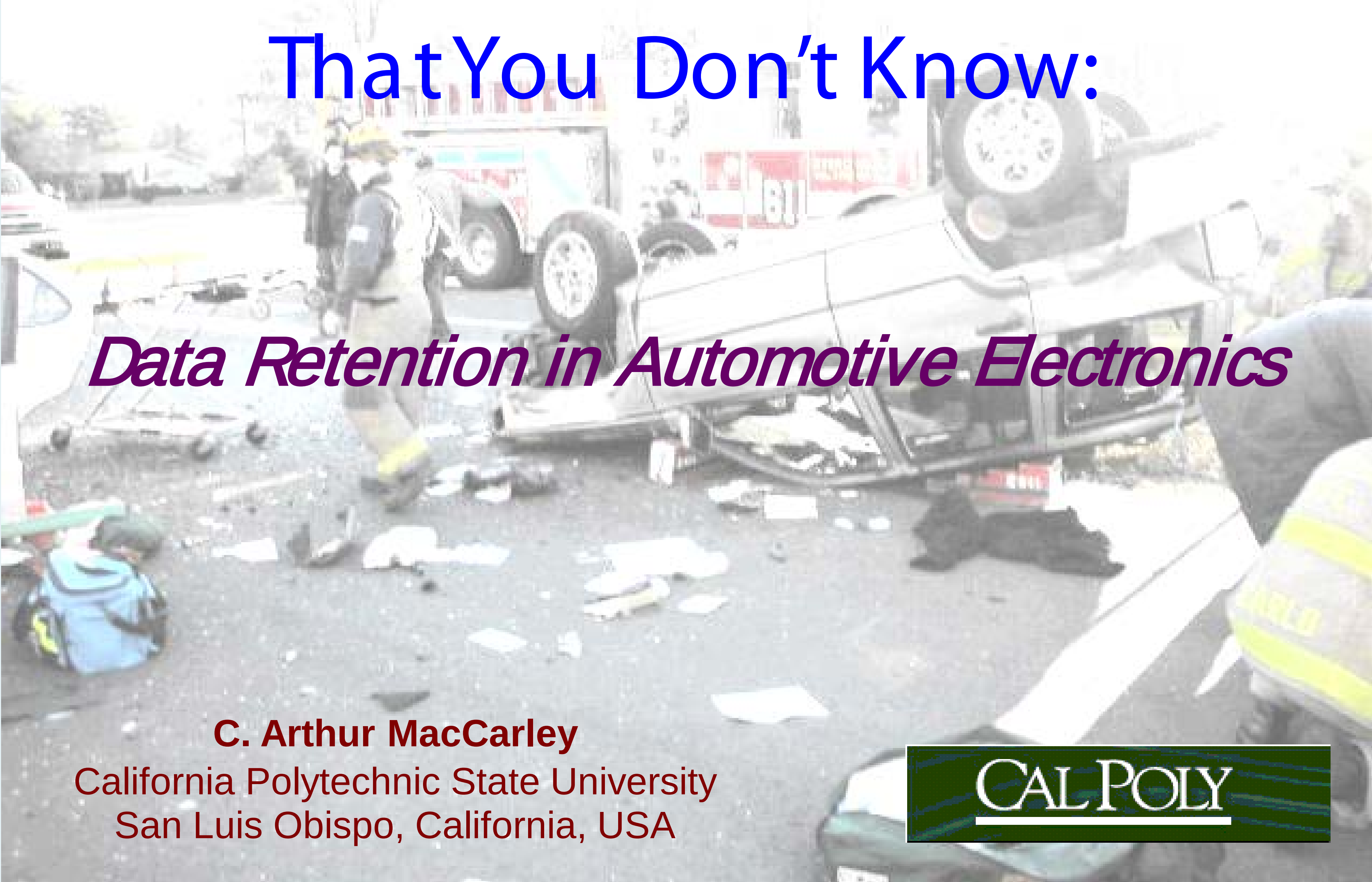
What Your Car Knows About You That You Don’t Know:



Data Retention in Automotive Electronics

C. Arthur MacCarley
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San Luis Obispo, California, USA

CAL POLY

Reality, Misconceptions and Media Hype

Black Box?

Event Data Recorder?

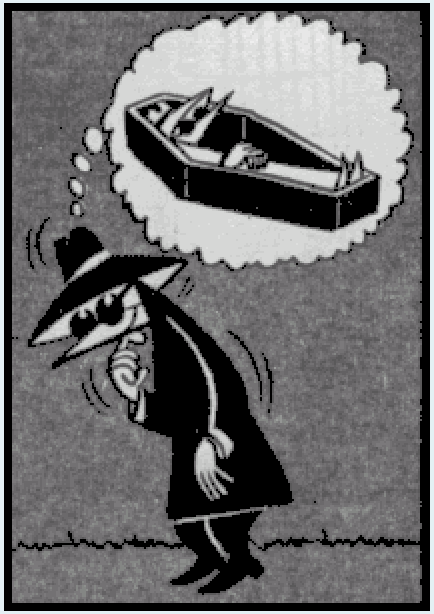
Spy under the hood?

What does my car know?

Why does it need to know it?

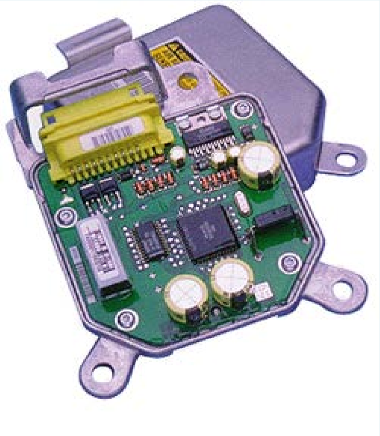
Who can access this information?

Who owns it?



How come they didn't tell me this when I bought my car?

A secret now out in the open, and our attempts to balance privacy with the public good



NHTSA creating universal standard for automotive 'black box'

Posted Aug 7th 2006 4:58PM by John Neff
Filed under: Gadgets, Government/Legal, Tech

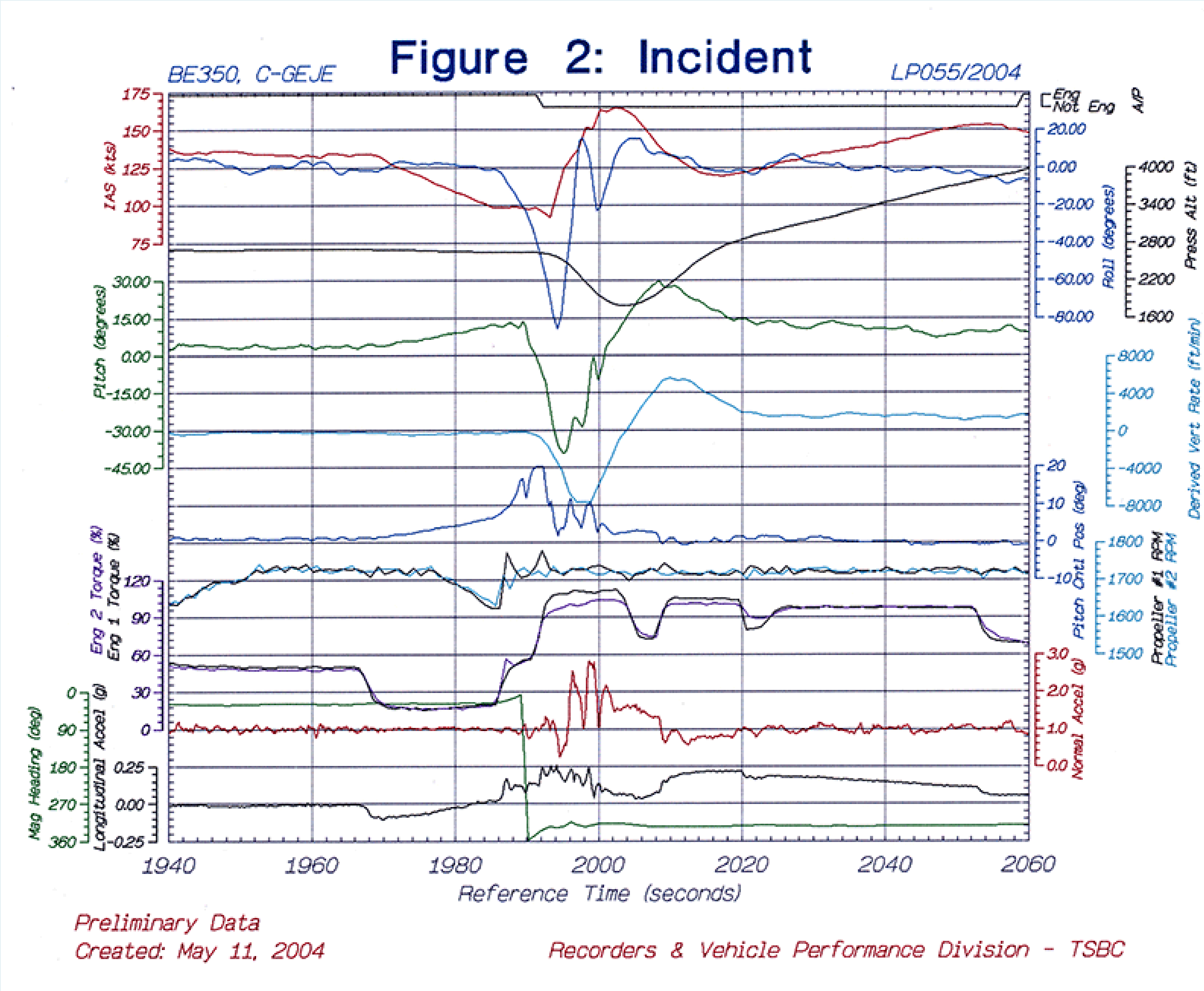
Though you may not realize it, your car is probably equipped with an automotive 'black box'. Also known as Event Data Recorders, these devices record information from a vehicle's various sensors during a crash – everything from airbag performance to the angle of the steering wheel to the speed of the vehicle is retained. Though an estimated 90 percent of new vehicles are shipped with the devices, each manufacturer uses their own hardware, software and file formats.

The National Highway Traffic Safety Administration will rule on a universal format for Event Data Recorders in the next 30 days, according to Automotive News. While not going so far as to make EDRs mandatory in every new vehicle, the ruling will create a standard format for data collected by EDRs across many different vehicles. The Society of Automotive Engineers has been given the task to come up with the universal format.

The new ruling will only cost automakers about $8 million, which isn't much in the grand scheme of things. To date these black boxes have aided in voluntary recalls and accident investigations, and automakers claim they're used to make vehicles safer. Of course, the real debate is whether information recorded by an EDR can be submitted as evidence against a driver in court. In that case, Big Brother may now be riding shot gun.

[Source: Automotive News]

Aviation “Black Box” Flight Data Recorders or Cockpit Voice Recorders



Aviation Investigation Report
Aircraft Stall During Instrument Approach
Grant Executive Jets Inc.
Raytheon B300 (Super King Air) C-GEJE
Timmins, Ontario
22 April 2004

History of On-Board Diagnostics and Data Retention

- The beginnings of data retention lay in the introduction of electronic fuel injection.

- Electronic fuel injection (EFI) was first successfully deployed in production cars in 1968 (the Bosch D-Jetronic system available as an option on some Volkswagon models).

- EFI had actually been introduced first in 1958 as an option on the Chrysler 300 Sedan. The Bendix analog control system with electromagnetic fuel injection valves improved fuel economy and reduced emissions while maximizing power compared with carbureted models. But the system was an oddity well beyond the understanding of mechanics, and was a commercial failure. Fewer than 300 were built and no examples remain today.

- Computer-vehicle data links evolved concurrently with electronic fuel injection. These allowed a dealer mechanic to connect a diagnostic “computer” to the EFI Electronic Control Unit (ECU) that would reveal problems with sensors, actuators or the ECU itself. They also helped to increase the service market share of dealers.

History of On-Board Diagnostics and Data Retention

- In 1967, the California Air Resources Board (CARB) required the first emission controls (for HC and CO only) on vehicles sold in California.

- The Federal government through the US Dept of Transportation (DOT) extended these requirements nationwide in 1968.

- These regulations were the first external incentives for manufacturers to provide “computer monitoring” of engine functions for emission compliance reasons.

- Congress passed the Clean Air Act in 1970 and established the Environmental Protection Agency (EPA).

- By the mid-1970’s, diagnostic connectors were becoming common on high-end vehicles.

- In 1978 Intel introduces the 8080 microprocessor which quickly dominates the home PC market. Motorola introduces the MC6800 which quickly dominates the automotive engine control market. Fuel injection and ignition control go digital.

History of On-Board Diagnostics and Data Retention

- Although developed in the USA by Bendix and GM, Oxygen-Sensing feedback fuel controls were first introduced into the mass market by Robert Bosch in 1979 as the “Lambda-Sond” system on Volvo sedans.

- This technology made possible the use of three-way exhaust catalysts, which concurrently reduce NOX as well as HC and CO. This enabled a dramatic reduction in automotive (gasoline) pollutants.

- The early oxygen sensors used by these systems were their weak point, and the “check engine” light was introduced initially to make the driver aware if the sensor failed.

- Computer diagnostic interfaces became the norm on vehicles with closed-loop fuel control systems. Each manufacturer and sometimes each car model had their own proprietary connector and protocols.

- By 1980 the Society of Automotive Engineers (SAE), International Standards Organization (ISO) and American Society of Testing and Materials (ASTM) began the development of standards for diagnostic and emission certification interfaces.

History of On-Board Diagnostics and Data Retention

• In 1988, the Society of Automotive Engineers (SAE) admitted almost all proprietary manufacturer's connectors, protocols and data sets under broad standards, designated by the EPA as OBD-I. They required, however, a minimum set of data items that must be made available for emission testing purposes (e.g., engine speed, engine load inferred from manifold vacuum, coolant temperature, oxygen sensor output, throttle position, and later, the brake light status, etc.) OBD-I was born.

• Between 1988 and 1995, a large number of standards were developed by several different institutions affecting connector design, data requirements and protocols.

• Passed in 1994, federal (EPA) law required that all model year 1996 and some 1995 vehicles sold in the US must comply with, at a minimum SAE Standard J19962 specifying a common connector (Diagnostic Link Connector or DLC) and a canonical set of diagnostic tests and codes (Diagnostic Trouble Codes or DTCs). OBD-II was born.

History of On-Board Diagnostics and Data Retention

• *Real-time* data and *freeze frame* data behind each code is also required. This is a snapshot of selected powertrain parameters at (or near) the time the code was set.

• Communications protocols and network hardware are still manufacturer-specific. Four have been assigned SAE or ISO standards, and are in common use.

• Manufacturers usually include a number of additional DTCs for their own purposes. These include data from a number of ancillary systems that control non-powertrain functions. Late model vehicles store possibly hundreds of DTCs, many with related freeze frame data.

• DTC’s now include data from automatic braking systems (ABS), traction control or acceleration slip control (ASC), stability enhancement systems, adaptive cruise controls, back-up warning, climate control, seat and mirror position memory, illumination, audio systems, and many more.

History of On-Board Diagnostics and Data Retention

• Prior to 1990, all systems "lost their memory" when battery power was disconnected for more than a few seconds. But in the mid-1990's, inexpensive nonvolatile memory (EEPROM, Flash and variants) made possible data retention even if the vehicle electric power distribution system fails or is disconnected.

• OBD-II remains the current standard (2007) but OBD-III will replace it as soon as 2009. OBD-III will mandate enhanced monitoring of multiple non-engine functions in addition to basic emissions tests and codes.

• In addition to OBD-related diagnostics, powertrain and other ECUs often retain additional information, usually in raw form in non-volatile memory, accessible only to the manufacturer using non-standard proprietary interfaces.

• Although airbags have been in use in automobiles since the 1980's, in the mid-1990's, "smart airbag" controllers replaced the crude inertial switches used on early airbags. These were followed by "supplemental restraint system (SRS)" modules which also controlled pyrotechnic seatbelt tensioners and dual-stage passenger-mass sensing airbags.

History of On-Board Diagnostics and Data Retention

• All SRS controllers retain rapidly-sampled deceleration data (the crash pulse) during the deployment event, intended to help incrementally improve the design and protect the manufacturer from liability.

• Some contain much more data, including typically five seconds of pre-crash data and a flash image of the status of many other systems.

• These features have lead to media references to the SRS controller as an "Automotive Black Box" or "Event Data Recorder (EDR)", both references to flight data recorders used in commercial aviation.

• All SRS modules contain non-volatile memory. All except the earliest are intended for one-time-use only and are not reprogrammable. These features have lead to a degree of confidence in the retained data in forensic analyses.

• There are currently no standards for retained data or access methods to SRS modules. Because of this, misinterpretation of data is probable and proper interpretation of the data in conjunction with physical data is critical

History of On-Board Diagnostics and Data Retention

• Only GM and Isuzu (beginning 1994) and Ford (beginning 2001) have made available information on accessing data stored in SRS modules, under license to Vetronix Corporation, a division of ETAS, recently acquired by Robert Bosch GmBH.

• For these vehicles, data access is via the DLC, or directly from the module via specialized connectors, over 50 in use since year 2000.

• For all other manufacturers, data in their SRS modules is retained, but only the manufacturer can access it. Some manufacturers are more cooperative than others. For example, Ford will download their non-Vetronix-accessible modules for a flat fee of $5000. Toyota and Honda refuse to assist claiming proprietary issues. Daimler-Chrysler will deny that data is even retained (even though they use the same modules as GM and Ford).

• Auto manufacturers do not manufacture their own SRS modules – there are currently only four major suppliers: Robert Bosch, Siemens, Takata, and Delphi. Manufactures usually do their own firmware design, however.

History of On-Board Diagnostics and Data Retention

• Approximately 40 million vehicles registered in the USA contain some form of SRS control system that retains data.

• In addition, subscriber GPS-based wireless services retain and report location as well as operating data to a central location:

- • OnStar™ has over 4 million subscribers (according to Automotive News) and serves an estimated (by GM) 95 million people. It uses GPS to report location, and automatically opens a transaction if commanded by the SRS (SDM) module. Uses CDMA and GPRS.

- • i-mob™ USA. OnStar competitor.

- • Lojack™ transmits the GPS location of a vehicle over the CDMA cellular phone network.

- • Guidepoint™ – navigation, emergency notification, and internet tracking of vehicle.

Handheld OBD code scanners

Anyone can access OBD-II DTCs and real-time data

OBD-II Scanner-to-Vehicle communications:

Only the connector and core dataset is standardized.

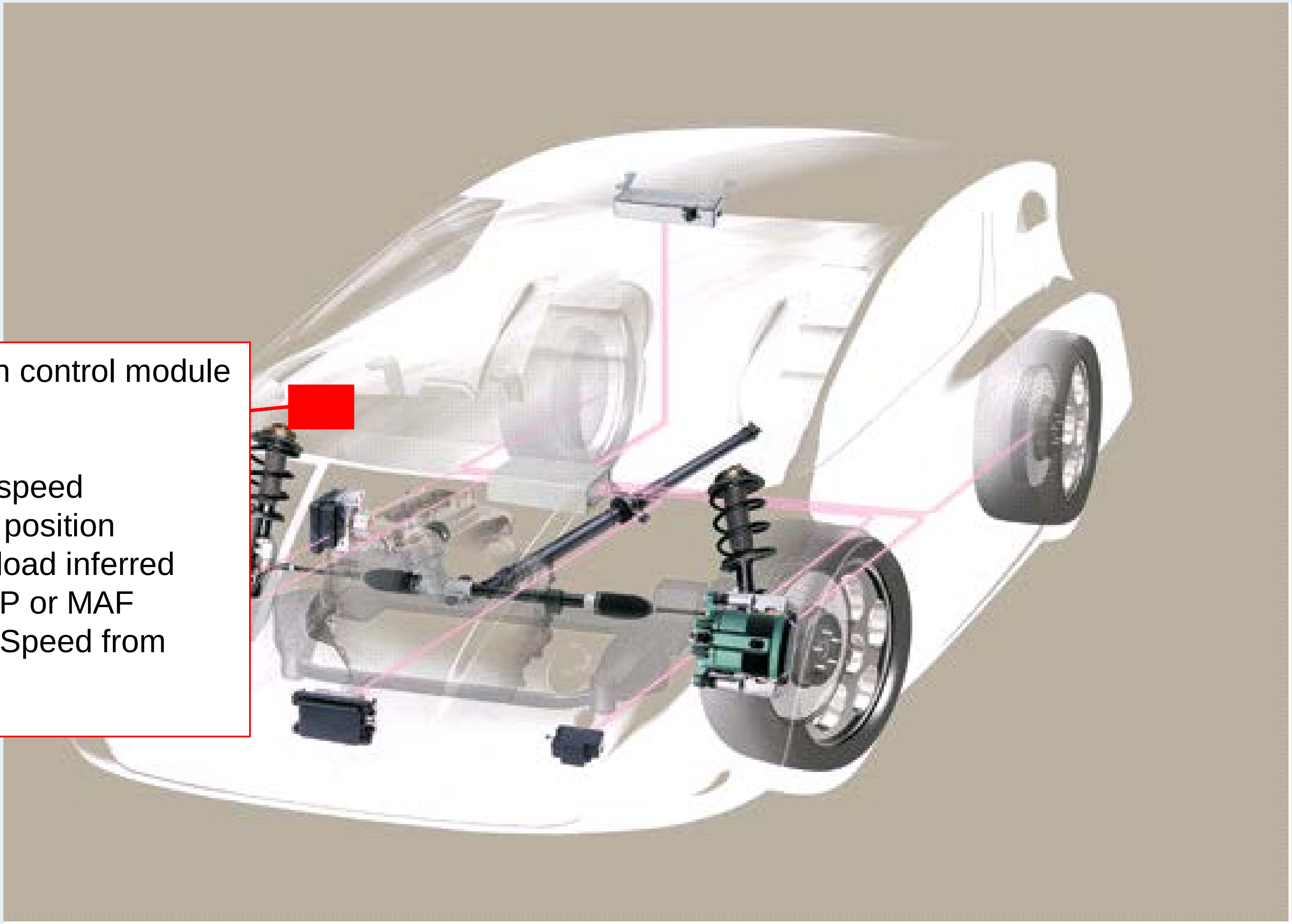
Four hardware specifications and serial protocols in common use:

ISO 9141	Single wire, 10.4kbps
SAE J1850	Two-wire CAN, PWM, 41.6 Kbps
SAE J1850	Two-wire CAN, PWM, 125 Kbps
SAE J2284	Two-wire CAN-HSC, PCM, 500 kbps

Mandatory Data under OBD-II Standards: SAE J1979 and J2178

- DTC's related to all components and functions related to emissions.
- Key cycles since one or more required emissions auto-tests
- Real-time and freeze-frame data:
  - Engine speed (RPM)
  - Throttle position (%)
  - Ignition timing advance (deg)
  - Manifold air pressure (MAP) or air flow rate (MAF)
  - Engine load, inferred from manifold absolute pressure (%)
  - Short and long-term fuel trim (% deviation from open-loop map)
  - Air temperature (deg C)
  - Coolant temperature (deg C)
  - O2 sensor voltage (mV)
  - Vehicle speed (mph or km/h), from VSS if equipped

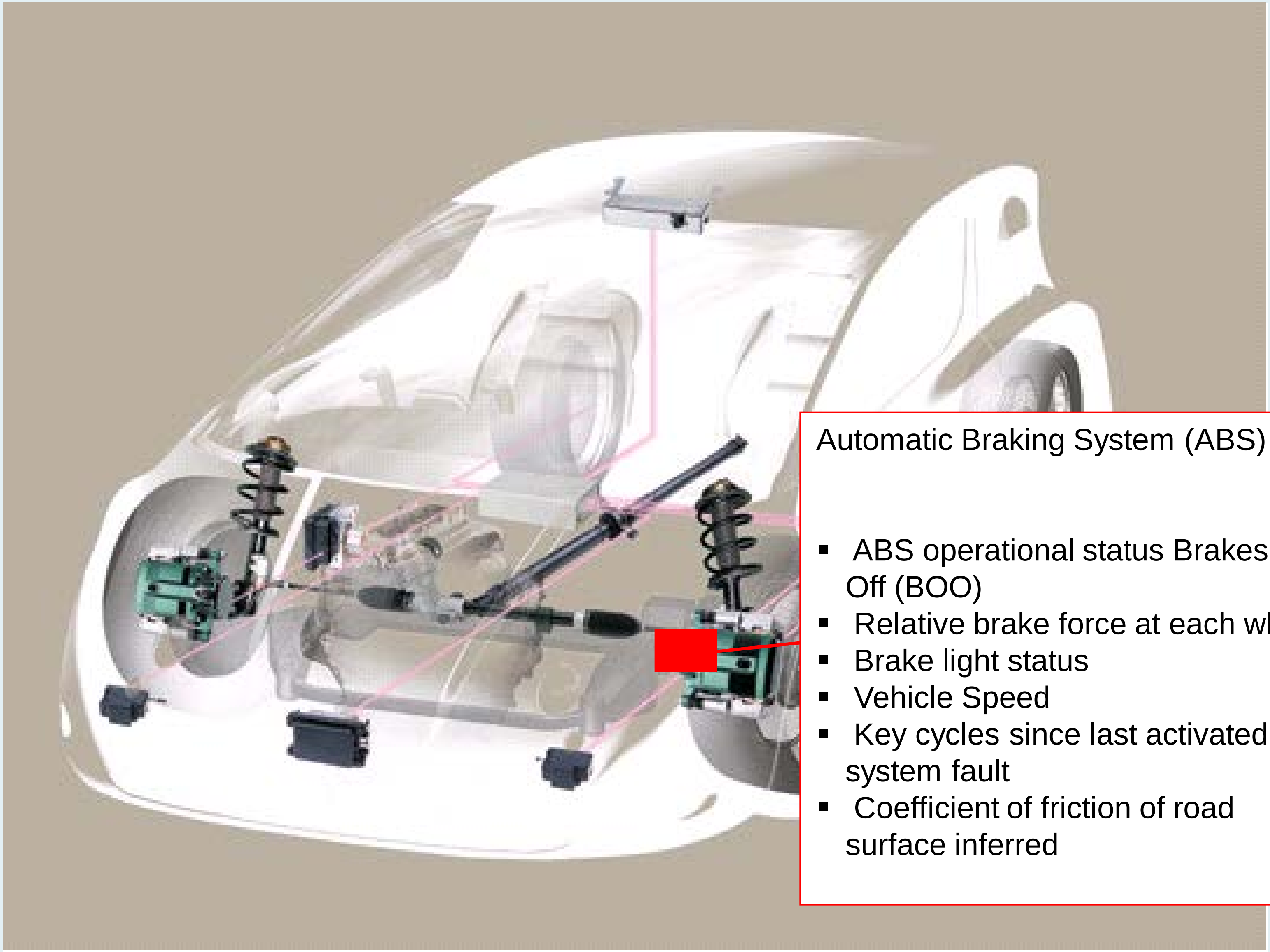
Automotive Systems that Retain Data with Forensic value



Powertrain control module (PCM)

- Engine speed
- Throttle position
- Engine load inferred from MAP or MAF
- Vehicle Speed from VSS

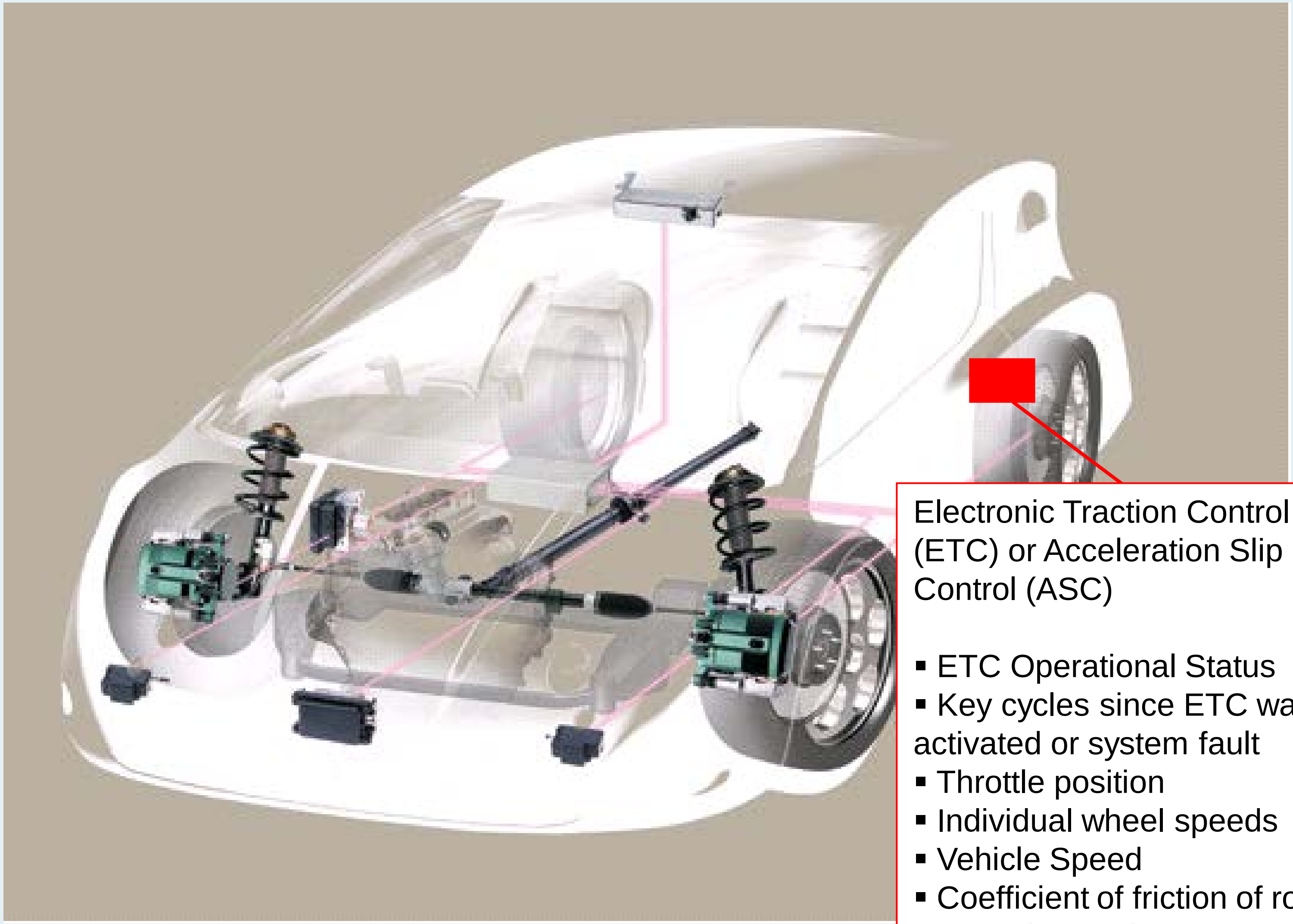
Automotive Systems that Retain Data with Forensic value



Automatic Braking System (ABS)

- ABS operational status Brakes On-Off (BOO)
- Relative brake force at each wheel
- Brake light status
- Vehicle Speed
- Key cycles since last activated or system fault
- Coefficient of friction of road surface inferred

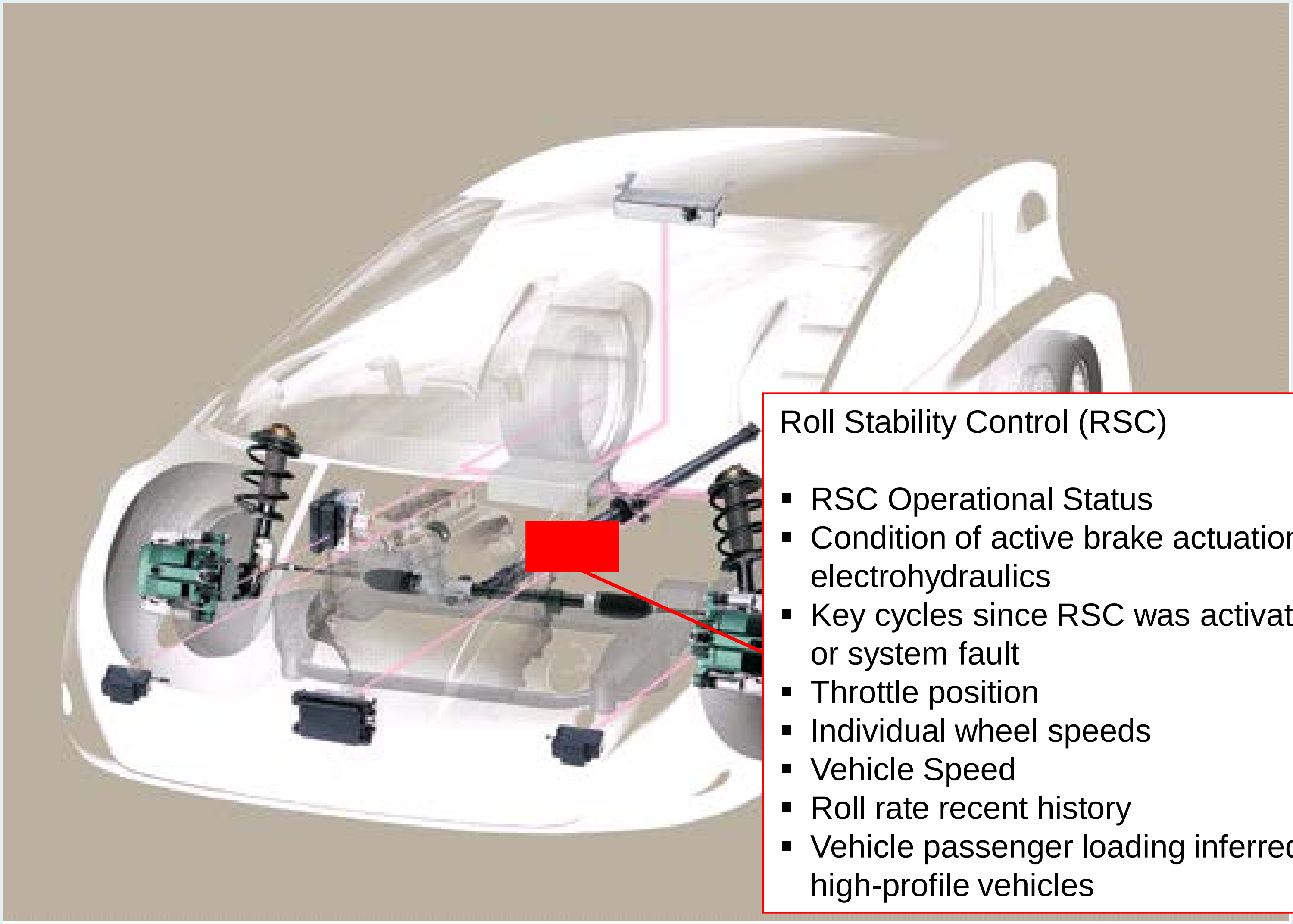
Automotive Systems that Retain Data with Forensic value



Electronic Traction Control (ETC) or Acceleration Slip Control (ASC)

- ETC Operational Status
- Key cycles since ETC was activated or system fault
- Throttle position
- Individual wheel speeds
- Vehicle Speed
- Coefficient of friction of road surface inferred

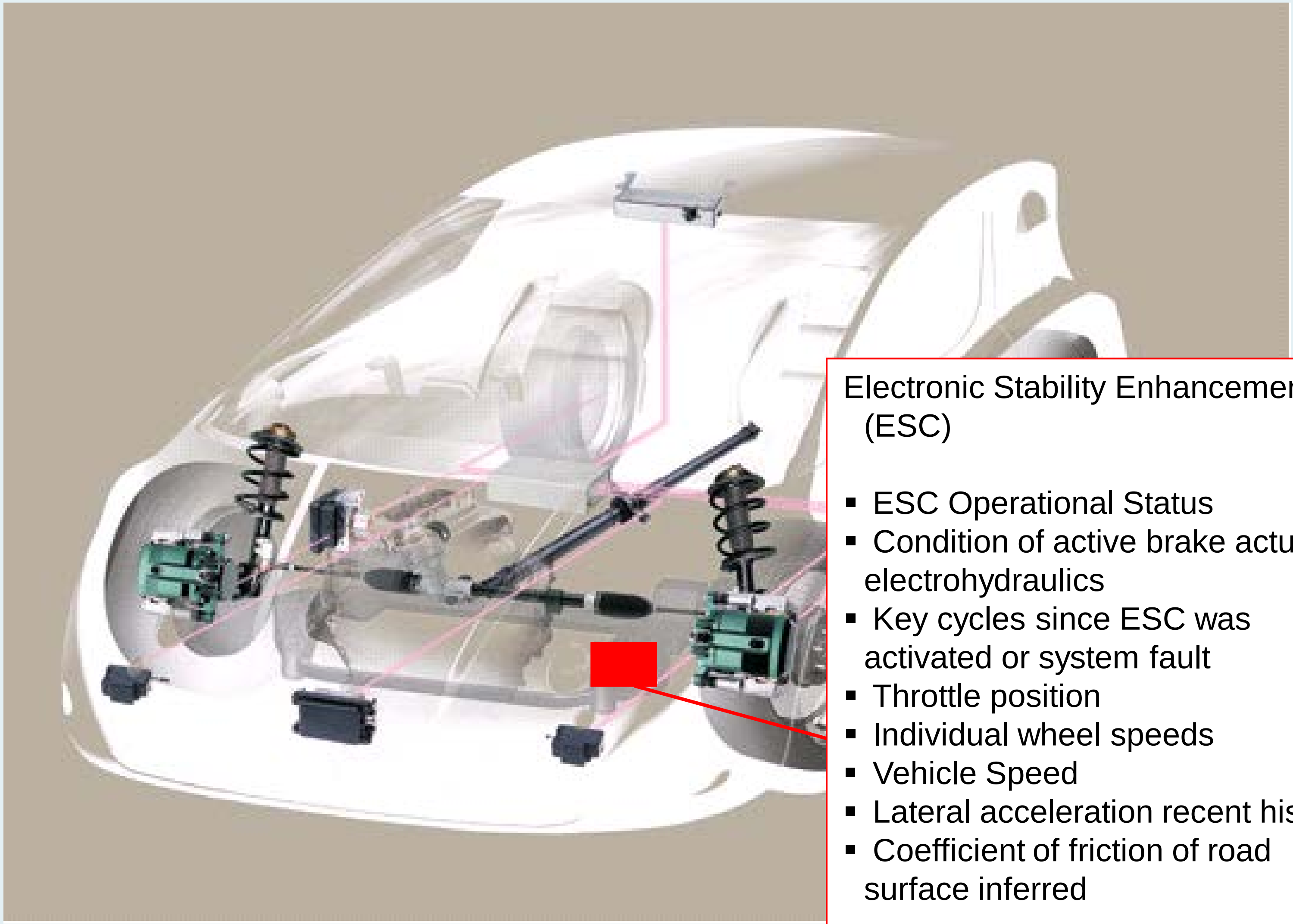
Automotive Systems that Retain Data with Forensic value



Roll Stability Control (RSC)

- RSC Operational Status
- Condition of active brake actuation electrohydraulics
- Key cycles since RSC was activated or system fault
- Throttle position
- Individual wheel speeds
- Vehicle Speed
- Roll rate recent history
- Vehicle passenger loading inferred, high-profile vehicles

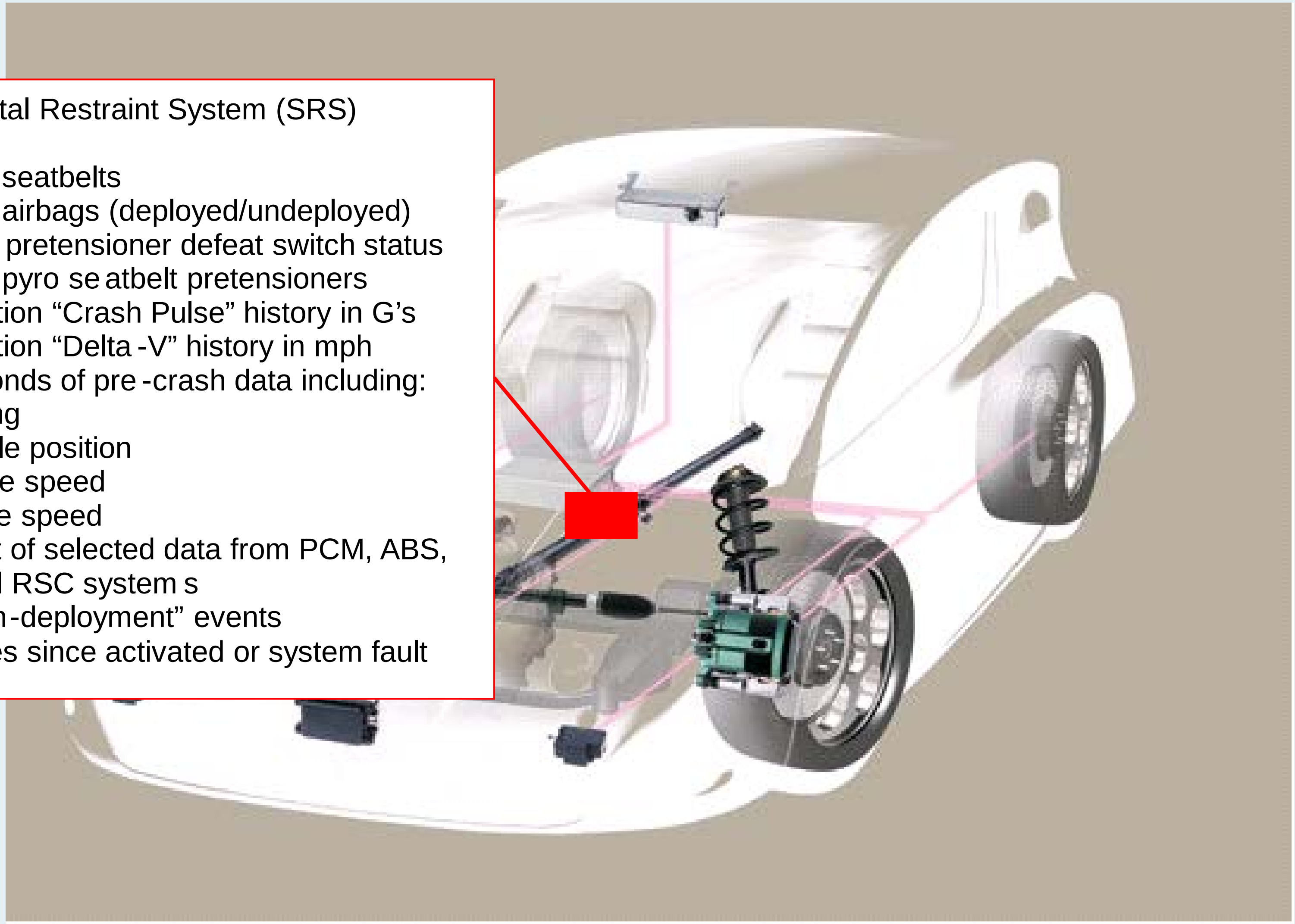
Automotive Systems that Retain Data with Forensic value



Electronic Stability Enhancement (ESC)

- ESC Operational Status
- Condition of active brake actuation electrohydraulics
- Key cycles since ESC was activated or system fault
- Throttle position
- Individual wheel speeds
- Vehicle Speed
- Lateral acceleration recent history
- Coefficient of friction of road surface inferred

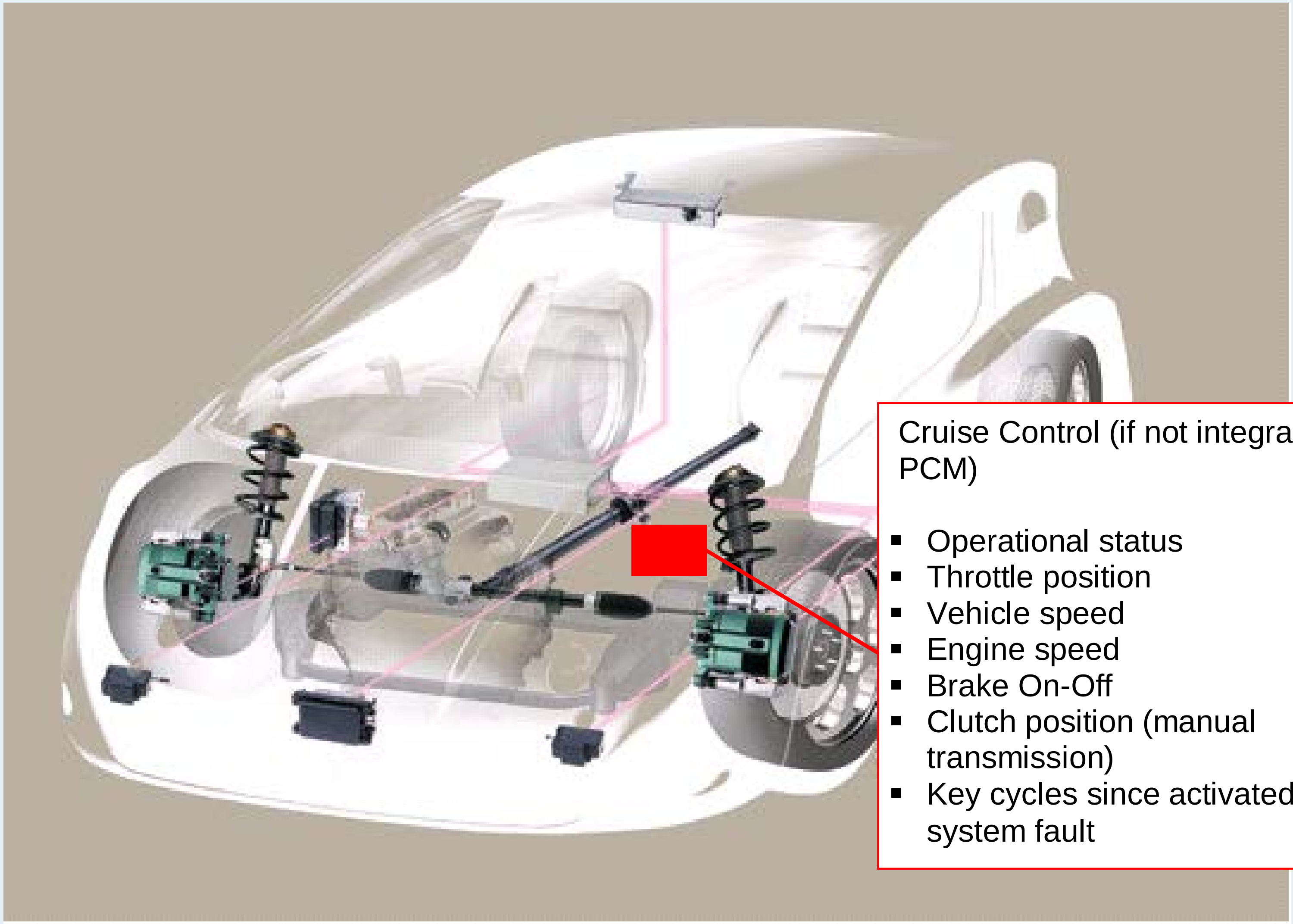
Automotive Systems that Retain Data with Forensic value



Supplemental Restraint System (SRS)

- Status of seatbelts
- Status of airbags (deployed/undeployed)
- Airbag or pretensioner defeat switch status
- Status of pyro seatbelt pretensioners
- Deceleration “Crash Pulse” history in G’s
- Deceleration “Delta-V” history in mph
- Five seconds of pre-crash data including:
  - Braking
  - Throttle position
  - Vehicle speed
  - Engine speed
- Snapshot of selected data from PCM, ABS, ESC, and RSC systems
- Prior “non-deployment” events
- Key cycles since activated or system fault

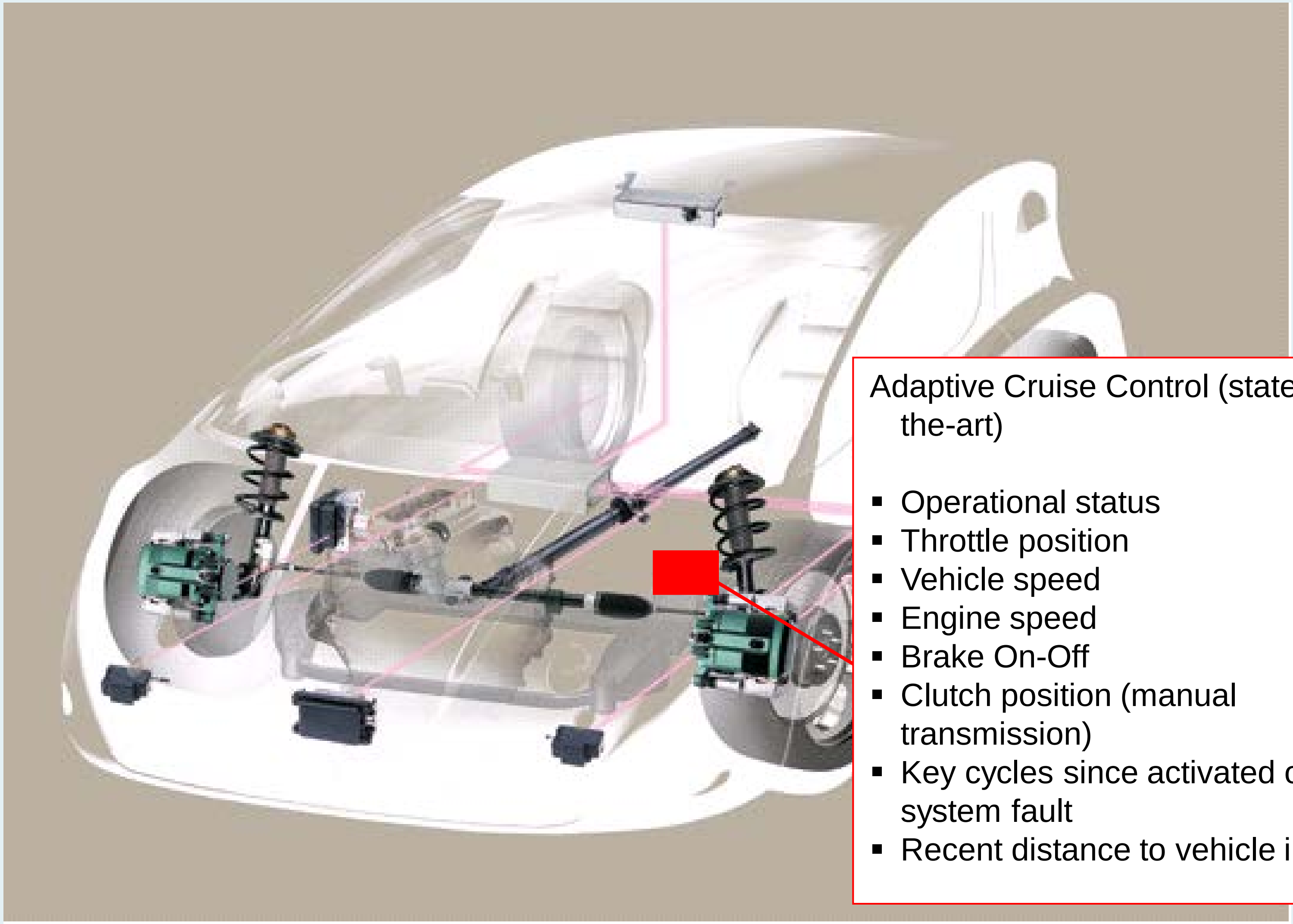
Automotive Systems that Retain Data with Forensic value



Cruise Control (if not integrated in PCM)

- Operational status
- Throttle position
- Vehicle speed
- Engine speed
- Brake On-Off
- Clutch position (manual transmission)
- Key cycles since activated or system fault

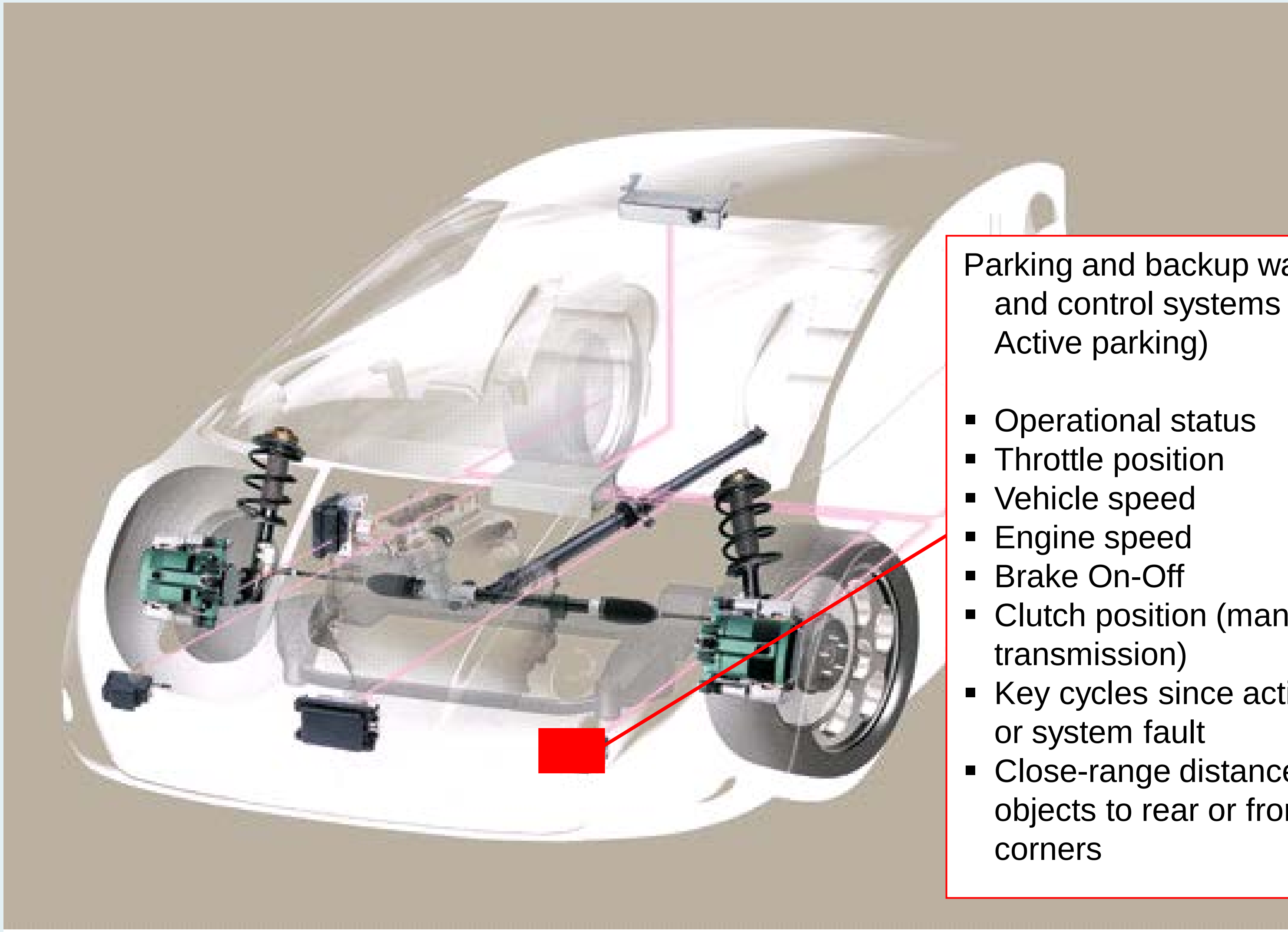
Automotive Systems that Retain Data with Forensic value



Adaptive Cruise Control (state-of-the-art)

- Operational status
- Throttle position
- Vehicle speed
- Engine speed
- Brake On-Off
- Clutch position (manual transmission)
- Key cycles since activated or system fault
- Recent distance to vehicle in front

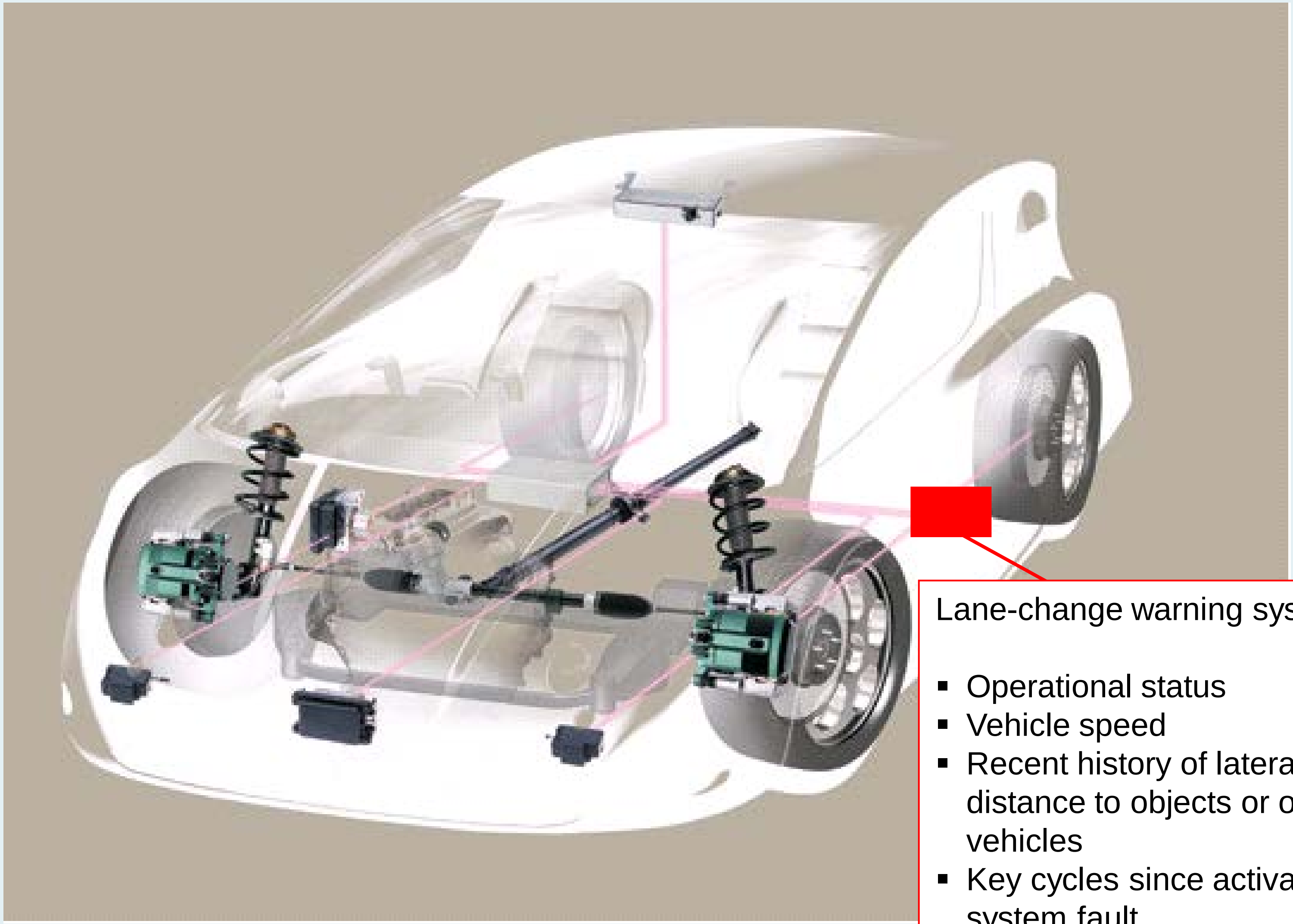
Automotive Systems that Retain Data with Forensic value



Parking and backup warning and control systems (incl. Active parking)

- Operational status
- Throttle position
- Vehicle speed
- Engine speed
- Brake On-Off
- Clutch position (manual transmission)
- Key cycles since activated or system fault
- Close-range distance to objects to rear or front corners

Automotive Systems that Retain Data with Forensic value



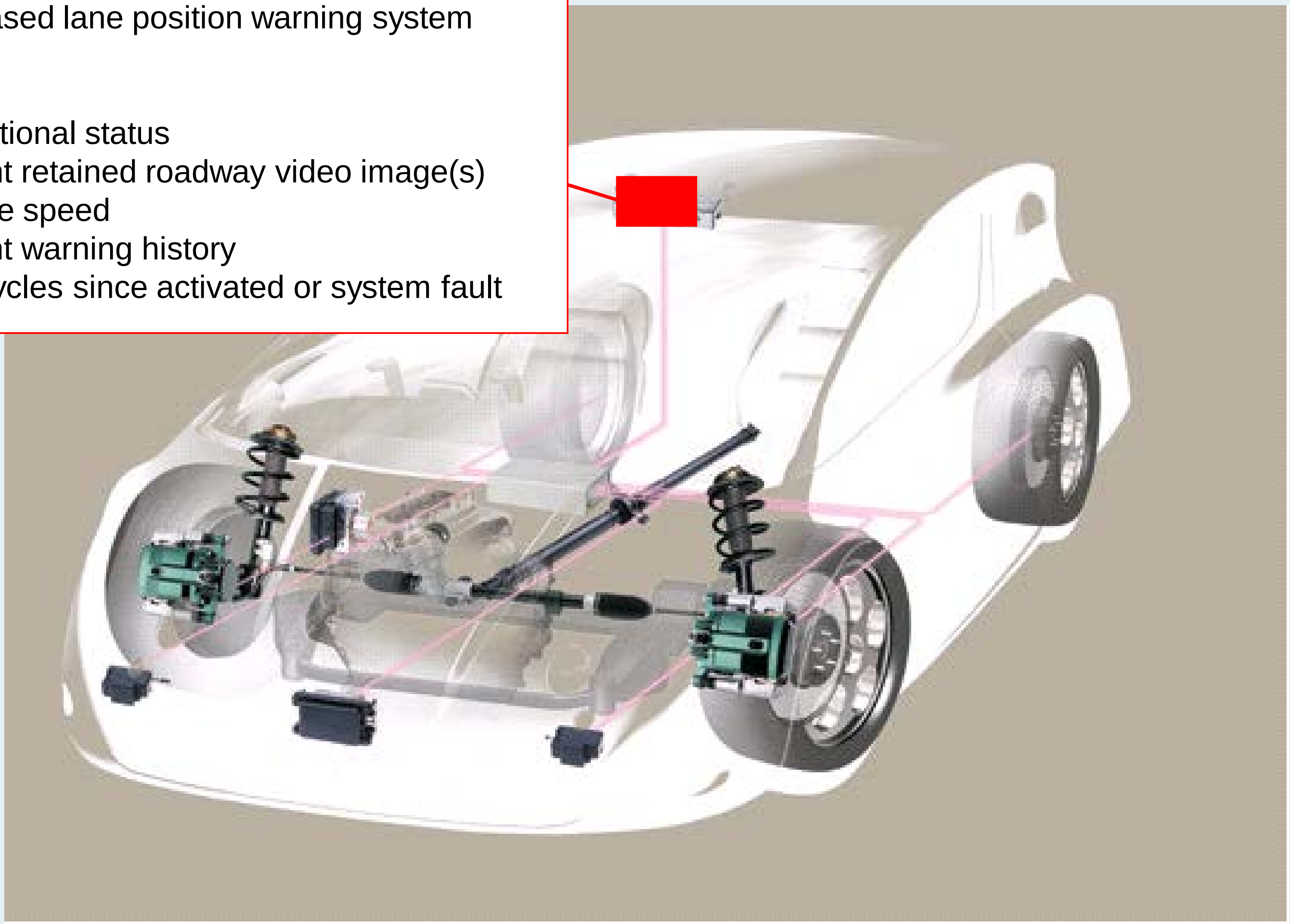
Lane-change warning system

- Operational status
- Vehicle speed
- Recent history of lateral distance to objects or other vehicles
- Key cycles since activated or system fault

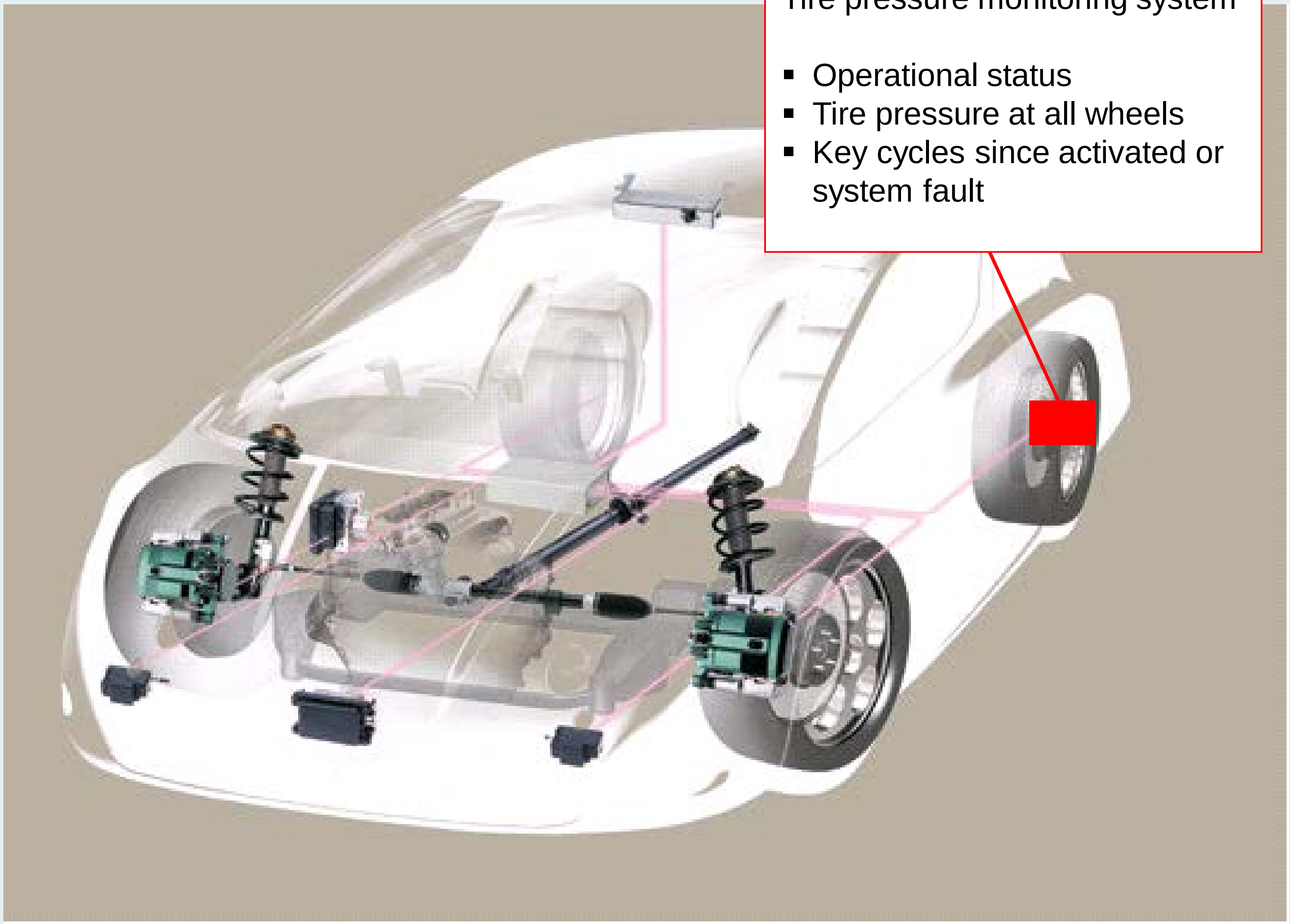
Automotive Systems that Retain Data with Forensic value

Vision-based lane position warning system (Iteris)

- Operational status
- Recent retained roadway video image(s)
- Vehicle speed
- Recent warning history
- Key cycles since activated or system fault



Automotive Systems that Retain Data with Forensic value



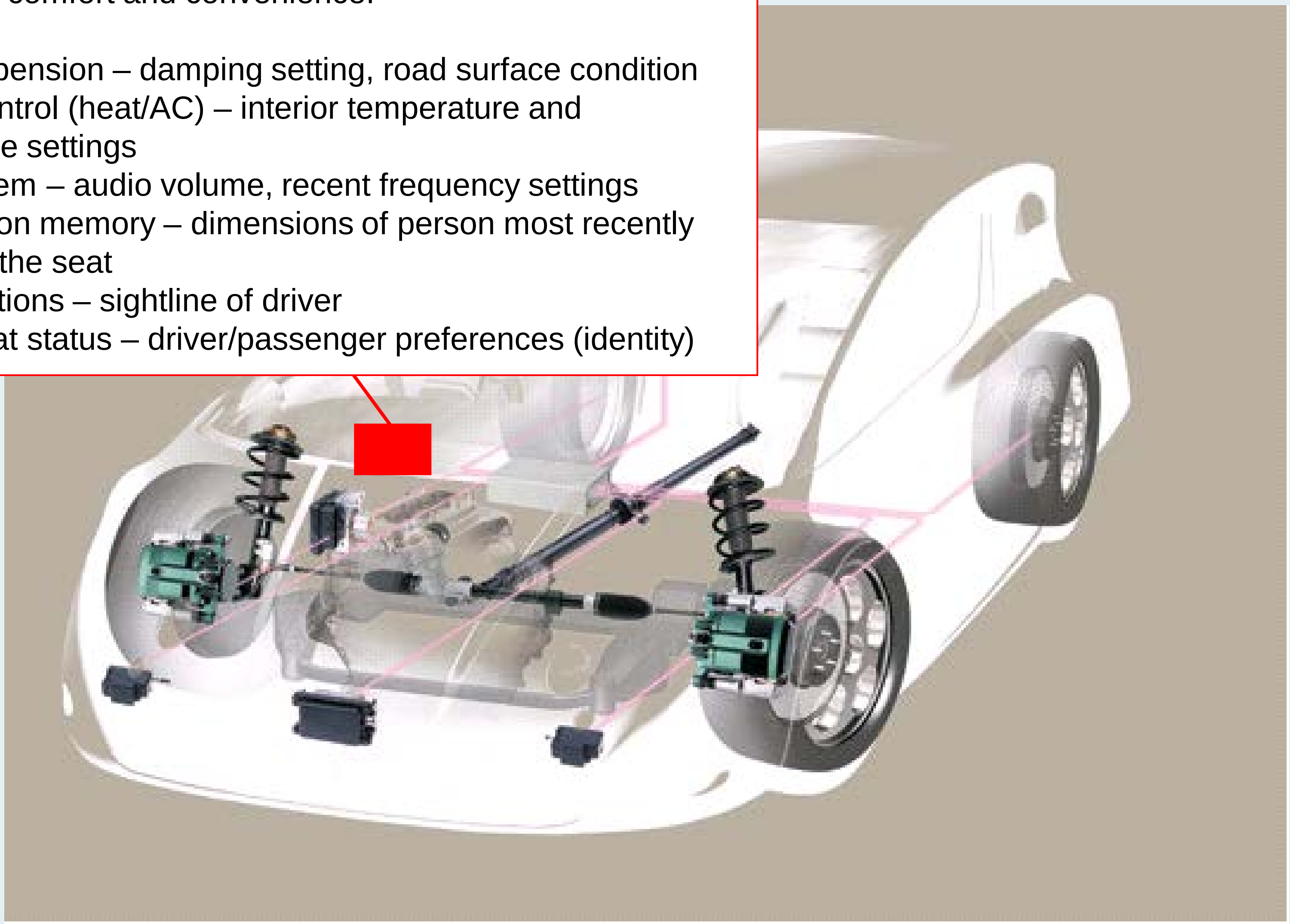
Tire pressure monitoring system

- Operational status
- Tire pressure at all wheels
- Key cycles since activated or system fault

Automotive Systems that Retain Data with Forensic value

Passenger comfort and convenience:

Active suspension – damping setting, road surface condition
Climate control (heat/AC) – interior temperature and temperature settings
Audio system – audio volume, recent frequency settings
Seat position memory – dimensions of person most recently occupying the seat
Mirror positions – sightline of driver
Heated seat status – driver/passenger preferences (identity)



Automotive networks in current use:

ISO 9141	Single-wire (slow), International Standard
CAN-I	Controller Area Network, Gen. 1 (10.4 – 41.6 kbps)
CAN – II	Controller Area Network, Gen. 2 (125 kbps)
CAN – HSC	Controller Area Network, High Speed (500 kbps)
SCP -	Serial Corporate Protocol, proprietary, non-standard
UBP -	UART-Based Protocol, proprietary, non-standard

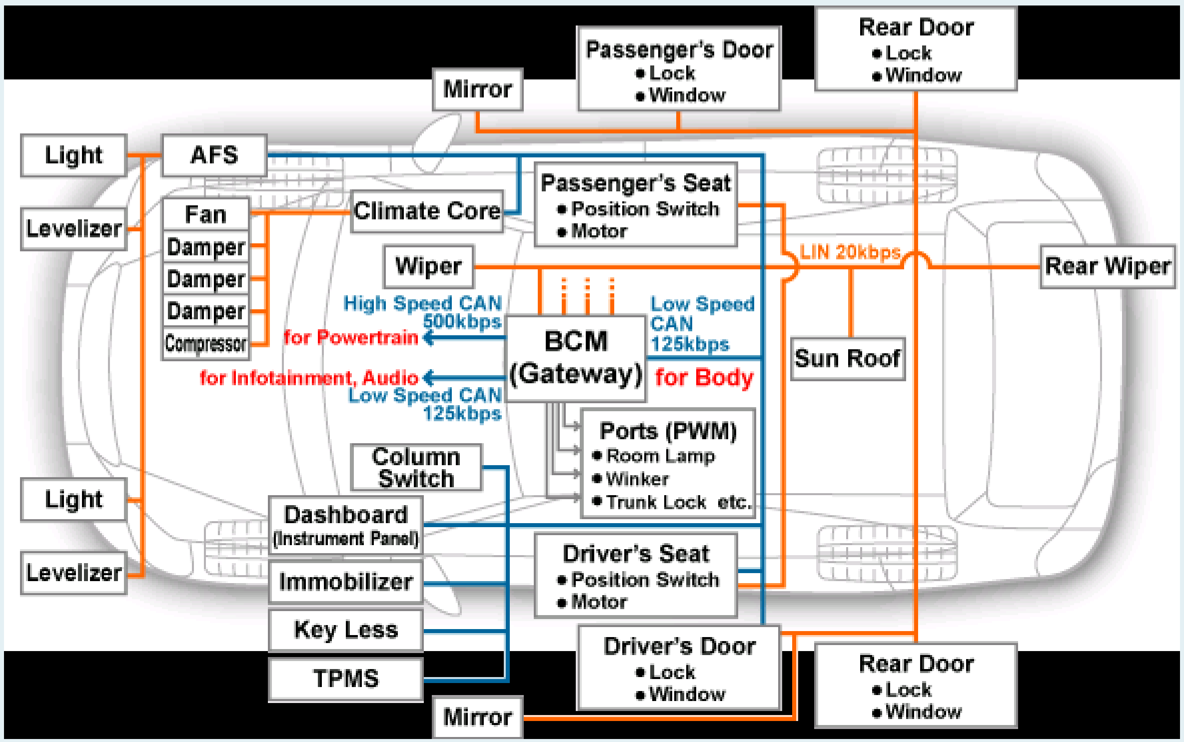


Figure from
http://japan.renesas.com/

SRS "Black Box" Modules

Downloading SRS data from accessible vehicles…

Requires specialized equipment, and number of supported modules is limited

Sample Supported GM Vehicles

1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

1994

Make Model Cable Module Location

Buick Commercial **02003002 *** LF side under dash

Buick Roadmaster **02003002 *** LF side under dash

Cadillac Commercial **02003002 *** LF side under dash

Cadillac Fleetwood **02003002 *** LF side under dash

Chevrolet Caprice **02003002 *** LF side under dash

Chevrolet Commercial **02003002 *** LF side under dash

Pontiac Grand Prix **02003002 *** Under RF seat

1995

Make Model Cable Module Location

Buick Commercial **02003002 *** LF side under dash

Buick Le Sabre **02003002** Under RF seat

Hexadecimal Data

This page displays all the data retrieved from the air bag module.
It contains data that is not converted by this program.


```
B600:  31 40 4C 00 04 00 00 00
B608:  AA 00 00 00 00 00 00 00
B610:  AA 00 00 00 00 30 93 F9
B618:  F9 F9 F9 F9 F9 F9 FF 00
B620:  AA AA 00 00 00 00 00 7D
B628:  00 00 40 18 06 09 0F 18
B630:  20 27 2D 31 33 35 36 38
B638:  3A 3A 3B 3D 3E 3F 40 41
B640:  42 43 43 44 44 45 45 46
B648:  46 47 2F 5F 1B 00 00 FF
B650:  00 55 55 55 AA AA 00 00
B658:  00 00 7D 00 00 00 00 00
B660:  00 00 00 00 00 00 00 00
B668:  00 00 00 00 00 00 00 00
B670:  00 00 00 00 00 00 00 00
B678:  00 00 00 00 00 00 2F 4F
B680:  00 00 00 55 AA AA AA AA
B688:  00 00 00 38 92 00 00 3A
B690:  93 00 00 3A 94 00 00 00
B698:  00 00 00 31 8E 00 00 34
B6A0:  8F 00 00 38 90 00 00 38
B6A8:  91 00 00 00 00 00 00 00
B6B0:  00 00 00 00 00 00 00 00
B6B8:  00 00 00 00 00 92 6E C6
B6C0:  34 4E 1A 01 00 64 02 AA
B6C8:  AA AA 00 00 00 00 01 01
B6D0:  BE B1 C6 A5 B7 AE BE AC
B6D8:  F7 6F B4 78 D9 E0 00 00
B6E0:  00 00 FF FF 00 00 01 53
B6E8:  01 55 00 00 00 00 00 00
B6F0:  FF 03 F0 05 50 06 0C 22
B6F8:  58 6E 6E 6E 6E 6E 6E 6E
B700:  6E 6E 6E 6E 6E 6E 6E 6E
B708:  6E 73 79 81 88 91 98 A3
B710:  AA B6 C0 CA D3 DD E5 ED
B718:  F3 FC 40 43 45 47 49 4C
B720:  4F 51 54 57 59 5C 5E 60
B728:  62 64 66 67 69 6A 6B 6C
B730:  6E 6F 70 71 72 73 74 74
B738:  75 76 77 7C 82 87 8C 90
B740:  94 99 9D A1 A7 AB B1 B6
B748:  BB BF C3 C7 CC CF D3 D6
B750:  DA FF FF FF FF FF FF FF
B758:  FF FF FF FF FF 00 48 01
B760:  68 05 04 46 28 12 10 01
B768:  06 AA 00 46 47 37 37 37
B770:  39 3A 42 42 42 48 4A 4B
B778:  4B 4F 54 57 5D 5E 5E 5E
B780:  5E 5E 5E 5E 5E 5E 5E 5E
B788:  5E 5E 5E 5E 5E 5E 5E 5E
B790:  63 67 6C 71 76 7B 80 85
B798:  8A 8A 8C 8F 8F 8F 8F 8F
B7A0:  8F 8F 8F 8F 8F 8F 8F 8F
B7A8:  8F 8F 8F 8F 8F 8F 8F 8F
B7B0:  8F 8F 8F FF FF FF FF FF
B7B8:  FF FF FF FF FF 00 AA 00
B7C0:  00 00 C0 57 00 00 00 00
B7C8:  00 00 00 00 00 00 00 00
```

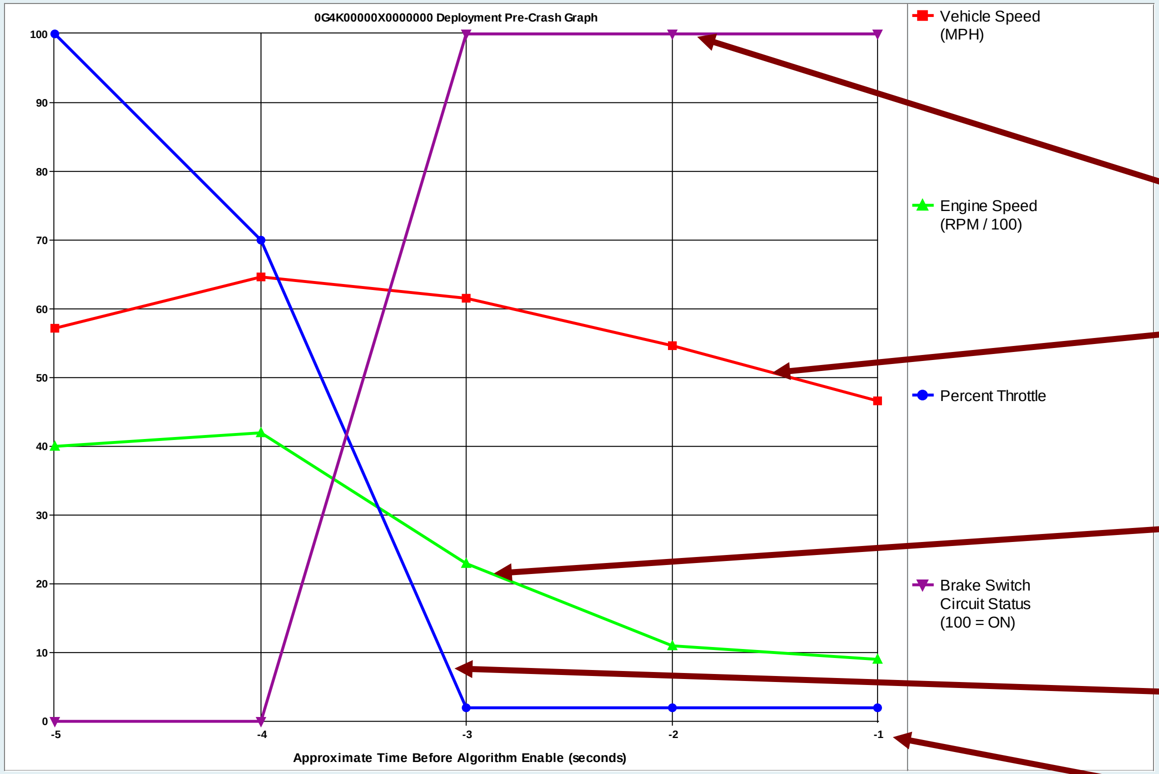

Demonstration of an SRS module
download – 1998 Saturn Sedan

System Status At Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	UNBUCKLED
Ignition Cycles At Deployment	187
Ignition Cycles At Investigation	213
Time From Algorithm Enable to Deployment Command Criteria Met (msec)	18.75
Time Between Non-Deployment And Deployment Events (sec)	N/A

Pre-crash data:

Often used in litigation



Brake switch (on/off)

Vehicle speed (RPM)

Engine speed (RPM)

Throttle position (%)

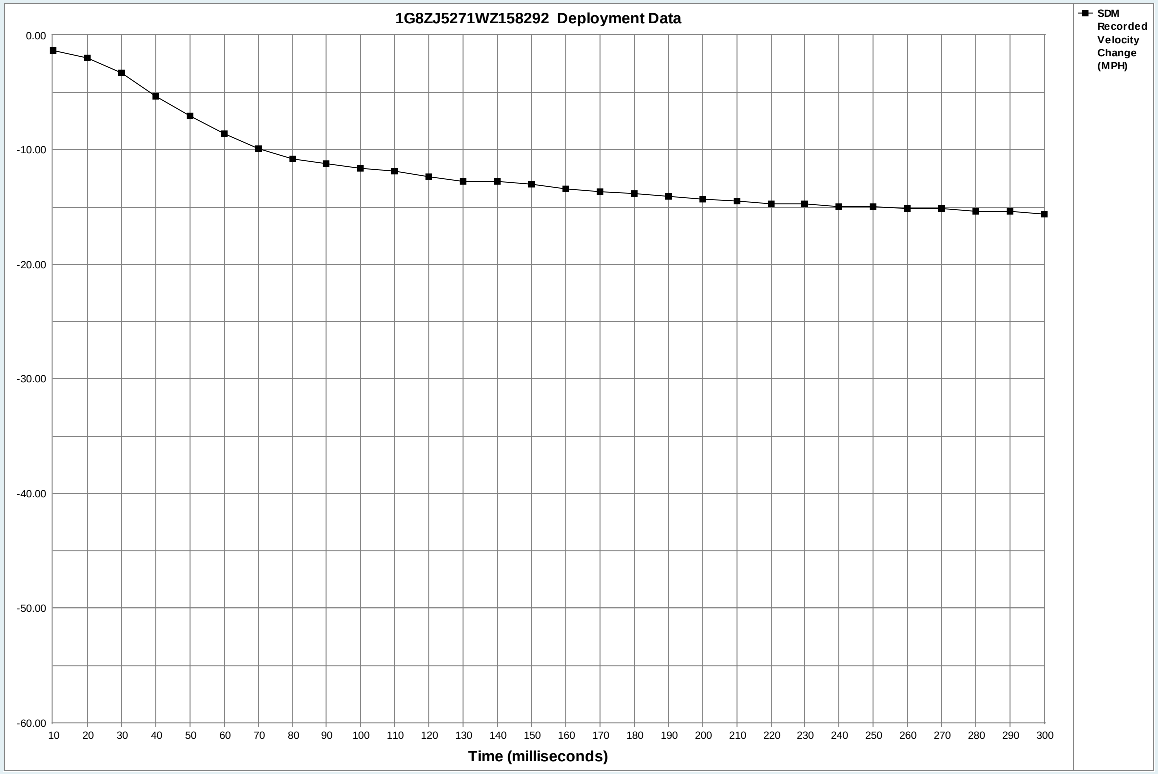
1 second before impact

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	57	4032	100	OFF
-4	65	4160	70	OFF
-3	62	2304	2	ON
-2	55	1088	2	ON
-1	47	896	2	ON

Numeric data: 5 samples of each parameter, T=1 second

System Status At Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	UNBUCKLED
Passenger Front Air Bag Suppression Switch Circuit Status	Air Bag Not Suppressed
Ignition Cycles At Deployment	12127
Ignition Cycles At Investigation	12147
Time From Algorithm Enable To Deployment Command (msec)	30
Time Between Non-Deployment And Deployment Events (sec)	N/A



The Crash Pulse:

Sampled deceleration and speed data used to gauge the severity of the forces on the occupants and verify that active restraints operated correctly.

Legislation Affecting Automotive Data Retention

Legislation has been enacted in at least 4 states in 2006: Colorado, Maine, New Hampshire, Virginia, and introduced in at least 20 states in 2006. Ten states have enacted laws since 2004.

Example:

COLORADO
S.B. 224
06/06/06 Signed by Governor, Chapter 329
Sponsors: Traylor, Grossman, and Tupa
Requires motor vehicle manufacturers to disclose that a motor vehicle has an event data recorder. Prohibits retrieval of event data from a motor vehicle except under specific circumstances. Prohibits the release of event data unless released to a motor vehicle safety and medical research entity or data processor in order to advance motor vehicle safety, security, or traffic management.

For complete list: http://www.ncsl.org/programs/lis/privacy/blackbox06.htm

Legislation Affecting Automotive Data Retention

In 2004, California became the first state to enact legislation (Calif. Vehicle Code § 9951) requiring manufacturers to disclose to customers whether event data recorders or "black boxes" are installed in vehicles. The law also prohibits downloading data without the owner's permission or a court order.   24 states have followed this lead as of 1/1/07.

Further, California (Calif. Civil Code § 1936) and New York (New York Gen. Bus. Law § 396-z) passed laws prohibiting rental car companies from using electronic surveillance or GPS-based devices to impose fees, charges or penalties relating to the renter's use of the vehicle.

The National Highway Traffic Safety Administration (NHTSA) opened debate in 2004 (NHTSA-2004-18029) resulting in Federal law passed August 2006 requiring automakers to inform new car buyers if the vehicle is equipped with crash-related EDR capability, beginning with model year 2011 cars.