

The MUARC-TAC Enhanced Crash Investigation Study: Using Event Data Recorders and Simulated Crash Reconstructions in the Analysis of Crash Causation

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Background

Road crashes represent an immense cost in social, personal and economic terms. Since its establishment in 1987, the Transport Accident Commission (TAC) has been responsible for providing care and rehabilitation to individuals injured on Victorian roads. In recognition of the magnitude of serious injury crashes, the TAC commissioned the Monash University Accident Research Centre (MUARC) to establish the Enhanced Crash Investigation Study (ECIS). The ECIS study aims to investigate the causes and consequences of 400 serious injury crashes involving passenger vehicles. The program objective includes informing the development of road safety programs and countermeasures by providing a comprehensive understanding of crash causation and injury severity. To date, MUARC has investigated and analysed over 100 real-world crashes via a case-by-case systems failure analysis and identified multiple policy options based on 'best practice' prevention.

Crashes of specific interest are simulated using crash reconstruction software (Human Vehicle and Environment (HVE, V11.01)). The process of crash reconstruction permits a deeper understanding of factors and driver behaviours that could have contributed to the severity of the crash. While a simulated crash is validated against the narrative of the crash and damage measures such as the Collision Deformation Classification (CDC), change in velocity (delta-V), principal direction of force and crush measurements (determined from vehicle inspections), generating the simulation involves various driver controls being assumed, including reaction times and braking rate, steering and throttle position, yaw rate and the deceleration of the vehicle upon impact. These assumptions, in turn, limits the simulation's outcome in understanding driver behaviour and vehicle kinematics both pre-crash, during-crash and post-crash.

An Event Data Recorder (EDR) is a device installed in a motor vehicle to record technical vehicle and occupant information for a brief period of time before, during and after a crash. The primary purpose of EDRs is to permit an assessment of vehicle safety system performance. The USA's National Highway Traffic Safety Administration (NHTSA) has issued a regulation (49 CFR Part 563) requiring that vehicles manufactured on or after September 1, 2012 that are voluntarily equipped with EDRs must record 15 data elements at a minimum in a standardized format, such as 5s of pre-crash speed, engine throttle and braking and also 250ms of longitudinal delta-V after the initial impact. Most vehicle EDRs capture data during a frontal collision, typically those causing visible damage to the vehicle (NHTSA, 2006). EDR data has been previously used to study driver behaviour and vehicle performance during real-world crashes (Kusano and Gabler 2011, Kusano and Gabler 2013, Iraeus and Lindquist 2014, Johnson and Gabler 2014, Su, Liu et al. 2014).

The aim of this study was to examine the feasibility of performing full crash reconstructions using two ECIS cases for which EDR data had been downloaded from the vehicles. Using the EDR data in the crash simulation, it was to be determined whether modifying certain parameters, such as braking, throttle and initial speed, would have made a difference to the outcome of the crash. By applying the crash pulses from two separate real-world impacts to two crashes reconstructed in the simulated environment, this paper aims to determine if the integration and use of EDR data could

improve the accuracy of the crash simulations. This in turn bears on the level of confidence that can be had with regard to contributing factors and crash avoidance and injury severity countermeasures.

Method

Participant drivers were recruited into the ECIS study following admission to The Alfred hospital, one of the two adult trauma centres in Victoria. Participants provide informed consent that permits the collection of a detailed description of all injuries sustained, ambulance notes and medical records. Participants also undertake an interview and provide consent for their vehicle to be inspected. EDR data is collected during the vehicle inspection. MUARC crash investigators also document the level of deformation and intrusion, impact severity and potential pre- and post-impact vehicle factors which may have contributed towards the crash outcomes.

The EDR data downloaded from two real-world case vehicles were integrated within HVE simulation software. Data were applied to the Centre of Gravity (CG) of two simulation vehicles so that pre-, during- and post-crash kinematics could be studied. Given the application of a crash pulse to a vehicle's CG will only provide the CG trajectory and not necessarily result in the post-crash angular orientation of a vehicle, the vehicles' trajectories upon application of the EDR data was validated against the case narrative and physical data, as well as velocity (for one case) and yaw rate (for the second case) from the simulation package. Three variables were then varied to determine when the raw crash pulse would take effect, and from this, determine if the crash could have been avoided; these three parameters being 1) applying a driver reaction of 375N brake force one second before the crash pulse; 2) reducing the driver's initial speed by 5km/h; and 3) reducing road friction to 0.5.

Results

Case 1: A 2012 Mazda3 hatchback, the case vehicle, ran a red light in a 70km/h zone and collided with a 1995 Holden Commodore that was turning right.

Case 2: A 2013 Toyota Aurion sedan, the case vehicle, failed to give way trying to cross to the opposite side of the road and was struck on the driver's side by a 2013 Toyota Corolla that was continuing straight on the road.

Real-world evidence from the vehicle and scene inspections show the probable paths taken by the case vehicles before they came to rest (Figure 1), where point of impact (POI) and point of rest (POR) are shown for the case vehicles. The B vehicles were unavailable for inspection and no EDR data was obtained.



Figure 1. Scene diagrams show the probable paths taken by the case vehicles (green) in Case 1 (left) and Case 2 (right), showing the POI and POR. The B (non-case) vehicle is shown in red.

Case 1: The case vehicle's EDR data reports a two event collision with approximately 2.5s between events. Scene and vehicle inspections indicate that the second event was possibly triggered when the case vehicle hit a curb. Since the 2012 Mazda3 was not represented in HVE's vehicle database, a Honda Civic (1992-1995) was used to represent the case vehicle in the simulation. The vehicles weight was adjusted to represent the Mazda with the occupant (1366kg). The EDR data, including initial speed, lateral and longitudinal delta-V, pre-impact throttle from events one and two were entered into HVE to simulate the kinematics of the Mazda3 after the first event was triggered. Yaw data and steering data were not available.

Case 2: EDR data reports a single impact event. The 2013 Toyota Aurion was not available in the HVE database, hence a Toyota Camry LE (2007-2011) was chosen to represent the case vehicle with weight adjusted to match the real-world vehicle plus occupant (1610kg). This was an advanced EDR module and provided a greater number of outputs compared to the EDR from the Mazda. The longitudinal forces (pre-impact) and lateral forces (impact and post impact) were entered into HVE, along with initial speed, steering input and throttle. Forces were calculated by computing the vehicles acceleration from the EDRs delta-V output and multiplying the data by the vehicles kerb mass. Figure 2 shows the crash pulses applied to the two representative vehicles over the duration of the crash.

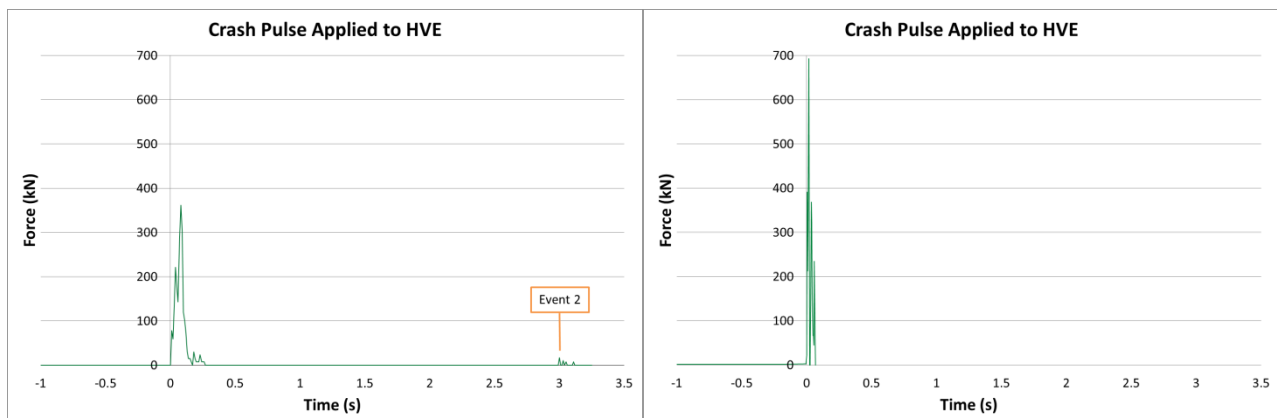


Figure 2. The crash pulses from Case 1 (left) and Case 2 (right) showing the magnitude of forces during the impact. Note that crash pulses were zero from $t = -5$ to $t = 0$ s in case 1 and small (i.e. under 3kN) from $t = -4.75$ to $t = 0$ s in case 2 but does not appear on the graphs due to the large force scale.

Case 1: Upon application of the crash pulse, the case vehicle was pushed laterally but continued without much rotation in the Z-plane given no steering data or yaw data was entered into HVE. To validate the EDR application in HVE, an output of the vehicle velocity over the duration of the crash pulse from HVE was compared to the velocity recorded on the EDR (given that no yaw data was available).

Case 2: The case vehicles trajectory upon application of the crash pulse appeared reasonable. Initial velocity and throttle and steering over the duration of the crash pulse were applied to the simulation vehicle. The yaw rate (output from HVE) was used to validate the application of the crash pulse given the EDR also recorded yaw rate. Figure 3 compares the EDR with HVE data.

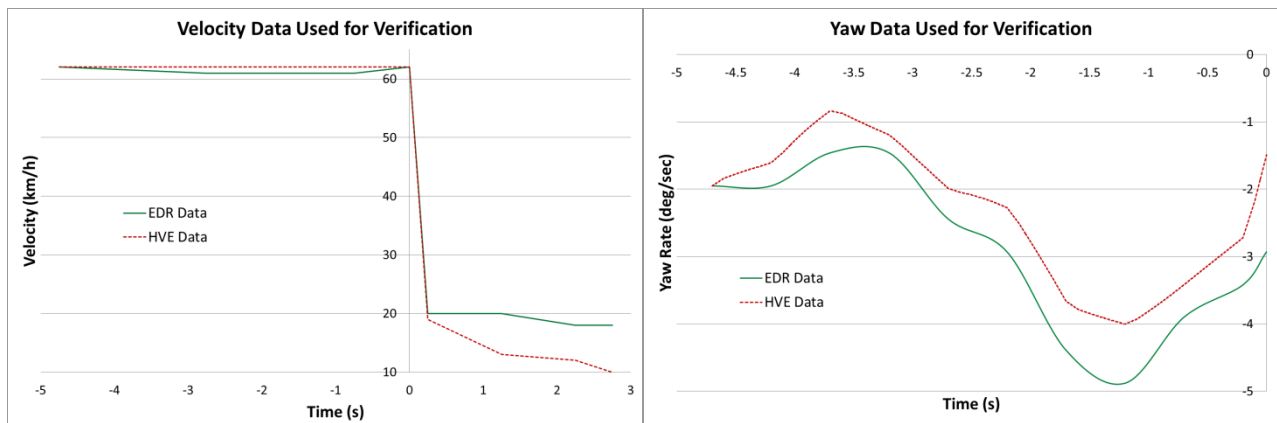


Figure 3. Pre-impact velocity data and yaw data from the EDR was compared to the outputs from HVE to validate Case 1 (left) and Case 2 (right) respectively. Note that time at zero seconds is the event trigger.

The same crash was then simulated with the EDR data and (estimated) steering applied beyond the crash pulse until the final resting position of the simulation vehicles matched that of the real-world crash (verified by physical evidence). No driver inputs other than steering were applied. The trajectories of the vehicles with only EDR/crash pulse data applied and EDR/crash pulse data and steering applied are shown in Figure 4, overlaying each other to demonstrate the limitation of using EDR output alone to reconstruct the two crashes. The simulations of the impacts with EDR/crash pulse data and steering inputs applied were used here forth.

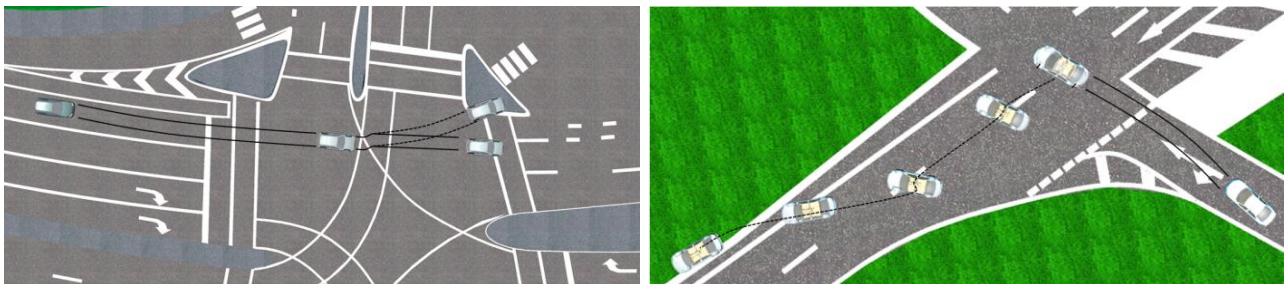


Figure 4. Images showing the vehicles at the starting position that the crash pulse was applied, the point of impact and following the application of EDR data alone (solid lines) vs. EDR data plus approximated steering (dotted line) for case 1 (left) and case 2 (right). The solid line showing the path the car takes with EDR data alone in Case 2, is barely visible given the 68ms of crash pulse that was available.

The following variables were applied to the Mazda (Case 1) and Toyota (Case 2) to determine if there would be a notable difference in outcome to the crash: braking (375N) was applied one second before the EDR was triggered (crash event, $t=0s$); driver velocity (initial) was reduced by 5km/h (from 62km/h to 57km/h for the Mazda and from 22km/h to 17km/h for the Toyota; and road friction was changed from 1.0 to 0.5. Panicked braking of 0.5G (applied by a 75kg driver) was assumed, hence of 375N was applied in the simulations to model panicked braking. Using the simulation, the vehicles' distance to the point of impact is shown in the table below (where '-ve' values indicate a distance which the vehicle stops before the original point of impact, a '+ve' value indicates a distance past the original point of impact).

Table 1. The distance to/from the point of impact when parameters are altered in a crash scenario. The point measured is to/from the right front tyre.

Scenario	Case 1		Case 2	
	Approximate distance to/from original point of impact	Probable outcome	Approximate distance to/from original point of impact	Probable outcome
Original case	0m	Impact	0m	Impact
Braking applied (375N, 1s before collision)	-4.5m	Impact avoided	-3.0m	Most likely impact avoided
Reduced speed (57km/h for Mazda, 17km/h for Toyota)	-2.5m	Impact avoided	-4.8m	Impact avoided
Reduced road friction (0.5)	+ 1.3m	Impact (positioned at driver side door)	+0.4m	Impact

The simulations demonstrated that, when applying brakes (375N) prior to impact and reducing speed, the two crashes could have been avoided. Reducing road friction was shown to have little effect on impact point, possibly making the impact more severe in both cases as the car would have travelled further into the path of the oncoming vehicles.

Discussion

Data downloaded from EDR modules provide valuable pre- and during-crash measures which support case narratives determined from arduously collected real-world crash data. Depending on the EDR module, it can provide basic crash measures (Case 1) or multiple outputs including yaw, steering and throttle position for the crash (Case 2). Independent of the variables recorded, EDR data in the cases studied only provided 250ms of during-crash data from which driver reactions could be studied. Using simulation software, it was shown that the 250ms of during-crash data captured by the EDRs provide limited information regarding vehicle trajectories or driver inputs over the duration of the entire crash. Should EDR data capture 5 seconds of data post-crash as it does pre-crash, this will limit the driver input assumptions required in the reconstruction, resulting in more accurate determination of causal factors and crash outcomes. It is noteworthy that previous research has demonstrated that EDRs underestimate lateral delta-V by up to 4km/h (Tsoi, Johnson & Gabler, 2014). This underestimation of the delta-V may have contributed to the inaccuracy of the reconstruction rest position compared to real-world evidence.

Simulation software provides the opportunity to easily visualise the effects of forces when experimenting with real-world and EDR data, including the effects of braking, steering, speed or environmental factors on impact scenarios. The variables adjusted in the simulations here (braking application, reduced speed and reduced friction), were mainly used to validate the car's behaviour to driver inputs while the EDR data was used as a marker of impact. Our simulations showed that even extremely light braking (375 N) could have prevented the crash. This suggests that the drivers were likely completely unaware of the impending crash. Despite the limitations of EDR data and the simulation software, this study demonstrates the value of using EDR data and crash reconstruction techniques in combination with real-world data to determine crash causation and assist in developing countermeasures that could see a reduction in road trauma.

Implications

This paper presents a comprehensive and robust method for integrating real-world data and EDR data in combination with simulation software. This represents a valuable means of identifying and

investigating relevant and effective countermeasure options related to crash causation, including the potential impact of alternative braking scenarios and lower pre-crash speed. The value of this information is that it can assist in the prioritisation of road safety countermeasures and policies.

References

- Iraeus, J. & M. Lindquist (2014). Analysis of delta velocity and PDOF by means of collision partner and structural involvement in real-life crash pulses with modern passenger cars. *Traffic injury prevention* 15(1), 56-65.
- Johnson, N. S. & H. C. Gabler (2014). Evaluation of NASS-CDS side crash delta-v estimates using event data recorders. *Traffic injury prevention* 15(8), 827-834.
- Kusano, K. D. & H. Gabler (2011). Method for estimating time to collision at braking in real-world, lead vehicle stopped rear-end crashes for use in pre-crash system design, *SAE Transactions, Journal of Passenger Car - Mechanical Systems*, SAE Paper No. 2011-01-0576, v. 4 no. 1, pp. 435-443.
- Kusano, K. D. & H. C. Gabler (2013). Characterization of lane departure crashes using event data recorders extracted from real-world collisions. *SAE International Journal of Passenger Cars-Mechanical Systems* 6, Paper No. 2013-01-0730, 705-713.
- National Highway Traffic Safety Administration (2006). Final Regulatory Evaluation: Event Data Recorders (EDRs), Office of Regulatory Analysis and Evaluation, National Center for Statistics and Analysis. Vol. 49 CFR Part 563 [Docket No. NHTSA-2006-25666], 1-62, Washington DC, USA. Accessible at: <http://www.nhtsa.gov/Laws+&+Regulations/Vehicles>
- Su, S., Liu, W. J., Wang, F. P., Li, K., & Yin, Z. Y. (2014). Comparison of Different Means to Determine Post-crash Velocity in a Real-World Vehicle-Pedestrian Accident. Paper presented at the *Applied Mechanics and Materials*.
- Tsoi, A., Johnson, N., & H. Gabler (2014). Validation of event data recorders in side-impact crash tests. *SAE International Journal of Transportation Safety*, Paper No. 2014-01-0503, 130-164.