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In November of 1998, Triodyne published a Safety Bulletin entitled "Electronic Control Module - The 'Flight Recorder' of Heavy Trucks," by John Goebelbecker and Christopher Ferrone. We have had so many requests for more information that we decided to reprint this longer article which John and Chris wrote for the Society of Automotive Engineers (Paper No. 2000-01-0466)

Utilizing Electronic Control Module Data in Accident Reconstruction

By John M. Goebelbecker, P.E.*
and Christopher Ferrone**

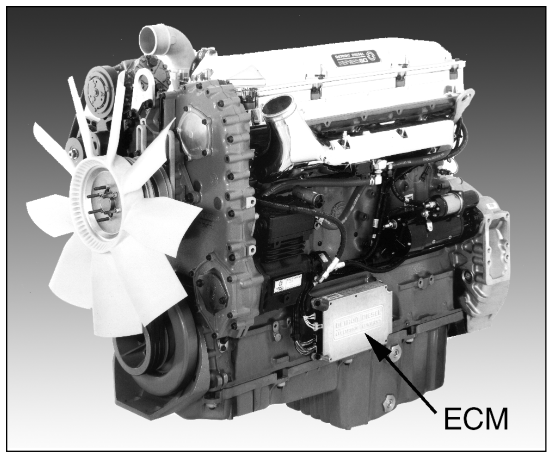

Figure. 1: Detroit Diesel Series 60 Engine

ABSTRACT

A heavy truck manufactured in the late 1990's is likely to be equipped with an electronic control module (ECM) which has the capability of being the truck's "flight recorder" in a serious accident. Extracting data from the ECM often answers critical questions regarding vehicle speed and the driver's actions leading up to, during and after a vehicle accident. This paper will briefly discuss the development of the diesel engine ECM from the late 1980's to the present with emphasis on the data recording capabilities related to vehicle accident reconstruction. In particular, vehicle diagnostic sensors which continuously monitor engine speed, vehicle speed, brake switch condition (on/off), clutch position (on/off), cruise switch condition (on/off), etc. will be discussed, as well as software capabilities which track rapid deceleration events ("quick stop occurrences") and provide a "snapshot" of the vehicle's properties during the moments just prior to and after a collision. Recommendations on how one might interrogate an ECM and preserve post-crash data will be presented. Several case studies highlighting the use of data obtained from a truck's ECM after a crash will be discussed.

INTRODUCTION

The electronic control module acts as the brain of the engine and controls all aspects of the engine's operation. It is typically mounted to the engine block, as shown in Figure 1. A wire harness plugs into the input/output jack of the ECM and the unit is powered by the

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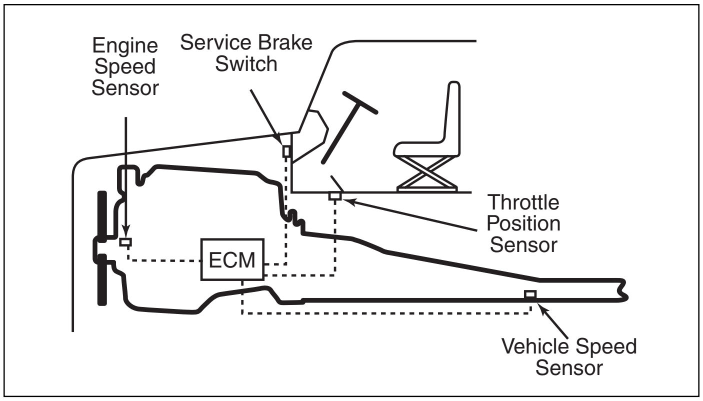


Figure. 2: Typical Sensor Placement

engine's 12 volt power supply. Numerous sensors located throughout the vehicle and engine provide input signals which are processed by the ECM. For example, Figure 2 illustrates the placement of several key sensors for accident reconstruction: the vehicle speed sensor, the engine speed sensor, the throttle position sensor and the brake switch sensor. In addition to controlling the engine's performance to minimize emissions and maximize efficiency, today's electronic control modules also have built-in memory capacity which records historical data about the operation of the vehicle. For example, overall fuel economy, idle time, number of hard braking occurrences and number of vehicle overspeeds assist a fleet manager to carefully monitor the performance of both the vehicle and the driver. Some typical parameters monitored by the ECM are listed in Table 1.

TOTAL VEHICLE DRIVING TIME	TOTAL VEHICLE DRIVING DISTANCE	TRIP DRIVING TIME
TRIP DISTANCE	FUEL CONSUMPTION (GAL/HR)	OVERALL FUEL ECONOMY (MPG)
LOAD FACTOR	IDLE TIME	AVERAGE DRIVING SPEED
VEHICLE SPEED LIMIT	ENGINE GOVERNED SPEED	# OF ENGINE OVERSPEEDS
MAXIMUM VEHICLE SPEED RECORDED	MAXIMUM ENGINE SPEED RECORDED	# OF VEHICLE OVERSPEEDS
# HARD BRAKE INCIDENTS	CURRENT THROTTLE POSITION (%)	CURRENT VEHICLE SPEED (MPH)
CURRENT ENGINE SPEED (RPM)	BRAKE SWITCH STATUS (ON/OFF)	CLUTCH SWITCH STATUS (ON/OFF)
MAX. AND MIN. CRUISE SPEED LIMITS	ODOMETER	CLOCK

Table 1 *- Engine and Vehicle Parameters Monitored and/or Controlled by the Electronic Control Module*

BACKGROUND

Detroit Diesel Corporation began research and development of electronic control systems in 1978 and introduced the industry's first fully integrated electronic fuel injection and governing system for heavy duty diesel engines in 1985 with Detroit Diesel Electronic Control (DDEC). Competitive fuel economy and performance at legislated reduced exhaust emissions were the initial goals. In 1987, Detroit Diesel introduced DDEC II which was developed to take advantage of rapid gains in electronic technology. DDEC II utilized an engine mounted, fuel cooled electronic control module to act as the brain of the engine to control performance enhancing parameters such as injector timing and fuel/air ratios by continuously monitoring electronic sensors located throughout the engine. In addition, the customer could reprogram the ECM to specify maximum road speed, cruise control settings, high idle, power take-off operation, engine protection, governor overrun and idle shutdown.

Cummins introduced electronically controlled road speed governing and cruise control in 1986 and full authority systems in 1990 on the N14 and L10.

Caterpillar Inc. introduced its first programmable electronic engine controlled (PEEC) power units in 1987. In 1988, Caterpillar introduced its new 3176 electronically controlled diesel engine equipped with an ECM which was more powerful and flexible than PEEC. Sensors on the engine continuously monitored engine speed, piston position, boost pressure and fuel pressure. The standard software module allowed electronic engine governing, fuel/air ratio control, torque rise shaping, programmable engine ratings, injection timing control, and self-diagnostics. An optional vehicle software module allowed the customer to program progressive shifting limits, limit road speed and adjust an idle shut down timer, and the driver was provided a fuel consumption dashboard signal. These improved electronic controls led to a 3% to 5% improvement in fuel efficiency and compliance with EPA emission requirements through 1991.

In 1993, Caterpillar introduced its new generation ECM with its new 3176B and 3406E engines. Enhanced ECM capabilities included a soft-cruise feature which modulated fuel delivery above and below cruise set speed. The ECM also tracked engine lifetime and trip information such as miles driven, hours of operation, idle time, average speed, average mpg and average load factor.

Detroit Diesel introduced DDEC III in 1994 in response to government regulations for more stringent air quality standards, demand from customers for additional electronic engine features and electronics improvements in microprocessor capabilities. DDEC III was eight times faster and had seven times the memory capacity of its predecessor, DDEC II.

In June 1996, Caterpillar announced the availability of Fleet Information Software, Version 2.0, which included the "Engine Event Report" and "Quick Stop Recorder." The former provided a time and date stamp when a significant engine or vehicle event occured, such as a quick stop occurrence, low oil pressure and vehicle overspeed. The latter recorded the status of six items: engine speed (rpm), throttle position (% throttle), clutch switch (engaged/disengaged), vehicle speed (mph), cruise control (on/off), and the vehicle braking switch (engaged/disengaged) during a rapid deceleration of drive wheel speed.

Also in 1996, Caterpillar's 3406E engine was capable of transmitting real time vehicle and engine data to the home office utilizing the engine's ECM and mobile communications gear. Caterpillar's Fleet Information Software then

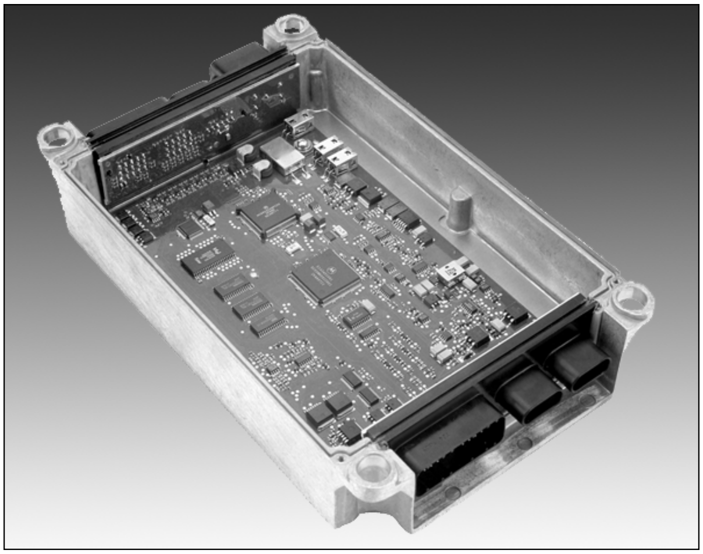


Figure. 3: Detroit Diesel DDEC IV ECM

organized, stored the data and prepared reports which included road and engine speed, incidents of sudden deceleration and graphs of idling percentages.

In 1998, Caterpillar introduced the 3126B engine which incorporated an all-new ECM with a 32 bit, 16Mhz processor and in 1999, Caterpillar introduced its Advanced Diesel Engine Management (ADEM) 2000 which is three times faster than its predecessor and is equipped with additional memory. Used properly, ADEM can offset any loss of fuel economy from stricter EPA emissions regulations for medium and heavy-duty trucks by precisely monitoring and controlling the fuel-injection process and responding quickly to ever-changing operating variables of the engine.

In 1998, Cummins discontinued production of the L10 and introduced the ISL which is controlled by Cummin's latest microprocessor-based engine controls. Besides the usual diagnostic and prognostic capabilities, the ECM can provide a range of functions such as fan clutch control, remote throttling, retarder controls, fuel temperature compensation and gear down/out of gear protection.

Detroit Diesel introduced its newest generation of electronic controls, DDEC IV, in 1998. See Figure 3. It was touted as the most powerful electronic control system available on any heavy duty engine. The new ECM has 57% more memory and 50% more speed than its predecessor, DDEC III. Some features include ProDriver which gives drivers feedback on their performance and Optimized Idle System which automatically starts and stops the engine. DDEC IV has data recording capabilities which can be used for accident reconstruction. Data records of the last two hard braking events are stored in the ECM's memory. As additional hard braking events occur, the most distant record is overwritten. Vehicle speed, engine speed, throttle position and brake and clutch switches are recorded for a period of time before and after the hard braking event occurs. The Detroit Diesel Series 60 is the most popular heavy duty truck engine in North America.

ECM DATA AND ACCIDENT RECONSTRUCTION

Many commercial vehicle accidents involve heavy braking before, during and/or after an impact. When the property damage is extensive and/or persons are injured, the events leading up to the accident are scrutinized. The actions of a truck driver and the operation of the vehicle in the seconds prior to an accident will determine whether the driver and his employer acted in a reasonable way. Certain electronic control modules can record data automatically when a driver applies the brakes in an emergency. If the vehicle wheels decelerate at a rate of 7 mph/sec (default value set by the factory) or more, the ECM will take a snapshot of the data it continuously accumulates and monitors. The time span and interval for data collection vary, but data collection every second for one minute before the onset of rapid deceleration and 15 seconds after is not uncommon. Hence, with over a full minute of vehicle and driver data stored in the ECM's memory, an accident reconstructionist can access this critical data for use in the reconstruction analysis. In particular, parameters such as vehicle speed (mph), throttle position (%), brake pedal application (on/off), clutch status (on/off), and engine speed (rpm) are monitored and recorded every second as shown in Figures 4 and 5. Such data indicate the vehicle speed, throttle position and engine speed before the driver was faced with the hazard. Once faced with the hazard, the driver may have removed his foot from the accelerator, disengaged the clutch and applied the brake, as reflected in the ECM data record. If the truck collided with another vehicle or fixed object, the subsequent change in vehicle speed may be reflected in the ECM data, thus identifying the time of impact. (Collisions between automobiles and heavy trucks do not generally show a significant change in the truck's speed due to the large disparity in weight of the two vehicles.)

Figures 4 and 5 depict typical data generated by Detroit Diesel's DDEC IV ECM and Reports, Version 3.00 software. The data can be displayed in either tabular or graphical form on a laptop computer and saved to a disk to be printed onsite or at the office. The hard brake incident is marked by a vertical line on the graphs corresponding to t=0s. At t=0s, a rapid deceleration has been detected. Sixty seconds of data prior to and fifteen seconds of data after the hard brake incident are recorded and displayed. The jagged plots of engine speed and throttle position indicate gear changes as the vehicle increased speed. Column 5 of the tabular report and the bottom of the graphical report show clutch status (engaged or disengaged), further describing the action of the driver. After achieving a maximum speed of 29.0 mph, the driver released the clutch, moved his foot off the accelerator and applied the brake between t=-2s and t=-1s. The vehicle came to rest in less than four seconds.

The vehicle speed is determined by a sensor located on the output shaft of the transmission. A rotating speed sensor ring creates pulses which are calibrated to the vehicle's differential ratio and the rolling radius of the tires. Those two parameters define the number of pulses generated per mile which is then utilized by the ECM software to calculate vehicle speed based on the rate of signals detected at the speed sensor ring every second. For example, on a truck equipped with an axle

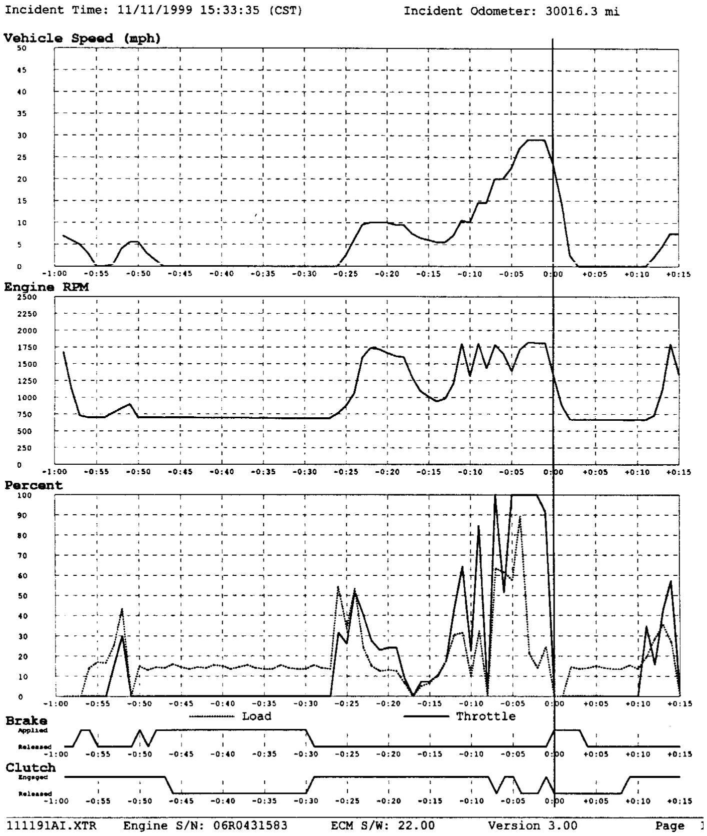


Figure. 4: ECM Hard Brake Data Graphics

Incident Time: 11/11/1999 15:33:35 (CST) Incident Odometer: 30016.3 mi

Time	Vehicle Speed (mph)	Engine Speed (rpm)	Brake	Clutch	Engine Load (%)	Throttle (%)	Cruise	Diagnostic Code
-0:20	9.5	1615	No	Yes	12.50	24.00	No	No
-0:19	9.5	1598	No	Yes	6.50	8.80	No	No
-0:18	7.5	1302	No	Yes	0.00	0.00	No	No
-0:17	6.5	1096	No	Yes	5.00	7.20	No	No
-0:16	6.0	1011	No	Yes	6.50	7.20	No	No
-0:15	5.5	939	No	Yes	10.50	10.00	No	No
-0:14	5.5	980	No	Yes	17.50	17.60	No	No
-0:13	7.0	1203	No	Yes	30.50	43.20	No	No
-0:12	10.5	1799	No	Yes	31.50	64.40	No	No
-0:11	10.0	1316	No	Yes	10.00	22.40	No	No
-0:10	14.5	1804	No	Yes	32.50	84.80	No	No
-0:09	14.5	1432	No	Yes	0.00	0.00	No	No
-0:08	20.0	1782	No	No	63.50	100.00	No	No
-0:07	20.0	1653	No	Yes	61.50	51.20	No	No
-0:06	22.5	1390	No	Yes	57.50	100.00	No	No
-0:05	27.0	1711	No	No	89.50	100.00	No	No
-0:04	29.0	1819	No	No	21.00	100.00	No	No
-0:03	29.0	1811	No	No	14.00	100.00	No	No
-0:02	29.0	1809	No	Yes	24.50	91.60	No	No
-0:01	23.5	1336	Yes	No	0.00	0.00	No	No
0:00	14.5	879	Yes	No	0.00	0.00	No	No
+0:01	2.5	668	Yes	No	14.50	0.00	No	No
+0:02	0.0	668	Yes	No	13.50	0.00	No	No
+0:03	0.0	667	No	No	14.00	0.00	No	No
+0:04	0.0	667	No	No	15.00	0.00	No	No
+0:05	0.0	667	No	No	14.00	0.00	No	No
+0:06	0.0	667	No	No	13.50	0.00	No	No
+0:07	0.0	668	No	No	13.50	0.00	No	No
+0:08	0.0	666	No	Yes	15.50	0.00	No	No
+0:09	0.0	667	No	Yes	13.50	0.00	No	No
+0:10	0.0	666	No	Yes	19.50	34.80	No	No
+0:11	2.0	724	No	Yes	28.50	15.60	No	No
+0:12	4.5	1113	No	Yes	35.50	42.40	No	No
+0:13	7.5	1793	No	Yes	26.50	57.20	No	No
+0:14	7.5	1340	No	Yes	0.00	0.00	No	No

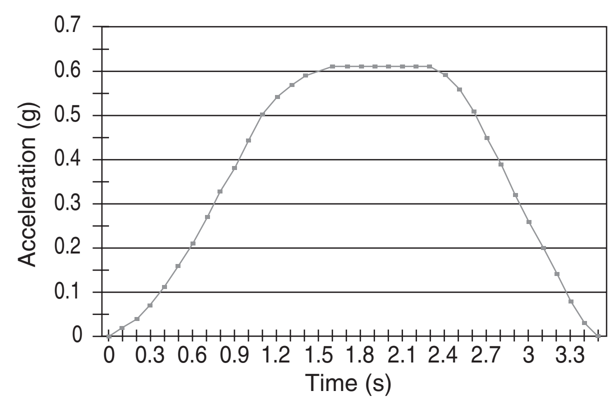
Figure. 5: ECM Hard Brake DataTable

differential ratio of 3.9, tires which rotate at a rate of 495 rev/mile and a 16-tooth vehicle speed sensor ring, the magnetic sensor will detect 30,888 pulses per mile. It is important to recognize that the ECM vehicle speed parameter is not a true vehicle speed and erroneous data will be generated if the tractor drive tires slip, such as when a driver locks up the brakes in an emergency, or when the tires slip during acceleration on a slick surface.

Speed validation tests were conducted for the purpose of evaluating the reliability of the speed data extracted from an ECM after a hard brake occurrence. A 1999 Freightliner 2-axle conventional tractor equipped with the required ABS system and a DDEC IV electronic control module was instrumented with a G-Analyst™ vehicle accelerometer. The accelerometer was installed on the floor of the cab, immediately in front of the driver's seat. The data displayed in Figures 5 and 6 depict a hard brake incident conducted during these tests. The data shown in Figure 6 represent the vehicle's deceleration levels every tenth of a second during the hard brake maneuver. Utilizing the relationship

$$\Delta V = \Sigma a_i t_i$$

the overall change in velocity of the vehicle was calculated. This calculation yielded an initial speed of 29.1 mph, which is in good agreement with the speed recorded in the ECM (29.0 mph).



Time (s)	Acceleration	Time (s)	Acceleration
0.0	0.0	1.8	0.61
0.1	0.02	1.9	0.61
0.2	0.04	2.0	0.61
0.3	0.07	2.1	0.61
0.4	0.11	2.2	0.61
0.5	0.16	2.3	0.61
0.6	0.21	2.4	0.59
0.7	0.27	2.5	0.56
0.8	0.33	2.6	0.51
0.9	0.38	2.7	0.45
1.0	0.44	2.8	0.39
1.1	0.50	2.9	0.32
1.2	0.54	3.0	0.26
1.3	0.57	3.1	0.20
1.4	0.59	3.2	0.14
1.5	0.60	3.3	0.08
1.6	0.61	3.4	0.03
1.7	0.61	3.5	0.00

Figure. 6: Hard Braking Acceleration Data

Caterpillar engines manufactured from 1996 to the present are equipped with electronic control modules capable of recording quick stop occurrence data snapshots. The data sets are stored in memory within the ECM. Later model ECM's are equipped with an internal Lithium battery which acts as a backup for times when the normal external power source (the truck's battery or the engine's alternator) is removed. The expected service life of the Lithium battery is four to six years. Therefore, if a truck is in an accident, the ECM will maintain the quick stop data record for as long as six years after the date of the accident.

A Detroit Diesel electronic control module equipped with DDEC IV is equipped with an internal energy source which maintains the internal clock. However, the quick stop data is stored in non-volatile memory which does not require a power supply thus eliminating concerns about data loss due to battery failure.

In some cases, electronic control modules can be removed from the engine block to preserve the stored data without having to preserve the entire vehicle. Prior to removal, the proper function of the brake switch, clutch switch and throttle position should be confirmed. Then, if the ECM has an internal backup battery, the ECM can be removed for further analysis. If however, the ECM is connected to a 12 volt power source after being removed from an engine, the ECM will detect active fault codes due to the absence of the many sensors which normally provide signals to the ECM. To avoid these fault codes, the ECM can be installed on another engine or a harness which simulates an engine can be connected to the ECM.

Extracting data from an ECM can be accomplished through the SAE multiple pin connector on the driver's side in the cab's dash, as shown in Figure 7. Whereas the communication hardware varies slightly from manufacturer to manufacturer, all utilize the same an SAE multiple pin connector, a communication adapter and a laptop computer loaded with the appropriate software. If the cab is badly damaged from an accident, the connection to the ECM may be damaged as well. In such cases, the ECM can be interrogated directly using alternate wiring.

The hard brake data recording feature can be enabled or disabled by the owner. For example, setting the rate of deceleration to 0 mph per second in Caterpillar engines disables the feature and Detroit Diesel engines have a toggle switch in the ECM software which can be turned on or off by the end user.

CASE STUDIES

COLINEAR IMPACT. When a tractor trailer rear-ends another tractor trailer, conventional methods of accident reconstruction utilizing conservation of energy and conservation of momentum techniques do not readily yield a unique solution for pre-impact speeds. Knowing the point of impact, impact to rest position distance and overall drag factor of the vehicles, the post impact speed can be calculated. Conservation of momentum principles can be employed to establish a relationship between

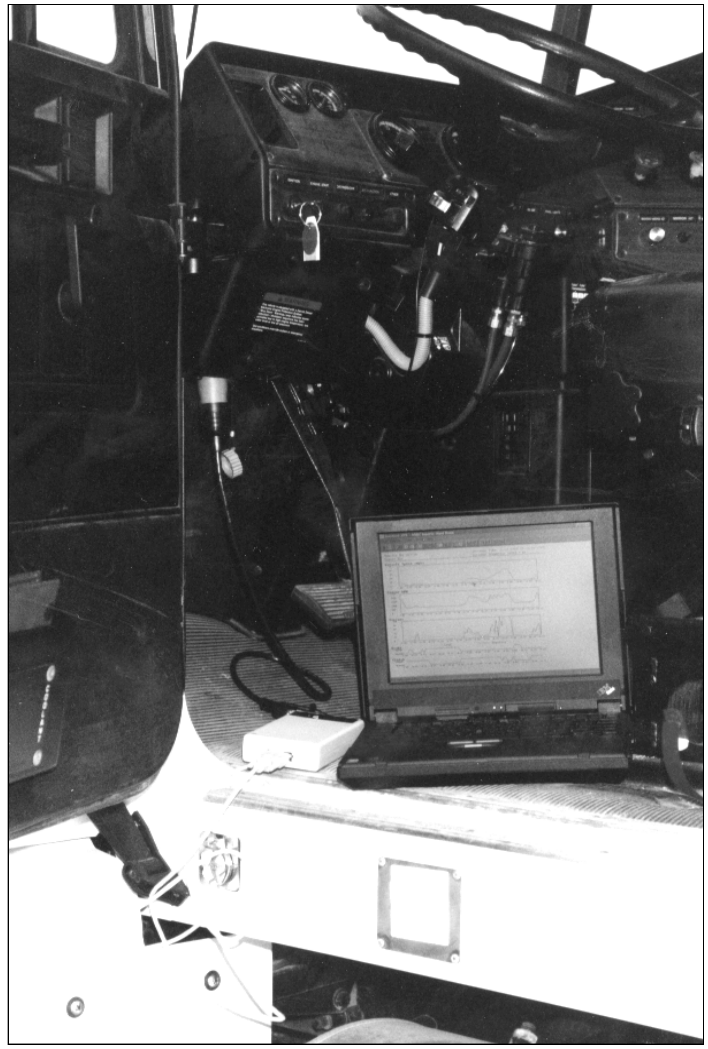


Figure. 7: Communicating with the ECM Through the Dash

the pre-impact speeds of the two vehicles. Because the vehicles' movements were colinear, conservation of momentum can only be applied in one dimension, thus yielding only one equation. With only one equation, only one unknown variable can be determined, whereas the vehicles must have had different speeds (two unknown variables) prior to the impact in order for an impact to occur. In such cases involving passenger vehicles, analysis of the residual crush to the rear of the struck vehicle and to the front of the bullet vehicle can provide insight into the severity of the impact and the associated ΔV. Such analysis relies heavily on stiffness coefficients derived from crash tests of similar vehicles. However, when a tractor trailer is involved, no such data is available and the reconstructionist is faced with estimating a ΔV by subjectively evaluating the damage to the two vehicles.

If one of the vehicles is equipped with an ECM with hard braking or quick stop occurrence data recording, the pre-impact speed of that vehicle can be determined. With one of the unknown pre-impact speed variables eliminated, a unique solution is possible.

DRIVER ACTION. After a quick stop occurrence, data reflecting the vehicle's operation up to a minute prior to the quick stop is automatically captured by some ECM's. Such information is useful for evaluating a driver's actions before the quick stop event occurred. For example, a tractor trailer rear-ended a stopped truck on a 60 mph highway during a snow storm killing the driver of the stopped truck. A witness traveling in the opposite direction claimed that the truck driver was traveling at an excessive speed. The truck driver of the bullet vehicle was charged with reckless homicide due to the negligent, unsafe and reckless operation of his vehicle. The prosecution argued that he should have seen the stopped truck in time to avoid it. Because there was no evidence of braking prior to impact, they also concluded that he was inattentive and that fatigue played a role.

The truck was equipped with an electronic control module which had quick stop data recording capabilities. An accident reconstructionist acting on behalf of the bullet vehicle motor carrier extracted the data after the ECM had been removed from the engine and impounded by the police. The data indicated that the driver had downshifted to reduce his speed 15 seconds prior to impact and that the vehicle was traveling only 37 mph at the time of the collision. Testifying at the criminal trial, the reconstructionist opined that the driver had reduced his speed in a reasonable manner, that his downshifting was evidence that he was not asleep at the wheel, and that the weather conditions prevented the driver from detecting the stopped vehicle sooner. The jury found the ECM data compelling and acquitted the driver of the criminal charges.

RECOMMENDATIONS FOR ECM DATA ACQUISITION

If a late model truck is involved in a serious accident, assume that the engine's electronic control module has useful information. Determine the make and serial number of the truck's engine and contact the manufacturer to arrange to have a qualified technician extract the data from the truck. It is best to extract the data from the ECM while it is attached to the engine so that operation of the various sensors can be confirmed. In addition, interrogating the ECM *in situ* reduces the risk of data loss. However, if the truck is to be salvaged or put back into service, the ECM can be removed for evidence preservation purposes if it has an internal battery backup or if the data is stored in non-volatile memory. The engine manufacturer should be contacted to ascertain whether removal of an ECM will result in data loss.

CONCLUSION

Many electronic control modules on heavy duty diesel engines have the capability of monitoring and automatically storing vehicle operational parameters which may be useful in reconstructing an accident. In most cases, the data is readily retrievable using a laptop computer and a wire harness. This data should be considered valuable evidence to all parties interested in the circumstances of the accident.

ABOUT THE AUTHORS

John M. Goebelbecker is a Senior Mechanical Engineer at Triodyne, Inc. He specializes in vehicle accident investigations and his projects include computer applications to accident reconstruction and mechanical failure analysis. He is co-inventor of AIRMAP, a patented aerial photography blimp system used in vehicle accident reconstruction and has worked for the U.S. Department of Energy and the Federal Aviation Administration to develop guide books that promote safe transportation of hazardous materials.

John holds a Bachelors of Science Degree in Mechanical Engineering and a Masters of Science Degree in Mechanical Engineering, both from the University of Notre Dame. His graduate level research involved mathematical modeling of rigid body impacts. He joined Triodyne with engineering experience in installation and design of food packaging equipment, as well as teaching experience at the secondary level. He has completed Northwestern University Traffic Institute's advanced training in vehicle accident reconstruction.

John is a licensed professional engineer in the state of Illinois and is a member of the American Society of Mechanical Engineers, the Society of Automotive Engineers, the National Association of Professional Accident Reconstructionists and the Society of Accident Reconstructionists. He has given many seminars on vehicle accident reconstruction and has presented technical papers to the Society of Automotive Engineers.

Christopher W. Ferrone is the Director of Engineering Sciences at Triodyne's Center for Maintenance Strategy. He holds a Bachelors Degree in Engineering Mechanics from the University of Wisconsin - Madison (1986). His engineering experience includes heavy equipment chassis design, vehicle component logistical planning, diesel engine and automatic transmission failure analysis, and the development of design criteria and specifications for vehicle procurement.

Among his various career assignments, Mr. Ferrone has conducted in-chassis powertrain cooling tests for manufacturers' acceptance, performed computerized vehicle gradeability studies and developed computer simulations to model the performance of off-road trucks in mud. He is a certified automobile and master heavy truck mechanic. Mr. Ferrone is an active member of the Society of Automotive Engineers (truck and bus council member), The American Society of Mechanical Engineers and the Illinois Society of Professional Engineers.

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