The Present Limitations of Motor Vehicle Electronic Data Recording

An Open Letter to the NAS team working on the project: Electronic Vehicle Controls and Unintended Acceleration (TRB-SASP-10-03)

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December 11th, 2010

Summary

In October 2007 a Toyota Tundra crashed into a tree killing the driver. There were no witnesses of the accident. The event data recorder was extracted from the vehicle and pre-and post-crash data recorded an apparent change of speed of 177.2 mph following the crash. Such a figure was manifestly impossible.

Data recorded by present-day MVEDRs **(Motor Vehicle Event Data Recorders)** ***cannot, and should not, be believed, trusted or relied upon.***

- They cannot detect if the vehicle's electronics has malfunctioned
- Their data is partial, incomplete, and suspect
- They do not record the electronic errors that have been shown to cause sudden unintentional acceleration (SUA) events
- They can only be interpreted by the automakers themselves, who are not impartial observers

In our view, there is a clear requirement for the whole area of EDRs to be one of the utmost transparency regulated by Public Standards enforced by a competent regulatory body via independent auditors and where the downloading and interpretation of data are subject to the most rigorous protocols and the possibility of independent checking. Only then can a 'virtuous circle' of safety improvement be established.

1 Only very limited data is recorded

Motor Vehicle Event Data Recorders (MVEDRs, sometimes just called EDRs) or Crash Data Recorders (CDRs) record a limited set of about 10-20 key variables[1] for about 5 seconds before and for 2 seconds after the airbags are activated in a severe crash. This data[2] is stored in a table in the memory of the EDR and can subsequently be downloaded and processed into tables and graphs[3]. The data storage, downloading and conversion tasks are not unduly difficult or onerous (although the automobile manufacturers like to make it appear so).

Currently MVEDRs are very limited in their capabilities. No measurements are made, for example, of electrical system variables and of transients etc. As far as braking is concerned, the Brake ON/OFF signal, which is a key data element, is typically sampled at 1 second intervals in the 5 seconds before and two seconds after the crash[4], and then only an electronically-processed version, not the actual signal to the brake lights. Absolutely no indication is provided of braking force.

By way of contrast, in the electrical power generation industry and its transmission systems it is common practice to use transient recorders to detect electrical surges deriving from system faults and lightning strikes for example. As a consequence, the history of disturbances on the network will be known in some detail for many years prior to a fault developing. Data is gathered and stored continuously over a machine's lifetime. As a consequence it is often possible to see the role that various system disturbances that have occurred over the years have played in any particular breakdown.

In principle MVEDRs could be developed to have somewhat similar functionalities in the far less demanding automotive environment. It isn't as if recording technology of minimal cost is not available to be readily adapted, for example, the smallest USB memory stick one can now purchase to give away for free in a promotion, 1GB, can store about 6,000 photographs of standard-resolution computer screens, or about 300,000 pages of text (a stack of paper about 15 metres tall). In an automotive context, this is enough storage to record all relevant sensor data at high resolution for several hours!

Currently we can only surmise the presence of EMI (Electro Magnetic Interference) by the corruption that it may have caused to one or a set of data parameters. Thus we are always seeking anomalies in the vehicle's behaviour and then deducing failure modes and causes after the event. How much better, for example, it would be to capture the evidence of sudden changes in level or patterns of EMI as they occurred within the vehicle, and be able to correlate, or not – as the case might be – with intermittent electronic system malfunctions. This is an area which we feel needs looking into.

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[1] Vehicle speed, accelerator pedal angle, throttle position, whether or not the brake pedal is depressed, etc.

[2] In terms of the actual data gathered, this might b e up to about 500 data points per channel per second.

[3] EDRs, as currently specified, do not gather information about near accidents or less serious accidents. There is of course no reason why they should not do so with some modest changes to the triggering mechanism and increased storage capacity.

4 See DOT-VNSC-NHTSA-08-01 2008

2 EDR practice in other industries: Open standards for the whole signal/data processing and storage chain.

It is normal practice in other industries for the data recorded, measuring units, resolutions and frequency of sampling to be specified in an International Standard. Thus any competent engineer can download and read the event data, and then interpret its meaning scientifically.

In air accident investigations, for example, the EDR is handed to an independent authority that accesses and analyses the data, in the USA this is the FAA. In general, the results of such investigations are shared across the product specifiers, standard specifiers, designers and manufacturers to encourage safety improvements and future improvement not only of aircraft but of EDRs too. Recently such recorders have been adapted to provide 'real time' safety advice to the pilot based on the aircraft's performance (www.onbass.org).

In order for any post-Event analysis of MVEDR data to be credible and meaningful the whole signal/data chain and all processing within it must be known. For example:

- How the data is sensed for each parameter (signal origin, resolution and frequency of sampling)
- How it is processed before it is stored (filtered, interpolated ...)
- How it is stored (raw, compressed ...)
- How it is retrieved (raw, processed, interpolated ...)

It appears that so far no independent scientific analysis of the Toyota signal chain or how Toyota has come by its results has been commissioned. In our opinion, Toyota ought to be required to provide open access to the whole signal/recording chain - from sensor to readout - to a truly independent test house for checking and validation (i.e. not Exponent, NHTSA etc).

In our opinion the use of Toyota EDR data without complete transparency is scientifically meaningless and any use of interpretation of recorded data should not be accepted as credible legal evidence**.**

3. The questions that need to be asked about EDRs, especially Toyota EDRs

There are three main questions that need to be asked and answered regarding EDRs:

1) Does the data recorded by an EDR *accurately* represent all the relevant factors of the incident?
2) Is the data protected whilst it is stored and during transfer from the EDR?
3) Can we rely on the EDR data being *accessed and interpreted* consistently and correctly?

3.1 Does the data recorded by an EDR accurately represent what happened?

The best data recording practice would be to capture the data at source using separate sensors and separate data logging and processing systems to act as independent and reliable witnesses to unfolding events. This is how aircraft "black box" data recorders work. For automobiles however, independent monitoring and data storage seems to have been ruled out, perhaps on grounds of cost. This limits the extent to which the EDR data can be relied upon as sound evidence of the true state of the vehicle just prior to the crash. However memory cost have dropped by a factor of about 100 in the last ten years and so it would now be possible to record a comprehensive dataset at very modest cost.

Calling MVEDRs "black boxes" implies they are made to aircraft standards, which they are most definitely not. Their limitations are not generally recognised and there is a tendency to attribute far more credibility to the data than is justified and therein lies danger. Worse still there has been a widely held assumption that because some data parameters are recorded and retrieved, they must be correct and so can provide sufficient evidence for a particular proposition. This is not necessarily true, but because it is *believed* to be true it opens an entirely unjustified possible line of defence for motor manufacturers in legal cases.

In the past, Toyota themselves have expressed doubts about their MVEDRs. In 2008, Toyota questioned the reliability of the devices in an effort to prevent the driver of a Toyota Echo from using data from the crash recorder in a lawsuit against the automaker!

"The data retrieved from the EDR is far from reliable," a Toyota court filing said at the time. "The EDR was not intended to be used a reconstruction tool in the field. It has not been validated as a reliable reconstruction tool or crash data recorder for crash events in the field."

Toyota's attorneys also noted that although both sides in the case agreed that one of the passengers in the vehicle was belted and the other was not, the data recorder said both seat belts were unbuckled at the time. "Everyone agrees that's wrong," the Toyota attorney said, according to a transcript.[5] So clearly the veracity of the recorded data is questionable.

Automobile EDRs are a compromise between capability and cost. They capture some data from built in sensors, but most data is captured <u>indirectly</u> from various Electronic Sub-Assemblies (ESAs) <u>after it has been processed</u>. The unspoken design assumption is that the output values of key variables that the EDR records will <u>always</u> correspond with the input sensor values. *This is not necessarily the case.* If, for example, noise appears on a speed signal, corrupting its value, the ECU may calculate a speed that is very different from the actual speed[6]. In the extreme, with the vehicle stationary, the noise might be interpreted by the ECU as indicating that the vehicle had been moving with considerable speed.

The ECU, perhaps as a result of some intermittent electronic malfunction might" think" that it had received a genuine command to move to the wide open throttle position. The false (corrupted) command would be recorded as if it represented the actual accelerator position whereas, in reality, the pedal might not have depressed at all.

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[5] Event data recorders used in NHTSA study of Toyotas have history of problems. Peter Whoriskey, Washington Post Staff Writer, The Washington Post, Friday, August 20, 2010, http://www.washingtonpost.com/wp-dyn/content/article/2010/08/19/AR2010081906562.html

[6] The role of electrical contact resistance in maintaining automobile speed control system integrity. IET Colloquium on Reliability in Electromagnetic Systems, 14-25 May 2007, Paris, France. http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=4768593 http://www.antony-anderson.com/CRES2007_0001_paper-r.pdf

Recently both Professor David Gilbert and Professor Todd Hubing[7] have shown independently that Toyota accelerator pedal fault detection software can be fooled by a common influence or fault on the two accelerator pedal sensors. The ECU "believes" that the pedal has been moved by the driver whereas in fact it has not physically moved at all[8]. If such a "common-cause" error or fault were to occur in practice then the EDR might register an apparently fully depressed accelerator pedal when in fact it was not depressed at all. So it would be a false assumption to assume that that the results of an EDR download accurately reflected the values or commands recorded.

As well as the reasonably foreseeable electronic errors in the above example, there are many other ways in which ESAs may provide incorrect outputs that may be wrongly assumed to be correct.

For example, if the electronics that controls the throttle valve (which Toyota calls the engine management computer, ECM) is having a brainstorm and *thinks* the driver has pressed hard on the gas pedal, it will open the throttle wide and the EDR will erroneously but faithfully record this as if it was actually what the driver wanted. We all know that computers can sometimes behave in ways other than we intend, and ECMs are computers. The CAN bus used to communicate values of data between modules in the car is also susceptible to undetected corruption.

To use an EDR as if the sole witness of truth in the weighing of evidence is most certainly not justified.

In real life the EDR has the characteristic of someone recording - as if the gospel truth - the evidence of a witness who is reliable most of the time, but not necessarily always. It would therefore not be credible to consider EDR data in isolation. It will always be advisable to lookfor anomalous and unlikely results.

By way of warning, pre and post crash data recently downloaded from an EDR taken from a crashed 2007 Toyota Tundra recorded an apparent change of speed of 177.2 mph following the crash[9].

This is a figure that is manifestly impossible. However, if the results had not been so absurd, the pre and post-crash anomalies might never have been detected. This may explain why Toyota, and other manufacturers are so coy about providing open access to EDR data readouts and providing a transparent description of the recording chain from transducer data collection to result printout. Such open access would enable independent engineers to analyse the data for anomalies of all kinds, not just find the 'truth' that the manufacturers prefer and might wish to promote. Perhaps there is a freedom of information issue here? But currently, manufacturers hide the data on the basis that it is 'proprietary'.

So the EDR records what the various vehicle ESAs interpret as the driver's actions in the form of a limited set of values, but if the electronics is in error – or malfunctioning for some reason – then the EDR data might not represent the driver's actual actions.

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[7] Hubing, T.: Analyzing Unintended Acceleration and Electronic Controls
http://onlinepubs.trb.org/onlinepubs/ua/100701hubing.pdf

[8] The error could be positive or negative.
Slowing down unexpectedly (i.e. sudden deceleration) could be just as hazardous as sudden acceleration

[9] Rosenbluth W: Eves EDR Data Findings An Inductive Investigation of Toyota Tundra EDR Data 4 August 2010

3.2 Can we rely on the EDR data being *interpreted* consistently and correctly?

The correct way to record data that is required for legal purposes, is to have a peer-reviewed public standard defining what parameters are to be measured, and with what accuracy and reliability, and how the data is to be presented (i.e. its formatting), the means for knowing that it is stored and transferred without corruption and who is permitted to access it.

Also, the devices that perform such functions should be independently assessed against the relevant standards and not permitted to be used unless they have passed a stringent product design audit and usually and annual in-service audit, both by independent audit authorities. This is how, for example, weigh-scales, electricity meters, gas meters, telephone call registers, roulette wheels, voting machines, gambling machines, etc., are controlled, so that people can rely on the veracity of the product in use and are fairly charged for what they have purchased.[10]

In 2008 Volpe reviewed EDRs for NHTSA and while generally concluding their usefulness had these words of caution:

> "It is very important to understand the limitations of EDR data and care should always be exercised when interpreting any EDR-reported parameter. A wide range of EDR module-specific limitations exist, and therefore importance should be placed on module type identification. Also, a clear understanding of what (and when) the EDR is measuring needs to be gained before any analysis. Awareness of the EDR limitations is needed for correct interpretation and use of the data. …………………………… Ultimately, present-day EDR data can be a powerful investigative and research tool by complementing existing crash evidence and estimates. <u>It should always be used in conjunction with other data sources</u>, including a complete reconstruction, <u>since issues like the ones just described eventually limit the application of the EDR data</u>." [11]
> *(emphasis added by the authors)*

However, currently NHTSA, aided by Toyota, are downloading EDR data from a small sample of crash vehicles with a prototype of a downloading tool and proprietary Toyota software that has not been independently or publicly verified. They appear to be using the unvalidated information gathered as a litmus test of whether or not particular sudden accelerations are the fault of the electronics or the driver.

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[10] In the 'bad old days', the providers of certain goods or services would "adjust" the behaviour of such instruments to favour themselves, and this led to government regulation of such devices using the tools of peer-reviewed public standards and independent assessment by assessors with the power to ban the use of the device. The earliest example of this was the appearance of "certified" standard bronze weights (1oz, 4oz, 8oz, etc.) for calibrating weighing scales, back in the days when a vehicle meant a horse-drawn cart or buggy, or covered wagon, to try to prevent suppliers from exploiting their customers by giving short measure.

[11] DOT-VNSC-NHTSA-08-01 2008, www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/EDR/Research/810935.pdf

Recently NHTSA, after making a presentation to a congressional sub-committee, announced its preliminary results *ex-cathedra* by press conference without first submitting these findings to any kind of peer review. The results have rapidly become transformed in the public mind into proven fact of indubitable scientific pedigree that "proved" driver error. *The whole process being used simply does not stand up to scientific or safety scrutiny.* The way that NHTSA is currently handling Toyota EDR data and interpreting the results seems entirely at variance with the cautious approach that Volpe were advocating in 2008.

In our opinion, EDR downloads should most definitely be treated with a certain amount of caution and especially when processed by the automaker of the questioned vehicle using proprietary software that has never been independently assessed and is totally under their control. How is it possible to have *any* credence in data that an interested party provides, unless it has been checked for completeness and accuracy by an independent assessor?

How can a government agency simply take the word of a manufacturer that may stand to gain by presenting the data in a certain way? This would not be acceptable in any other area of potential legal dispute – it runs contrary to principles of independent and impartial regulation which enforces honesty on suppliers. For example, in the UK Rail Industry the signalling recorder is literally "arrested" after the crash and taken to an independent crash investigator.

Just as with accounting procedures and spreadsheets, so in the matter of downloaded automobile data, there should be clear standards of accountability and a clear audit trail. It should not be possible to put results into the public domain as has recently happened in the case of NHTSA examination of Toyota sudden acceleration incidents, without at the same time declaring the data and method by which those results have been obtained.

There is a clear requirement for the whole area of EDRs to be one of the utmost transparency, regulated by Public Standards enforced by a competent regulatory body via independent auditors and where the downloading and interpretation of data are subject to the most rigorous protocols and the possibility of independent checking. Only then can a 'virtuous circle' of safety improvement be established.

Conclusions

For post-Event analysis of MVEDR data to be meaningful the whole signal/data chain and all processing within it must be known. In the case of Toyota the whole signal chain and its processing is proprietary and so unknown and it has not been subject to any kind of independent peer review to assess its features, benefits and limitations.

It is simply not credible for NHTSA to assert, as it were: "you can trust us, we know what we are doing regarding MVEDRs and we place our trust in Toyota". Trust has to be based on sound and transparent foundations. In this case trust has yet to be earned and the interpretation of results from any MDVR crash data should, in our opinion, therefore be treated with extreme caution.

As things stand at present, there is no basis for having *any* confidence that the data recorded by a Toyota EDR and downloaded using a proprietary Toyota download tool and software accurately represents the driver's actions. Furthermore we cannot rely on the correct interpretation of the limited data provided by either the automobile manufacturer or by NHTSA.

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December 11th, 2010

Appendix

Analysis of Event Data Recorder Data for Vehicle Safety Improvement

http://www.nhtsa.gov/Research/Event+Data+Recorder+(EDR)/Event+Data+Recorder+(EDR)+Research+Applications+of+Articles,+Products+and+Research

WORLD'S FIRST MOTOR VEHICLE 'BLACK BOX' STANDARD CREATED AT IEEE

ABSTRACT: Driven by a lack of uniform scientific crash data needed to make vehicle and highway transportation safer and reduce fatalities, the IEEE has created IEEE 1616, the first universal standard for motor vehicle event data recorders (MVEDRs) much like those that monitor crashes on aircraft and trains.

Sponsor: IEEE Vehicular Technology/Land Transportation

Title: IEEE 1616: Standard for Motor Vehicle Event Data Recorders (MVEDRs)

Status: Approved Publication of IEEE, Published Date: Dec 10, 2004

Contact: For non technical questions, including pricing, availability and ordering, please contact IEEE Customer Service at 800-678-IEEE (in the U.S. and Canada); or 732-981-0060 (outside the U.S. and Canada); or send a detail email to customer- service@ieee.org. To purchase this standard, or for pricing and availability go to http://shop.ieee.org/ieeestore and type in the standard number.

History: PAR APP: Dec. 06, 2001, BD APP: Sept. 23, 2004

Project scope: Motor Vehicle Event Data Recorders (MVEDRs) collect, record, store and export data related to motor vehicle pre-defined events. This standard defines a protocol for MVEDR output data compatibility and export protocols of MVEDR data elements. This standard does not prescribe which specific data elements shall be recorded, or how the data are to be collected, recorded and stored. It is applicable to event data recorders for all types of motor vehicles licensed to operate on public roadways, whether offered as original or aftermarket equipment, whether stand-alone or integrated within the vehicle.

Project purpose: Many light-duty motor vehicles, and increasing numbers of heavy commercial vehicles, are equipped with some form of MVEDR. These systems, which are designed and produced by individual motor vehicle manufacturers and component suppliers, are diverse in function, and proprietary in nature. The continuing implementation of MVEDR systems provides an opportunity to voluntarily standardize data output and retrieval protocols to facilitate analysis and promote compatibility of MVEDR data. Adoption of the standard will therefore make MVEDR data more accessible and useful to end users.

http://www.nhtsa.gov/DOT/NHTSA/NRD/Articles/EDR/PDF/Research/pr_1616.pdf

Annex A

Brief Biographies for
Dr Brian Kirk, Dr Antony Anderson, and EurIng Keith Armstrong

Dr Brian R Kirk BSc (Hons), MSc, PhD, MBCS, Chartered Engineer, MACM

Brian started working with computers in 1966 after gaining a BSc Hons (i.e. Cum Laudes) in Physical Electronics at Salford University followed by an MSc in Device Engineering, Processes and Computing at Imperial College, and a PhD in Active Safety Systems in 2008.

His career started in the Microelectronics Industry with Marconi Research (UK) and then General Instrument Corporation (USA) where he was involved in the design and manufacture of microprocessors and custom chips. He was the Development Manager for Microprocessors and Memory Devices in the UK.

He became a founding Director of Robinson Systems Engineering Ltd in 1976 trading as Robinson Associates. The company specializes in designing and building high Integrity and safety critical embedded computing solutions, including safety critical systems for the Transport sector (some using the CAN bus).

Systems experience includes safety critical systems and software for Medical Equipment Automation, Railway Systems and Tools, Juridical Recorders' "Black Box" for Rail Systems, and an Active Safety "Black Box" for Aviation.

Brian is a Member of the British Computer Society (UK) and a life member of the Association of Computing Machinery (USA).

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Since 1997 Dr Anderson has been working as an independent electrical consultant specialising in electrical machine and control system failure investigations and expert witness work. He has investigated a wide range of electrical/electronic related problems on behalf of various UK and US-based organizations in UK, France, Germany, Belgium, Mexico, Colombia and Canada.

He has investigated many issues, including: high speed stepper motor failures; switching transient problems in motor windings caused by pulse-width modulated inverters; electromagnetic bearing failures; mechanically induced EMI in generator rotors, and generator core failures.
Since 2000 he has also been investigating power electronics-related malfunctions in automobiles, including intermittent malfunctions of an electronic stability system and malfunctions in electronic speed control systems.

He has a BSc (Honours, i.e. Cum Laudes) in Electrical Engineering and a PhD (Electronic Control of Switched Reluctance Motors), both from the University of St Andrews, Queens College Dundee; Scotland, UK.

Previous experience includes: electronic control of rolling mill drives; simulation of variable speed drives; transient performance and stability of electrical machines; organizing superconducting machine design including minimization of effects of high strength rotating magnetic fields, screening etc; investigating transient electromagnetic field effects in large conventional a.c. machines.
He is a Fellow of the Institution of Engineering Technology (FIET) (formerly known as the IEE, Institution of Electrical Engineers, since 1871), a Fellow of the Institution of Diagnostic Engineers and a Member of the IEEE.

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Keith was awarded the BSc (Elec.Eng) with Honours (i.e. Cum Laudes) from Imperial College of Science & Technology, London, UK, in 1972, having specialized in electronic circuit design, control systems, and electromagnetic field theory.

He is a Group 1 European Engineer (EurIng), a Fellow of the Institution of Engineering Technology (FIET) (previously the IEE, since 1871), and a Senior Member of the IEEE.
His IEE/IET Fellowship and IEEE Senior Membership were awarded on the basis of his work since 1997 on the new discipline of "EMC for Functional Safety".

Keith has chaired the IEE/IET's Working Group on "EMC and Functional Safety" since 1997 and is the IET's official spokesperson on that topic.

He is the UK's expert on these International Electrotechnical Committee's teams:
IEC 60601-1-2 (EMC for safety of Medical Equipment and Systems)
IEC 61000-1-2 (Basic standard on EMC for Functional Safety)
IEC 61000-6-7 (Generic standard on EMC for Functional Safety)

He has published the following books and is working on one more on EMI/EMC:
The Physical Basis of EMC, October 2010, ISBN: 978-0-9555118-3-7
EMC Design Techniques for Electronic Engineers, November 2010, ISBN: 978-0-9555118-4-4
EMC for Printed Circuit Boards, Basic and Advanced Design Techniques, 2007, ISBN: 978-0-9555118-0-6.
EMC for Systems and Installations (co-authored with Tim Williams), Newnes 2000, ISBN: 0-7506-4167-3.

Since 1990 he has produced more than 191 papers, articles, guides and workshops in the USA, Europe and China, on EMI/EMC and "EMC for Functional Safety". Many have been translated by volunteers into Spanish, Chinese and Japanese (at their request).
Until 1990, Keith was employed in a number of industries as an electronic designer, later as project leader and design manager. Since 1990 he has been an Independent EMC and Safety consultant since 1990 with his own company, Cherry Clough Consultants Ltd, with over 700 customers in the USA, Canada, Europe, Australia, China and India.

As an independent consultant he has solved a huge range of EMC problems in a wide range of industries and applications, from tiny products through systems of any complexity to large installations (e.g. synchrotrons, air traffic control towers) – including electronic modules for rail, aviation and automotive vehicles – and also provided very highly-regarded training courses on EMI/EMC and "EMC for Functional Safety".

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