with the proprietary UDS software. A copy is usually made that may then be sealed as an exhibit and stored. Any analysis is carried out on a working copy of the downloaded data.

The integrity of the data is retained throughout. Every device has a unique serial number, which is also used as the file name for the dataset and stored within the data. The device is installed in a position where it cannot easily be tampered with and is sealed with tamper evident seals, as are both the cable connections.

Every dataset contains a vehicle passport (Figure 48) which includes:

i) vehicle data;
   - index No;
   - vehicle type;
   - chassis number;
tyre size;

 tyre tread depth;

 installation mileage;

 ii) distance pulse count (pulses per kilometre);

 iii) UDS installation position;

 iv) installation validation;

 seal code;

 installation date;

 installation comments - free text but usually includes position of download cable, job number and vehicle fleet number;

 v) status assignments.

Figure 48 – Example of UDS Device Passport

The vehicle passport is an integral part of the dataset and cannot be altered or separated from it.

There are three different levels of access which is controlled by the type of ‘dongle’ used. The first level (UDShow) is a basic level of access, which is given to supervising officers and allows the data to be downloaded and minimal analytical capability. This level of access does not display the whole dataset.

The second level of access (UDServi) is that used by the installation engineer, this allows access to all aspects of the first level (UDShow) and allows access to device
configuration and calibration, such as the information required in the device passport. This level of access also does not display the entire dataset.

The third level of access (UDScience) is given to specially trained Collision Investigation officers and allows the display of the full dataset and a comprehensive analysis to be carried out. This is the software that TRL has.

The primary data file cannot be altered through the analytical software by any of the levels of access. However, data from the file can be exported to another format and, for example, be displayed in an application such as Microsoft Excel. Therefore only a primary data file viewed through the UDS software can be guaranteed to have retained its integrity.

Once the data is downloaded from the device onto a lap-top the operator is offered the opportunity to delete the data from the device memory – it is the deletion of the data that extinguishes the warning light.

Unlike a computer hard drive, which simply allows the memory area that contained the deleted files to be overwritten, the IDR data overwrites the whole memory with zero’s. This ensures that there is no possibility of corruption from old files but also means that it is not possible to retrieve the data at a later stage.

Data Analysis

Before undertaking any data analysis, the user must be aware of the potential errors in the system, and take account of these in any subsequent analysis.

During use, wear of the vehicle tyres alters the number of pulses generated over a given distance. The consequence of this is that the speed trace in the dataset may not be inaccurate and it is therefore necessary to carry out a check of how accurately the device is recording vehicle speed. This check should be undertaken before making any report of an analysis.

It is possible to ensure the accuracy of the speed traces by checking the pulse count/impulses per kilometre figure, as shown in the device passport, by three different methods.

a) By comparing the speed trace against the longitudinal acceleration trace.

The speed trace is obtained from a direct feed from the vehicle speedometer drive. The acceleration traces are obtained from the accelerometers in the IDR device, independently from the speed trace.

Recalculate the pulse count/impulses per kilometre figure by comparing the speed difference between two known points on the speed trace against the speed difference calculated from the average acceleration rate between the same two points.

b) By conducting a test track check.

Recalculate the pulse count/impulses per kilometre figure by carrying out a test track check.

c) By comparing the odometer reading of the vehicle to the mileage recorded by the IDR.
Recalculate the pulse count/impulses per kilometre figure by carrying out a comparison between the mileage covered as recorded by the vehicle speedometer and the mileage covered as recorded by the IDR.

If the calibration is correct or the appropriate allowance has been made, the displayed speeds can be quoted to an accuracy of ±3 km/h (2 mph).

The acceleration of the vehicle can be measured within the range of ± 500 m/s², with an accuracy of 0.3 m/s² for the 16 Hz data and 0.5m/s² for the 256 Hz data. The average resolution of 16Hz and 256 Hz data is 0.04 m/s² and 0.08 m/s² respectively, meaning that the acceleration recorded by the IDR is in steps of either 0.04 m/s² or 0.08 m/s².

The IDR is fitted with a quartz clock that, in common with similar timepieces, can be subject to drift. When the data from the device is downloaded into a laptop computer a check is automatically made on any difference between the time recorded on the IDR and the system time on the laptop.

As previously discussed, the IDR records both continuous data, such as speed and acceleration, and also status information, such as whether or not the brake light was on. Data is recorded at 16 Hz for up to 30 seconds before and 15 seconds after the incident event and at a maximum rate of 256Hz (filtered from 512 Hz) during high acceleration events.

Figure 49 below shows a typical status signal report for a Police vehicle using both sirens and blue lights. A number of areas of braking can be seen; however, this is only the status of the brake light, which might be illuminated before or after braking is applied.

![Figure 49 – Example of Status Signals](image)

The status signal for the braking does not provide any indication of the severity of brake application. To assess this, the acceleration data should be use (Figure 50).
The acceleration trace shows the area of high resolution data in the grey area. The UDScience software allows the user to zoom in on this area to view a more detailed acceleration pulse.

There are two different speed traces shown by the UDScience software, and while they are both derived from the same source, they are displayed in two different configurations.

The speed plot called v-tacho is the speed value which is taken directly from the same feed that runs to the vehicle's speedometer and therefore indicates the speed of the road wheels. The second plot, named v-spli, is the average speed of the vehicle based on the previous seven and the next seven values for v-tacho.

The reason for providing two different traces for the speed is to allow the person interpreting the data to establish whether the wheel speed and the vehicle speed are the same. Under heavy braking in vehicles with and without ABS, the wheels can fully or momentarily lock up, and therefore the wheel speed and vehicle speed can be different.

Therefore, where the two speed traces are in agreement, the v-spline speed can be trusted to be an accurate representation of vehicle speed, providing the device is appropriately calibrated. Where the two traces are unsynchronised, the v-spline speed will not be a true representation of the vehicle speed.

In order to establish an impact speed which followed very heavy braking, the user should find a speed where v-spline and v-tacho are in agreement, prior to impact, and
then use the longitudinal acceleration data to determine the speed loss due to braking up to the point of impact.
Developing the Research Applications for High-Resolution Real-World Collision Data

Since 2006 TRL’s Incident Investigation and Reconstruction Group has worked with the Metropolitan Police to gain access to high resolution real-world collision data which has been generated during collisions suffered by Metropolitan Police vehicles fitted with the Kienzle Unfall-Daten-Speicher (UDS), a form of in-vehicle data recorder (IVDR) specifically designed to capture data in the event of a vehicle incident. It was considered that this data offers opportunities for new and innovative research in the field of road safety. To date, in excess of 200 incidents have been complied into a database and appended with details relating to the collision, including background information, photographs and the collision data.

There were two main themes to this project, these being to: assess the feasibility of using IDR data to enhance or develop new avenues of research across TRL, including vehicle safety, occupant injury, and driver behaviour; and to compare theoretical accident reconstruction methods with the incident data captured by the IDR device in order to identify the potential for enhancing theoretical collision reconstruction techniques.

A sample of incidents was provided to a number of research areas across TRL and their views on the potential benefits, technical issues and research opportunities were sought. In addition, five separate incidents were selected and reconstructed in detail to determine the effectiveness of various theoretical accident reconstruction techniques.

Four research groups at TRL provided positive feedback on the data, with several potential areas of future work being indentified; however, some of these would first require a better understanding of the accuracy of the data and access to more information about the incident, the vehicles and the injuries to occupants.

It was found that the theoretical techniques provided a range of possible speeds for a vehicle, with the speeds recorded by the IDR device being encompassed by these ranges in each of the reconstructions.

Other titles from this subject area
