

Diesel locomotive reliability improvement by system monitoring

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System monitoring for reliability (SMR) involves monitoring critical parts of a vehicle and informing the owning business of an impending fault. Diesel locomotives offer the largest opportunity for such systems and British Rail Research has developed a system designed to improve Class 47 locomotive reliability.

The vehicle-mounted equipment comprises a computer that continuously monitors the condition of the vehicle through sensors at key points. The computer is connected to a radio telephone and modem and a GPS satellite navigator. The key elements in the success of the system are the automated analysis of data on-board the vehicle and its ability to call for help ahead of the occurrence of service failures. The business interface is through a Windows based information display which runs on a personal computer connected to the public telephone network. This controls the display of messages from monitored vehicles and allows vehicles to be interrogated to check on current condition.

When fully implemented, a reduction in technical casualties of 40 per cent is anticipated. There are additional financial benefits from efficiency improvements and vehicle maintenance cost savings.

Key words: system monitoring for reliability, diesel locomotives

1 INTRODUCTION

The Vehicle Systems Unit of British Rail Research has undertaken a series of projects over many years concerned with the development of condition monitoring for railway rolling stock and diesel locomotives in particular. This work has recently concentrated on the development of systems to improve the reliability of vehicles. System monitoring for reliability (SMR) is the name given to monitoring critical parts of a vehicle in order to improve its reliability by informing the owning business of an impending fault.

This paper describes the development of a system for monitoring Class 47 locomotives. It begins with the guiding philosophy for SMR. It then goes on to describe the component parts; the on-board equipment and analysis of data; the communication of information to and from the vehicle; and the information display system. Finally, there is a review of the current position.

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2 PHILOSOPHY OF SYSTEM MONITORING FOR RELIABILITY

2.1 The economic background

Studies into maintenance and maintenance-related costs of typical types of rolling stock have been undertaken to determine the most cost-effective areas for the application of condition monitoring and diagnostic systems. The four main vehicle types used by British Rail have been examined; diesel locomotives, electric locomotives, diesel and electric multiple units.

The costs have been broken down by vehicle system and subsystem into five areas, three directly associated with maintenance; exams, repairs and overhauls and two indirectly related; the cost of unreliability and unavailability. The results, given in Fig. 1, show that the largest total cost is for diesel locomotives, and the largest element of this total is the cost of unreliability.

Examination of the reasons for unreliability showed that the total is made up of a small number of causes (see Fig. 2), many of which are easily monitored and

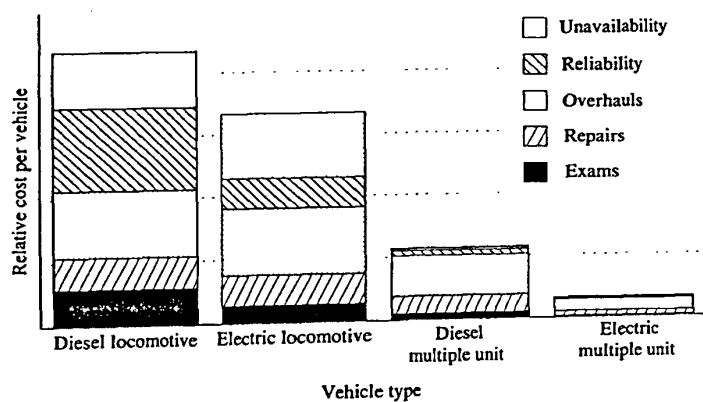


Fig. 1 Rolling stock maintenance and maintenance-affected costs

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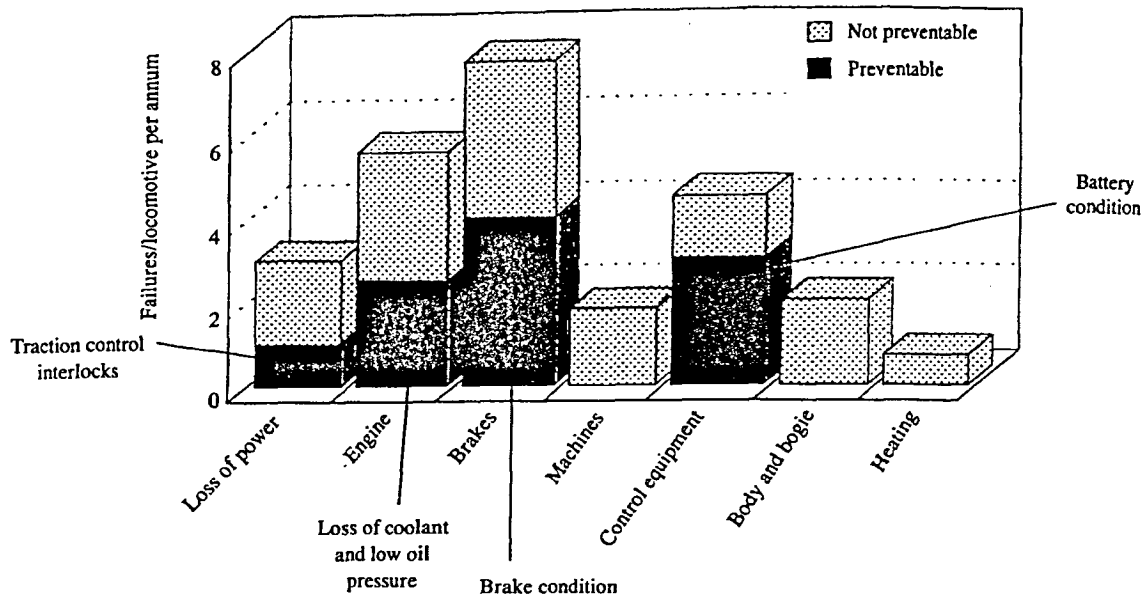


Fig. 2 Causes of Class 47 failures in service

allow warning to be given. About 40 per cent are considered preventable through appropriate monitoring and notification of impending failure.

2.2 Reliability emphasis

The factors described in Subsection 2.1 led to the concept of system monitoring for reliability which is specifically aimed at reducing in-service failure of equipment rather than reducing maintenance costs or increasing availability. This very specific approach gives a number of advantages:

- the number of measurands is significantly reduced;
- the maintenance philosophy of the vehicles does not change, so it is quicker and easier to implement;
- data analysis is generally easier since faults severe enough to cause a vehicle to fail are more easily identified than the comparatively smaller changes associated with a need for maintenance.

2.3 Importance of on-board analysis

Most approaches to vehicle monitoring have involved fitting data logging equipment and analysing the data after they have been downloaded. This requires the routine download of a large amount of data, the majority of which will indicate that the vehicle is healthy. It also introduces a delay in fault identification and will miss the majority of faults likely to affect service reliability on a daily basis.

An emphasis on reliability improvement requires that in order to achieve a fast response to developing faults, the analysis of data must be automated and done on-board the vehicle; the vehicle must also be able to call for help. It is this requirement for a high degree of vehicle system 'intelligence', in conjunction with a communications system where the vehicle can call for help or be called at any time that is the key to successful SMR.

The move towards an 'intelligent vehicle' gives two other major benefits. Firstly, it considerably reduces the

amount of data requiring transmission, which is particularly advantageous where communication is by radio. Secondly, it opens up the possibility of providing information to the driver or train crew in those situations where it can be usefully acted upon.

The provision of a continuous communications link between the owning business and an 'intelligent vehicle' allows information on condition to be provided on demand. Such vehicle interrogation may be useful as a check on condition just prior to assignment or for monitoring the development of a fault already reported.

2.4 Information required

System monitoring is really only half the story. In order for the service reliability to be improved not only must information about a fault be provided, but the information must be suitably acted upon in order to remedy the situation. If appropriate action is not carried out, the vehicle will fail just as it would without monitoring. In this respect the presentation of information to the end user is of paramount importance.

An important part is the information content. The majority of rolling stock is maintained by means of component replacement to facilitate rapid return to service and so the information provided should support this philosophy. In other words, faults in equipment need only be diagnosed down to the level of 'replaceable unit' or the level of action required to allow the vehicle to continue running, such as 'top up with coolant'. Diagnosis to this depth is particularly important in the case of a vehicle reporting a developing fault but a long way from a repair depot. Should the vehicle be brought back to the depot, repaired at an outstation, repaired by a mobile maintenance team or left for a while? If the vehicle does need to return to depot, diagnosis to replaceable unit level allows an indication beforehand of what spares and depot resources are required (for example, under cover, crane, pit, manpower etc.) This speeds up repair time considerably. Similarly, if a mobile maintenance team needs to be sent to the vehicle they will know what equipment to take with them.

Information from the system must be sent to the business maintenance controllers. They respond to calls from outstations reporting problems with vehicles and arrange repair or a replacement vehicle.

For fault diagnosis, messages should be sent from the vehicle immediately, but this is not necessarily the case when prognosis is involved. There are situations where, if the existing set of circumstances were to continue, the vehicle would fail, but the fault may be naturally remedied before it occurs. For example, a battery draining with the engine stopped may be just about to be charged following an engine start, or a vehicle with a coolant leak may be just running on to a depot to have its coolant topped up. In these circumstances the approach has been to define a failure limit and make predictions of the remaining time to failure. Messages can then be generated a set time before failure is estimated. The maintenance controller can then decide on whether the fault will require action based upon the duty of the vehicle.

3 ON-BOARD SYSTEM

3.1 Equipment fitted

The vehicle-mounted equipment comprises a computer that continuously monitors the condition of the vehicle through sensors at key points. The computer is connected to a radio telephone and modem allowing the system to ring out with fault messages or be interrogated by the owning business at any time. The com-

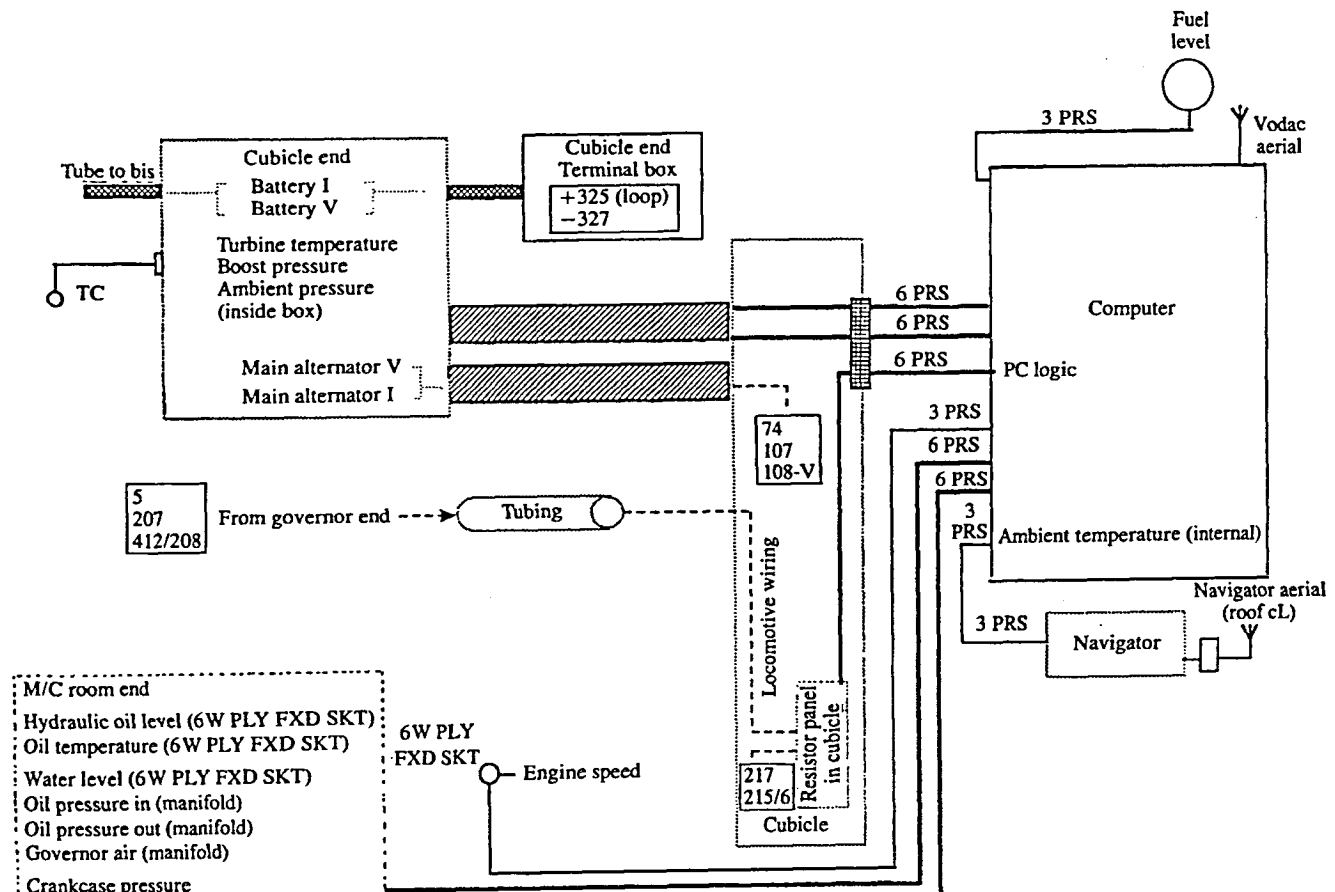
puter knows the vehicle's position through connection to a GPS satellite navigator.

The equipment is housed in three rugged steel enclosures sealed to IP66 and protected against the electromagnetic environment of the locomotive. Also fitted are a number of transducers mounted directly on to existing components, some small enclosures containing transducers and appropriate interconnection via high specification cable sealed into flexible conduit. Two aerials are also used, a short whip aerial mounted on the end of the vehicle, and a small flat antenna mounted on the roof for the GPS navigator. This equipment is designed to retrofit into the vehicle without interfering with its normal operation and maintenance. A general schematic is shown in Fig. 3.

3.1.1 Computer

Hardware. The on-board computer is an industry standard VME bus-based system made up of single height eurocards. The use of the VME bus standard allows a system to be made up in a very modular and flexible way using equipment from one or a number of suppliers. The system can be easily expanded to include additional processing power, memory, communications or monitoring channels.

Software. Most computers use an operating system as the master supervisor of their resources; memory, processing time and input/output devices such as sensors, modems and disk drives. The operating system also provides an interface between the computer and the



user, managing the basic operations of the system, loading and executing programs, managing input/output, managing a directory of files and allocating memory. Application programs performing data analysis, data storage and communications all sit on top of the operating system and call on it to perform low-level tasks.

The operating system used in the on-board computer is OS-9. This is a multi-tasking operating system similar to UNIX but specifically developed for use in real time embedded systems.

Multi-tasking means that several programs may run apparently simultaneously, by rapidly switching from one program to the next many times per second. This capability is used extensively for the on-board software. It considerably simplifies the task of managing data analysis, allowing for example, communications over the radio telephone to occur while analysing data from the oil system, while reading the position from the navigator, while storing vehicle operating data to file, etc. Each task can be written as a separate program simplifying development and testing, and removing any risk of programs interfering with each other.

3.1.2 Cellular radio telephone and modem

The computer is connected to a Racal Vodafone cellular radio telephone and modem. Modems for cellular radio link control (CDLC), which gives 100 per cent error-free data transmission at speeds up to 2400 bits per second. The modem is configured for auto-dial and auto-answer allowing the vehicle to call out or be called at any time. Development of additional hardware and a consider-

able amount of software has been necessary to ensure reliable phone management across the two-way link.

3.1.3 GPS satellite navigator

The vehicle is equipped with a 'Navstar' XR5 GPS receiver which gives satellite-based positioning. Position information from the receiver, accurate to a mean error of 28 metres, is available to the on-board computer through a serial data link. The latitude and longitude is converted to eastings and northings by the computer.

3.2 Data analysis

The general structure of the data analysis performed is shown in Fig. 4. This structure separates the data analysis from the hardware allowing more generalized program modules to be produced.

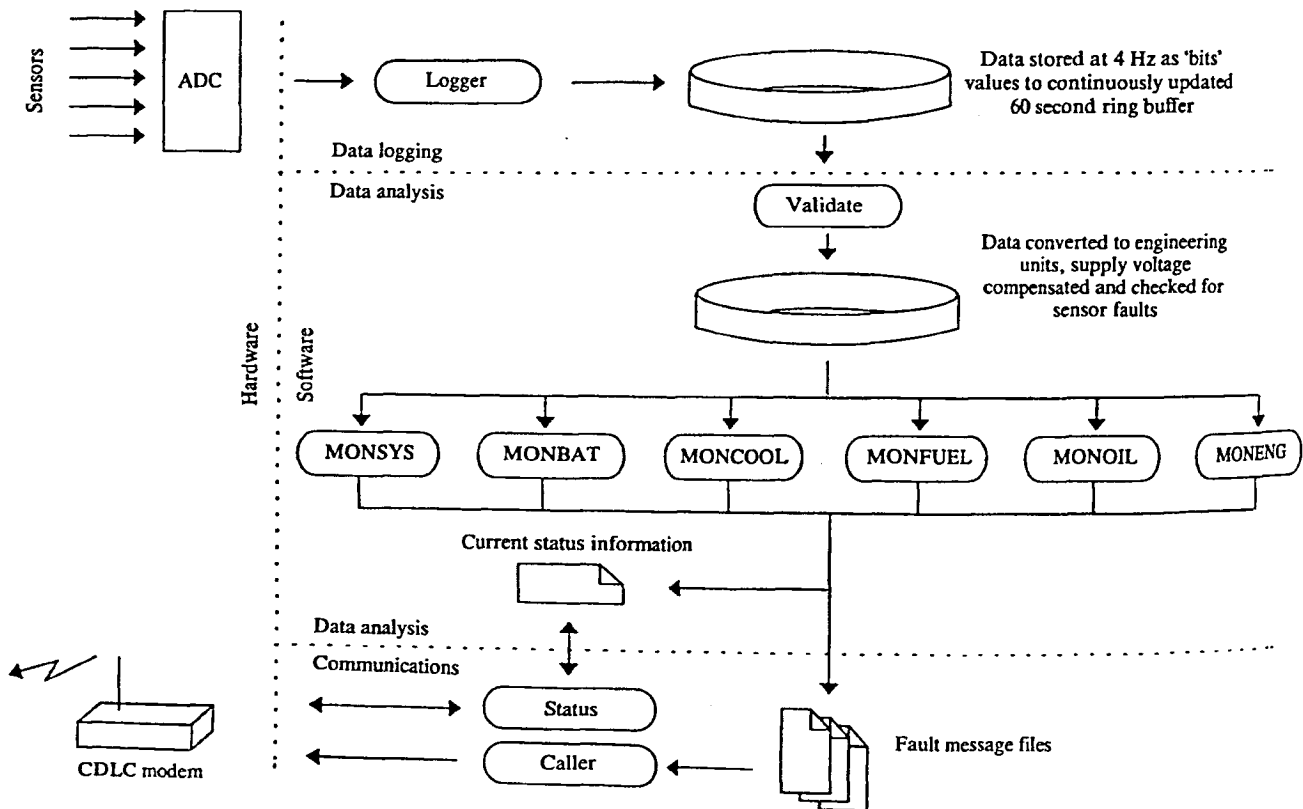
The program 'logger' reads all the sensors and the vehicle location from the satellite navigator and writes the data to a global buffer. The buffer holds all the measurements made over the last minute.

The program 'validate' takes information from the measurement buffer and places it in a second, similar buffer after:

- (a) converting it to engineering units;
- (b) adjusting it for the value of supply voltage existing at the time;
- (c) checking it against limits to ensure validity

'Validate' also sets 'flags' to identify engine operating status and transducer and power supply faults.

The analysis programs for individual systems then simply extract data from this buffer when their own criteria for analysis are met, for example the engine has



been at full power for a set time, or is idling, or has just been turned off.

If the results of the analysis require a message to be sent from the vehicle this is instigated by creating a file containing the message. This file forms the interface between the analysis program and the software controlling the communications link. A separate program identifies that a fault file has been created, establishes communications, via cellular telephone, with the information display system and passes over the information.

The complexity of on-board analysis varies with the parameter or vehicle system in question. There are a number of factors that lead to the task being more complex than is initially apparent, such as the effects of varying duty, the need to normalize for ambient conditions and the requirement to provide prognostic information.

The use of out-of-limit alarms is in general too simplistic for many parameters and will not provide the level of decision support needed if the system is to succeed. It is far more useful to know that failure is likely at a particular time as this then allows the controller to make a decision based upon the remaining duty requirement and the best point of repair. In other words the primary requirement is not one of simple diagnostics but of prognostics.

Prognostic estimates will always have a level of uncertainty. The approach that has been taken throughout has been to base all time to failure estimates on 95 per cent confidence limits. The statistics are obviously transparent to the information receiver who just sees an upper and lower time to failure. The information is given in absolute time so that it is not affected by any communication delays, it does not require the receiver to make mental calculations of likely failure time and it compares easily with operating schedules.

3.2.1 System development and testing

The first stage in the development of data analysis programs was the collection of data to see how the operation of the vehicle affected the results. It is easy to be 'swamped' in data by condition monitoring systems, so to avoid this it was decided that data collection would be targeted specifically for each of the systems of interest. Using past experience of condition monitoring data collection and analysis, specific data collection programs were written for each monitored system. These stored, at the appropriate time or engine condition and at an appropriate sampling and averaging rate, only the measurements considered relevant.

This resulted in completely different data collection programs for each monitored system, all running together at the same time. The data collected was automatically downloaded from the vehicle each night to a microVAX computer network where it was archived.

The data collected were stored in files compatible with standard spreadsheet programs. This meant that downloaded data could be placed straight into a spreadsheet where they could be plotted and manipulated with ease. Spreadsheet functions and macros were used to experiment with analysis possibilities before they were finally programmed. When a suitable method of analysing the data was decided upon, a program was

A comprehensive software test environment was created. The physical outputs from the sensors on the vehicle were replaced by a program that wrote data from a file into either of the data buffers in Fig. 3. The data file format used to seed the buffer was the same as that used for data storage. This gave an easily controlled and repeatable means of testing the response of the analysis programs to either previously collected real data or simulated fault data, designed to test the analysis under a particular set of circumstances.

3.2.2 Coolant monitoring

The level of water in the header tank is measured by a potentiometer attached to a pivoted float arm. During periods when the engine is off or idling the level stays fairly constant, provided there is no leak. However, when the engine is running under power, the level fluctuates due to vehicle movement. The level also changes due to expansion and contraction of the water with temperature. As the temperature of the water is measured and the capacity of the system is known, the level can be corrected for temperature. Prognostic analysis predicts the time at which the tank will be empty and sends out a message when this time is less than two hours away.

Refills need to be detected in order that predictions can be reset. Data have shown that sudden increases in level can occur normally when the engine is running, and the engine is not always stopped in order to refill the tank, so the refill detection method used depends on whether the engine is running at the time.

3.2.3 Fuel monitoring

A locomotive running out of fuel is a very rare occurrence so analysis simply involves sending a warning message if the level in the tank drops below ten per cent.

Fuel efficiency information is also calculated. The power output of the main generator is integrated to give the total energy provided and this is divided by the calorific value of the fuel used, over a reasonable time period.

Measurement errors occur while the vehicle is in motion due to acceleration or deceleration. Additionally, because of the arrangement of the fuel supply system, track gradients or cant can cause the engine to draw fuel from only one tank while the vehicle is stationary. Fortunately these effects are not significant when measuring engine efficiency over a tank of fuel since the amount of fuel burnt is quite large in comparison with the errors.

One problem with efficiencies calculated in this way is that the measured power output from the vehicle includes only that provided by the main generator. Therefore, power produced for auxiliary equipment (battery charging, electric train heating, etc.) is ignored.

3.2.4 Battery monitoring

There are two problems that occur with the battery system:

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