National Transportation Safety Board
Washington, DC 20594

Safety Recommendation

Date: December 19, 2002

In reply refer to: H-02-35

Mr. Daniel Senese
Executive Director
Institute of Electrical and Electronics Engineers
445 Hoes Lane
Piscataway, New Jersey 08854-1331

Dr. S. M. Shahed
President
Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, Pennsylvania 15096

The National Transportation Safety Board is an independent Federal agency charged by Congress with investigating transportation accidents, determining their probable cause, and making recommendations to prevent similar accidents from occurring. We are providing the following information to urge your organization to take action on the safety recommendation in this letter. The Safety Board is vitally interested in this recommendation because it is designed to prevent accidents and save lives.

This recommendation addresses the lack of standards for recording time and status information for the faults stored in electronic control units (ECUs). The recommendation is derived from the Safety Board's investigation of the December 21, 1999, motorcoach run-off-the-road accident near Canon City, Colorado,[1] and is consistent with the evidence found and the analysis performed. As a result of this investigation, the Safety Board has issued three safety recommendations, one of which is addressed to the Institute of Electrical and Electronics Engineers and the Society of Automotive Engineers. Information supporting this recommendation is discussed below. The Safety Board would appreciate a response from you within 90 days addressing the actions you have taken or intend to take to implement our recommendation.

About 9:05 p.m. on December 21, 1999, a 1999 Setra 59-passenger motorcoach, operated by Sierra Trailways, Inc. (Sierra Trailways), was traveling eastbound on State Highway 50 along a 7-mile long downgrade west of Canon City, Colorado, when it began to fishtail while negotiating a curve near milepost (MP) 272.3. At the time, the motorcoach was traveling 63 mph. The speed limit on the descent was 65 mph, with an advisory speed limit of 55 mph on the curves along this section of the roadway. The driver recovered the vehicle from the fishtail, and the motorcoach gained speed as it descended the mountain. Approximately 36 seconds later,[2] as

[1] For additional information, read National Transportation Safety Board, Highway Accident Brief, NTSB/HAB-02/19 (Washington, D.C.: NTSB, 2002).
[2] Time sequence derived from the Detroit Diesel Controls electronic control module (ECM) installed on the engine.

the motorcoach was traveling about 70 mph, the driver lost control of the vehicle on a curve. The motorcoach drifted off the right side of the road, struck MP 273 and a delineator, returned to the road, rotated clockwise 180 degrees toward the centerline, and departed the north side of the roadway backward. The vehicle rolled at least 1.5 times down a 40-foot-deep embankment and came to rest on its roof. The driver and 2 passengers were killed; 33 passengers sustained serious injuries and 24 sustained minor injuries.

The temperature at the time of the accident was in the low 20ºs F with light snow. A Colorado Department of Transportation road crew had been salting and sanding the road throughout the day and reported in a postaccident interview that parts of the roadway were icy. Passengers also described patches of ice and snow on the roadway.

The National Transportation Safety Board determined that the probable cause of this accident was the motorcoach driver's inability to control his vehicle under the icy conditions of the roadway; the driver initiated the accident sequence by inappropriately deciding to use the retarder under icy conditions. Why the busdriver did not, or was unable to, slow the vehicle before the crash could not be determined.

A National Transportation Safety Board simulation of events before the accident, using witness reports, physical evidence, and data downloaded from the Detroit Diesel Electronic Controls IV[3] (DDEC IV) ECM[4] installed on the engine, indicated that the fishtail probably occurred around the curve at MP 272.3. Although the ECM data did not differentiate between application of the brakes and activation of the retarder,[5] investigators were able to determine that the retarder activated before the curve and remained active as the bus entered the curve.[6] The combination of the longitudinal friction for the retarder and the lateral friction required to steer through the curve at 63 mph exceeded the available friction, and the bus fishtail was initiated at the drive axles. The retarder, when applied, requires longitudinal friction at the drive axle wheels. The simulation indicated that if the same longitudinal deceleration that was obtained for the bus using the retarder had been distributed to all six wheels using the bus's antilock brake system (ABS), the bus would have negotiated the curve without losing control because the longitudinal force would have been lower at each wheel.

A retarder/steering-induced wheel slip at the drive axle would have triggered an ABS event,[7] resulting in the retarder being automatically deactivated and the transmission lockup clutch being disengaged, which would have allowed the motorcoach to roll forward with little

[3] Detroit Diesel's fourth generation control module.

[4] The DDEC IV ECM provides operational data for a vehicle and its engine that are used primarily for diagnostic purposes. Maintenance and fleet managers can draw on the data to review and assess driving performance and its impact on the wear of the vehicle and its engine. The recorded data include trip activity, speed versus rpm, engine load versus rpm, periodic maintenance, engine usage, and hard brake activity.

[5] When active, a vehicle retarder provides a supplemental means of slowing a vehicle, thereby reducing brake wear. A retarder brakes only the drive axle and is activated when a driver releases the throttle. The transmission retarder on the accident motorcoach functioned by creating resistance to slow the transmission output shaft, which is connected to the main drive shaft that ultimately turns the wheels.

[6] Investigators primarily used the DDEC IV "hard brake" report to reconstruct the preaccident and accident events. A "hard brake" report includes data from the previous 1 minute prior to the braking event and 15 seconds after its occurrence. The "hard brake" data relate to vehicle speed at the drive axle, engine rpm, percent throttle, percent engine load, brake use, and clutch use. Brake application is not necessary to trigger a "hard brake" report if the drive axle wheels decelerate at a rate of 7 mph per second or more.

[7] An ABS event occurs when wheel slip is detected by the ABS. Such an event can occur when a driver is braking with the service brakes (brake pedal) on a slippery surface, when retarder-induced wheel slip is detected, or when a vehicle is sliding and wheel slip is detected by the ABS.

resistance. A few seconds after the fishtail, the DDEC IV data indicated that the busdriver shifted the transmission into neutral, which took the reverse torque off the drive axle and prevented the retarder from reactivating.[8] Witnesses reported that the busdriver seemed to regain control of the motorcoach at that time.

Data from the DDEC IV indicated that the motorcoach continued to slowly gain speed as it descended the mountain and that the busdriver stepped on the brakes six times before the crash. Five brake applications were held for about 1 second[9] and did not result in a reduction in speed.[10] One brake application lasted about 3 seconds and resulted in a 1.5-mph decrease in speed.

As the motorcoach approached MP 273, the busdriver made a throttle application of 2,200 rpm for about 6 seconds on a left-hand curve. About the same time, the bus yawed to the right, departed the roadway shoulder, and went onto the dirt. Physical evidence indicated that the bus struck MP 273 and a delineator before the busdriver was able to steer the motorcoach back onto the pavement. The simulation suggested that the busdriver's steering input was such that it probably angled the bus toward the north embankment on the opposite side of the roadway. The busdriver subsequently steered to the right, initiating a 180-degree-clockwise rotation of the motorcoach, and the vehicle traveled backward down the opposite lane. Evidence indicated that the motorcoach's left-rear bumper struck another delineator on the left side of the road, and the bus proceeded backward down the north embankment, rolling at least 1.5 times on its side before coming to rest on its roof.

Despite the fishtail about a mile before the accident site, the driver did not, or was unable to, reduce the speed of the motorcoach as it continued downhill. On December 22 and 23, 1999, Safety Board and Colorado State Patrol investigators conducted a preliminary brake inspection on the accident bus and found a small leak in a fitting for the service intake to the right-drive-axle air chamber. On February 3 and 4, 2000, the Safety Board and the Colorado State Patrol, together with Bendix Commercial Vehicle Systems and Setra personnel, conducted a full inspection of the braking system. When the brake system's damaged parts (the air chamber, push rod, and slack adjuster on the left drive axle and the service hose and fitting on the right drive axle) were replaced and the auxiliary air system isolated, investigators found no leaks or irregularities in the system.

During the full inspection, investigators downloaded the contents of the ABS's ECU. The contents included two fault codes, which is the maximum number of faults that this ECU can store. The faults pertained to errors in the right-front and right-rear modulator valves.[11] An engineer from the Robert Bosch Corporation believed that the modulator valve fault codes were due to low voltage from a drained battery. Checking the voltage with a voltmeter, the engineer found it to be 12.42 volts. (The Bosch ABS's ECU operates on a 24-volt system.) When the

[8] The Allison operator's manual states, "If you let the vehicle coast in N (Neutral), there is no engine braking and you could lose control." Had the driver instead placed the retarder lever in the "off" position, the reverse torque would have been taken off the drive axle and the driver would have been able to downshift and use engine resistance to help slow the motorcoach.

[9] According to Detroit Diesel engineers, a single application, representing 1 second on the DDEC "hard brake" report, can be from 1/40 second to 1 39/40 seconds long. The DDEC records brake applications that result in a minimum of 3.5 pounds per square inch of pressure or more.

[10] During four of the five brake applications, the speed of the bus increased 0.5 to 1.0 mph.

[11] A modulator valve is an electro-pneumatic control valve that contains the solenoids used to precisely modulate brake air pressure during an antilock braking system event.

motorcoach batteries were charged to 24 volts, the codes did not reappear. Further examination of the ABS using a standard checklist uncovered no problems.

On August 16, 2000, Safety Board investigators and a Setra field representative drained the motorcoach battery in an attempt to reproduce the modulator valve fault codes found during the February 3, 2000, inspection of the ABS. The battery was drained from 24 volts to 11.2 volts,[12] and no fault codes registered. Again on February 16, 2001, when Setra and Bosch engineers and Safety Board investigators tried to recreate the fault codes by draining the battery, the codes did not reappear. After charging the battery to 24 volts, it was drained twice to about 11 volts. The modulator valve fault codes could not be reproduced. However, an undervoltage code did appear at 12 volts and at 11.8 volts.

Fault codes such as those detected by the ABS's ECU can either limit the ABS function or revert the braking completely to conventional air brake control. The Setra operating manual states, "In the event of the fault occurring, the driver can usually still call upon the conventional service brakes."

Because the ABS ECU was designed to store no more than two fault codes, additional fault codes may have been present but ignored or overwritten by the ECU. The two fault codes present were not dated or time stamped, nor were they labeled as "active" or "inactive."

In addition to that data stored in the ABS ECU, data were also downloaded from the transmission ECU. Five fault codes were discovered. Two of the fault codes had been registered after the accident.[13] Two other fault codes occurred before the accident trip and would not have interfered with the driver's control of the bus.[14] The fifth (code 22-16), an "output shaft speed sensor" fault, indicated that before or during the accident, the transmission experienced either an interruption in its electrical contact with the shaft speed sensor or the transmission ECU sensed a speed change so rapid that it determined this change to be "unreasonable."

Under normal operation, the output shaft speed sensor only allows the driver to shift into neutral or into a gear appropriate to the current speed of the bus. When code 22-16 is registered, the driver is prevented from shifting into any gear, the transmission retarder is disabled, and the lockup clutch is disengaged. Attempting to correct the fault would require a driver to stop the motorcoach, turn off the ignition for about 10 seconds, and then restart the ignition. During interviews, no passengers mentioned the bus stopping. When discovered, the output shaft speed sensor fault (code 22-16) was inactive, indicating that the condition that triggered it was no longer present. The transmission ECU fault codes were not date and time stamped, so investigators were unable to determine when the fault occurred or whether the fault had any effect on the operation of the bus before the accident.

[12] Between 11 and 12 volts is needed to power the ignition; no testing could be done when the voltage dropped below that level.

[13] The ECU registered nine ignition cycles, which were probably recorded during the initial Safety Board and Colorado State Patrol vehicle inspections that occurred during the 2 days after the accident. When these data were downloaded, the information on two fault codes indicated that the engine had not been cycled since their registration, a sign that they occurred during download.

[14] An engine speed sensor code (22-14) occurred two ignition cycles before the accident trip. This fault would not have affected the transmission's ability to shift gears but can result in harsh shifts. A throttle message fault (66-00) occurred 12 ignition cycles before the accident trip. This fault also would not have affected the transmission's ability to shift gears.

On August 16, 2000, Safety Board investigators and Allison Transmissions technicians conducted electrical continuity testing between the shift control and the speed sensor. The test indicated no defects. On the following day, the output shaft speed sensor was placed into a sister vehicle (another 1999 Setra) and performed normally.

The fault codes stored in both the ABS ECU and the transmission ECU were not time stamped, and the ABS ECU faults lacked status indication. These factors limited the usefulness of both ECUs as diagnostic or investigative tools and made it difficult for investigators to determine whether the faults were factors in this accident. Furthermore, the limited capacity available for storing ABS ECU data means that additional fault codes may have been present but were overwritten. The Safety Board concludes that had the faults on the transmission and ABS ECUs been time stamped, had the status of the faults on the ABS ECU been known, and had the ABS ECU been able to store a greater number of codes, a more comprehensive account of the events leading up to the motorcoach crash would have been possible.

The National Transportation Safety Board recommends that the Institute of Electrical and Electronics Engineers and the Society of Automotive Engineers:

> Work together, as part of your initiative to establish on-board vehicle recorder standards, to develop standards for brake and transmission electronic control units that require those units to store a full history of electronic fault codes that are time stamped using a recognized clock synchronized with other on-board event data recording devices. (H-02-35)

The Safety Board also issued safety recommendations to the Federal Motor Carrier Safety Administration, the United Motorcoach Association, and the American Bus Association. In your response to the recommendation in this letter, please refer to Safety Recommendation H-02-35. If you need additional information, you may call (202) 314-6177.

Acting Chairman **CARMODY**, and Members **HAMMERSCHMIDT**, **GOGLIA**, and **BLACK** concurred in this recommendation.

Original Signed

By: Carol J. Carmody
Acting Chairman