AFFIDAVIT OF SARAH BROADHURST

I, Sarah Broadhurst, do hereby make oath and say as follows:

1. I am currently a Library and Archive Assistant for the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London SW1H 9JJ.

2. I have been asked to confirm certain dates regarding the following article: Fry, K. N., "Diesel Locomotive Reliability Improvement by System Monitoring," *Proceedings of the Institution of Mechanical Engineers*, Part F: Journal of Rail and Rapid Transit, Vol. 209, No. F1, pp. 1-10 ("the Fry article"), a true and correct copy of which accompanies this affidavit as Exhibit 1002.

3. The Institution of Mechanical Engineers has arranged for the publication of the Fry article. As indicated on the face of the article, the Fry article was originally published on behalf of the Institution of Mechanical Engineers by Mechanical Engineering Publications Limited. The article is currently available to the public from Sage Publications.

4. The Institution of Mechanical Engineers maintains records of the dates on which the articles it published were received, accepted for publication, and eventually published. These records are maintained as part of the ordinary course of business of the Institution of Mechanical Engineers, and I have personal knowledge of the records.

5. I have reviewed, on Sage Publications' website, the Institution of Mechanical Engineers' records relating to the Fry article.

6. The Institution of Mechanical Engineers' records confirm that the Fry article was received by the Institution of Mechanical Engineers on November 25, 1993; that it was accepted for publication on December 22, 1994; and was made available to the public as of January 1995.

7. In 1995, "Part F: Journal of Rail and Rapid Transit" of the Proceedings of the Institution of Mechanical Engineers was published semi-annually, in two separate issues identified as "F1" and "F2." The F1 issue published in January of each year. The F2 issue published in July of each year.

ENGLAND AND WALES)
) s.s.
CITY OF LONDON)

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is 10th day of February 2014 at
Birdcage Walk, Westminster,
ndon SW1H 9JJ, England

Sarah Broadhurst

ore me:-

MICHELLE SCOTT-BRYAN
NOTARY PUBLIC
London, England

This is the exhibit marked "1002" referred to in the Affidavit of

SARAH BROADHURST

sworn before me this tenth day of February 2014.

MICHELLE SCOTT-BRYAN
Notary Public
England and Wales

Diesel Locomotive Reliability Improvement by System Monitoring

K N Fry

Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 1995 209: 1
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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 owing 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.

The MS was received on 25 November 1993 and was accepted for publication on 22 December 1994.

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

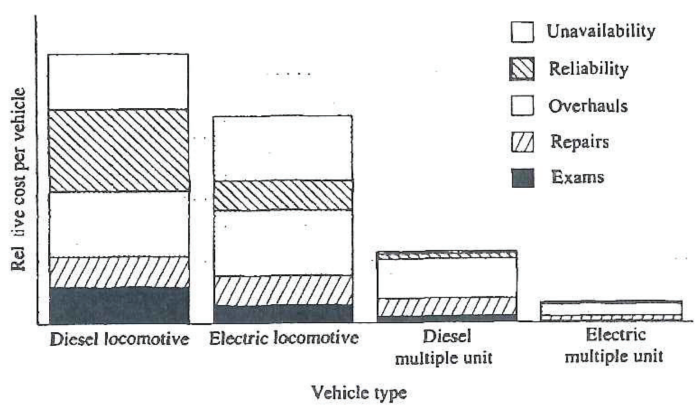

Fig. 1 Rolling stock maintenance and maintenance-affected costs

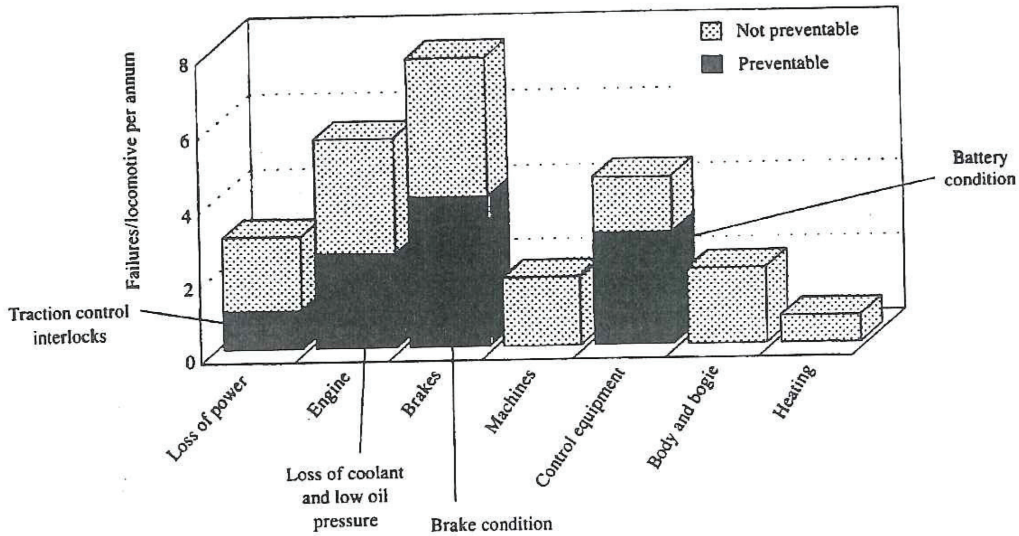

Fig. 2 Causes of Class 47 failures in service

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:

(a) the number of measurands is significantly reduced;
(b) the maintenance philosophy of the vehicles does not change, so it is quicker and easier to implement;
(c) 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 computer 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

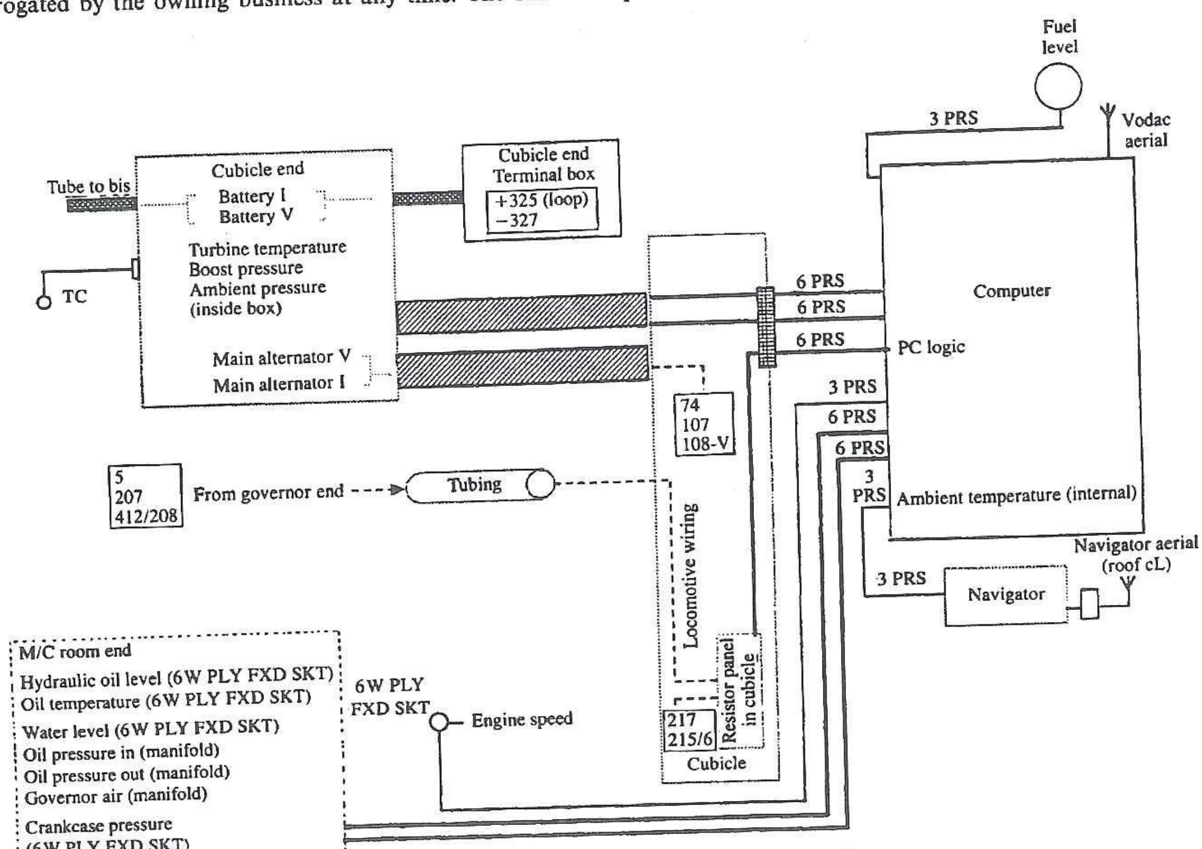

Fig. 3 Monitoring equipment general arrangement

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 require a special error correction protocol, cellular data 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 considerable 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

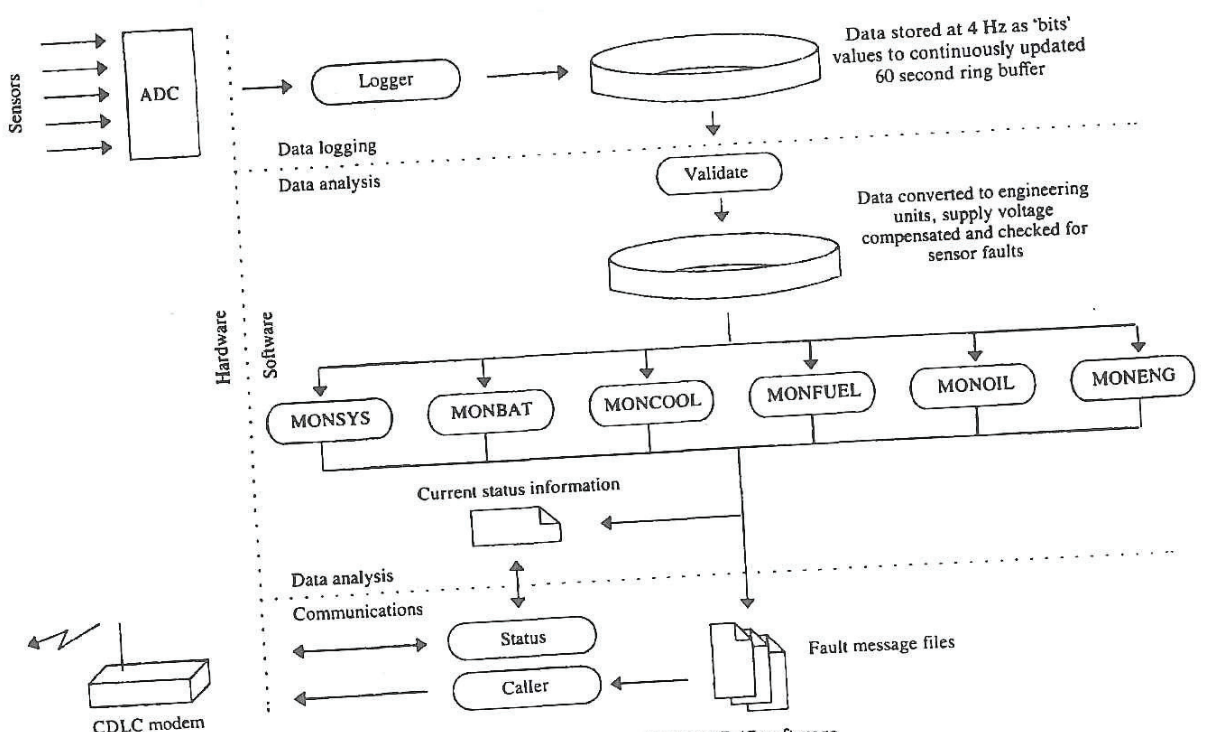

Fig. 4 Structure of DEMON SMR47 software

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

If the results of the analysis require a message to be ent 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 written for inclusion on the vehicle.

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:

(a) flat batteries due to poor battery health;

flat batteries due to excessive discharge over a period.

attery health. Battery health and state of charge can e determined by measuring the voltage drop under load. The load needs to be of reasonable magnitude and should last for some time. For the Class 47 locomotive the necessary conditions are met when the electrically powered fuel, oil and water triple pump runs with the engine turned off. This situation occurs before engine start-up and also after shutdown for a short time.

It is anticipated that battery health will deteriorate slowly, so that occasions when insufficient running to fully charge the battery happen (thus prohibiting the determination of condition) should not severely affect the prediction of battery maintenance need.

The fact that battery health and state of charge cause the same effect on the voltage drop under load means that the effect of battery deterioration on voltage drop can be determined from laboratory tests. Tests have been conducted to determine the voltage drop under an equivalent triple pump load for a good battery at known states of charge. A voltage drop equivalent to a value of health below 70 per cent generates a fault message.

Discharge monitoring and ability to start engine. The system predicts the time when the available energy will just meet the energy required to start the engine and then sends out a warning one hour before. The battery capacity available depends upon the amount of charging before engine shutdown, the amount of discharge since shutdown, the rate of the discharge, and the battery state of health. The amount of energy required to start the engine depends upon the engine temperature and condition.

As mentioned, the initial capacity of the battery can be determined when the engine is turned off by measuring the voltage drop due to the triple pump load. From the known initial charge it is possible to calculate the theoretical charge at any point in time by counting out the ampere-hours discharged. By assuming that the present discharge rate will remain unchanged, the battery capacity at any time in the future can be predicted.

The battery capacity required to start the engine at different temperatures is well defined as it is a value used in the vehicle design for battery sizing. These data relate only to the severest design case, where a locomotive is to be started from cold after an overnight stand. They do not cover the case where a vehicle has stood for a short time and is then required to start. In this case the energy required to start the engine will be much less and using the data above will be very conservative, resulting in unnecessary warning messages. To allow for warm start cases, the temperature–start capacity relationship has been extrapolated to higher temperatures and the engine oil temperature is used.

3.2.5 Oil monitoring

Experience has shown that idling is the best condition under which to analyse oil system data because this condition is the most critical with respect to possible engine shutdowns. Oil pressure is affected by the oil temperature and engine speed, complicating the detection of low-pressure faults since a reduction in pressure can be caused by a reduction in engine speed or a reduction in oil viscosity (due to either fuel dilution or an increase in oil temperature).

Neural networks can be envisaged as a 'black box' that can be trained to provide an output related to certain inputs. Work conducted by British Rail Research has shown that neural networks can be successfully used to normalize oil pressure data for oil temperature and the engine speed. The neural network is used to predict inlet and outlet pressures, and two new parameters are then produced, the difference between the measured and predicted inlet and outlet pressures. Using these new parameters a considerable increase in diagnostic sensitivity to genuine low-pressure faults can be obtained. These parameters are used to identify potential low oil pressure while the engine is still warming up and correct for the filter pressure drop variation with temperature.

A neural network was quickly and easily trained using data from the system in good condition. The network was then generated as computer code and embedded within the on-board analysis program for the oil system.

3.2.6 Engine monitoring

The engine monitoring program carries out two tasks. Firstly, it monitors the engine to provide a record of its duty. Secondly, it identifies the cause of engine power loss due to isolation of the engine power control.

Engine monitoring. When the engine is running, the governor air pressure, effectively a measure of engine power demand, is monitored and divided up into ten bands. The total amount of time spent in each band is calculated and stored.

Control relay monitoring. Power from the engine is controlled by the power control relay coil. Only when 110 V is supplied to this coil can power be provided by the main generator. When the engine is started the coil is directly supplied with 110 V. After this, when the engine is running normally, the 110 V is supplied via a number of other contacts. These contacts are controlled by the correct operation of the power control relay, the power earth fault relay, the load regulator, the auto air governor, the equipment governor and the control governor. When intermittent faults on these devices occur, the supply to the power relay coil is broken and the traction power is cut off. If this happens while the engine is running under power, power is cut off to the traction motors, and cannot be reapplied for at least 30 seconds. This type of occurrence is obviously very inconvenient for the driver:

When any of these devices has an intermittent fault it is very difficult to detect which one of them it is, because once power has been lost all of the healthy systems will react by opening their contacts as well. By the time the driver is able to examine the contacts it will not be possible to determine which contact opened first. It may also be difficult for the maintenance staff to identify the causes of such faults.

The analysis program monitors the voltage at each of the contacts, which control the supply to the power control relay, to see which contact opens first. When the state of any of the contacts changes the new condition is ched in hardware just after the change. The computer en reads the status of the contacts and the analysis rogram decides whether the change was due to a normal set of circumstances, such as the driver shutting down the engine, or a fault on one of the interlocking systems.

3.2.7 System self-monitoring

In order to provide reliable information it is important that the monitoring system is able to identify faults with itself and ensure that such faults do not result in misdiagnosis. Experience has shown that the automatic identification of monitoring system faults is vitally important if false messages are not to be produced and that in the majority of cases this can be handled fairly easily.

A comprehensive set of self-monitoring procedures are set up that cover the detection of transducer/channel faults, the detection of power supply faults, the detection of clock faults and the detection of computer faults.

4 DATA COMMUNICATIONS

There is an advantage to having a continuous link available in order to receive fault messages from and interrogate both moving and stationary vehicles; in practice this means radio is the only option for cost-effective communications.

Data communications between the vehicle and the maintenance controller are provided through the Vodafone mobile data service. Communications are generally good, though like any radio-based communications system, they are subject to certain limitations. Contact may not be possible if the land line to cellular conversion service is busy or if the vehicle is not in radio range, which can happen if it is located in a tunnel or a deep cutting, also if it is surrounded by high buildings or situated in a remote area not covered by the cellular network.

For these reasons communications are generally better if the vehicle is stationary, provided it lies in an area of good radio reception. Communication with moving vehicles works with a reliability dependent upon the geography of the surrounding area. In practice this limits call duration, the line being lost as the vehicle moves into areas of poor reception.

The required contact duration depends upon the amount of information to be transferred. For system development large quantities of logged data were downloaded, this being done at night when the vehicle was most likely to be stationary and the Vodafone network was not busy. The contact duration for fault message transfer and vehicle interrogation is quite short (less than a minute), so loss of line does not affect performance too frequently.

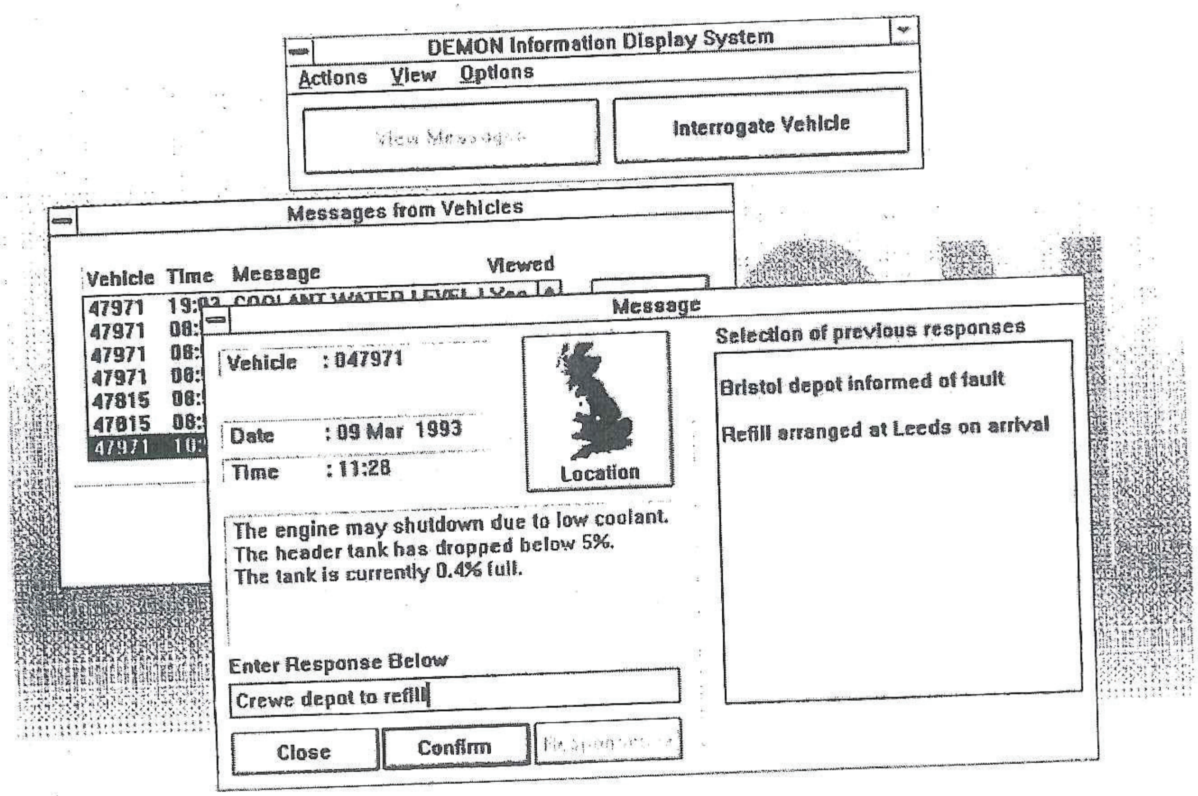

Fig. 5 Display system message screen

Table 1 Possible messages from vehicle

Trigger condition	Message
Generated when an empty header tank is predicted to be less than 2 hours away.	'The engine may soon shut down due to low coolant. It is estimated that the coolant tank will be empty between $time_{min}$ and $time_{max}$.'
Generated when the battery capacity will be less than that needed to start the engine within the next hour. Based on the current battery drain and the battery charge required at the present engine temperature. The charge needed to start the engine increases as the temperature drops.	'The present battery capacity will be too low to start the engine in approximately *X* hours. It is recommended that the engine be started now to charge the battery up.'
Fuel level below 81 gallons (no auxiliary tanks fitted)	'The engine may run out of fuel. The fuel tank is less than 10% full. There are *X* gallons left.'
Generated when the difference between the measured and neural network predicted oil pressure is less than −5 p.s.i.	'The engine may shut down if the oil pressure at idle falls below 16 p.s.i. The oil pressure may be too low when the engine is up to full temperature.'

Communications performance statistics show that two thirds of messages are received by the information display system within three minutes of detection by the on-board system, and over 80 per cent are received within ten minutes. A small percentage take very much longer to get through, probably because the vehicle was stationary in an area of poor radio reception.

5 INFORMATION DISPLAY SYSTEM

The business interface to the vehicle information is through an information display system which runs on a PC connected to the public telephone network. The information display system provides a means of displaying messages from monitored vehicles and inter-

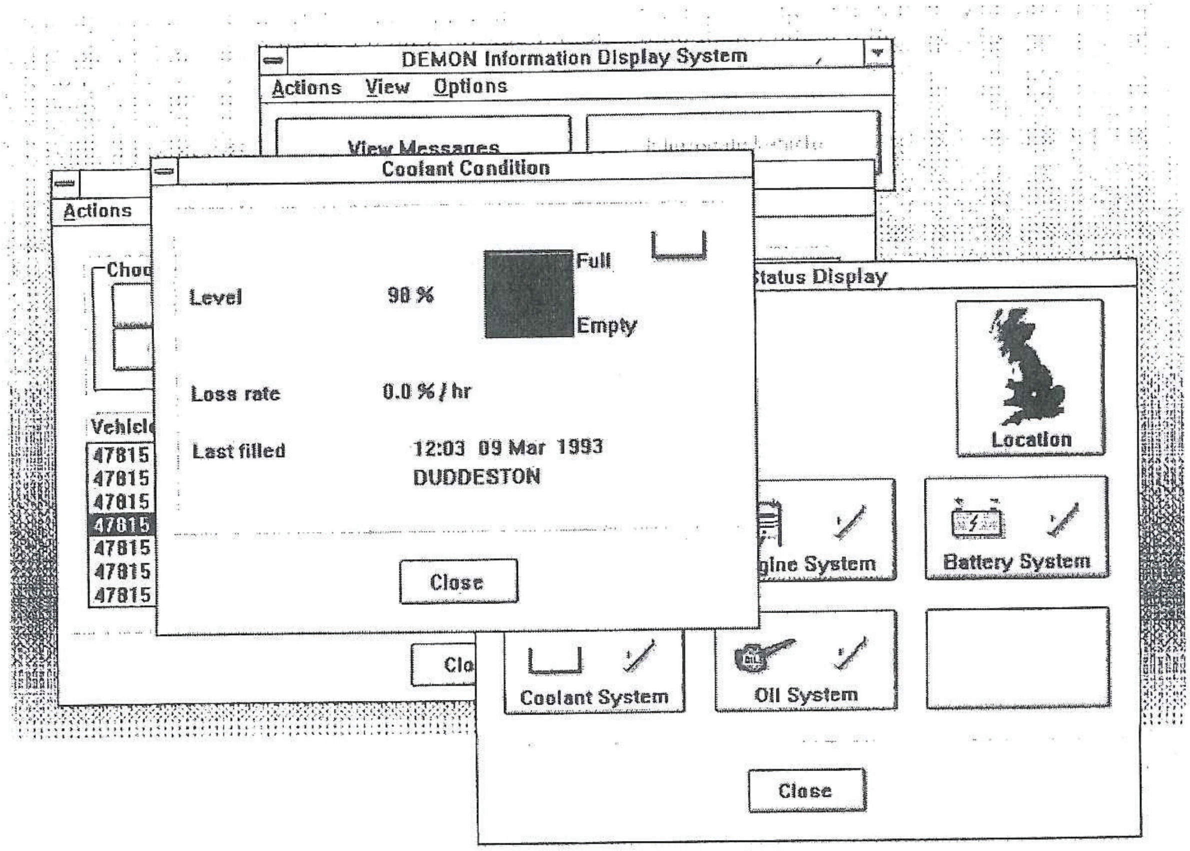

Fig. 6 Display system interrogation screen

ing them to check their current condition. The m is designed to be very easy to use and is based n the popular Windows graphical interface.

ssages from vehicles. The receipt of a message pro- ices a flashing message box telling the user that a new message has arrived. This allows the user to be performing some other task on the machine, for instance word processing, or using the system for vehicle interrogation, but still be informed that a new message has arrived. An example fault message is shown in Fig. 5 and a small number of example messages are given in Table 1. A log is produced which includes details of each of the messages received, the times of their receipt, display and action, and the response entered.

Interrogating vehicles. Vehicle interrogation provides information on the current condition of the vehicle's monitored systems. The information returned is presented in two levels. The first level provides a simple pass/fail indication based upon whether a fault is currently diagnosed for that particular system. The information is shown by means of a window with a series of buttons marked with symbols of the system they represent, along with a tick or cross. It should be remembered that faults causing a cross will have been notified to the user already through the generation of a fault message, so use of the interrogation facility is not necessary to determine if a vehicle has a fault. It is useful in determining the condition of particular aspects of the vehicle that may subsequently lead to a fault or in examining the progress of a fault already notified. To allow this a second level of more detailed condition information is available simply by clicking on the button of the system concerned. This brings up a variety of graphs and figures for the system of interest. As an example, information for the coolant system is given in Fig. 6.

6 CURRENT POSITION

At the present time eight vehicles are fitted, owned by four different railway businesses. The businesses are currently evaluating the performance of the system off line before giving it to their maintenance controllers.

Information from the vehicles so far suggests that on average one message per week is produced by each monitored vehicle. It must be remembered that not all messages will result in a service failure if not acted upon. The most frequent messages generated are warnings of high battery drain rate and low coolant reflecting the most common causes of failure in service.

While the system described here is aimed at improving the service reliability of Class 47 locomotives, with some development it can be adapted for use with other locomotive types. A related system has already been fitted to one high-speed train power car. The flexible nature of the equipment makes it suitable for a wide range of monitoring tasks. Systems based upon the same architecture have been fitted to 20 multiple unit vehicles operated by Regional Railways and Network SouthEast. These systems have been designed primarily

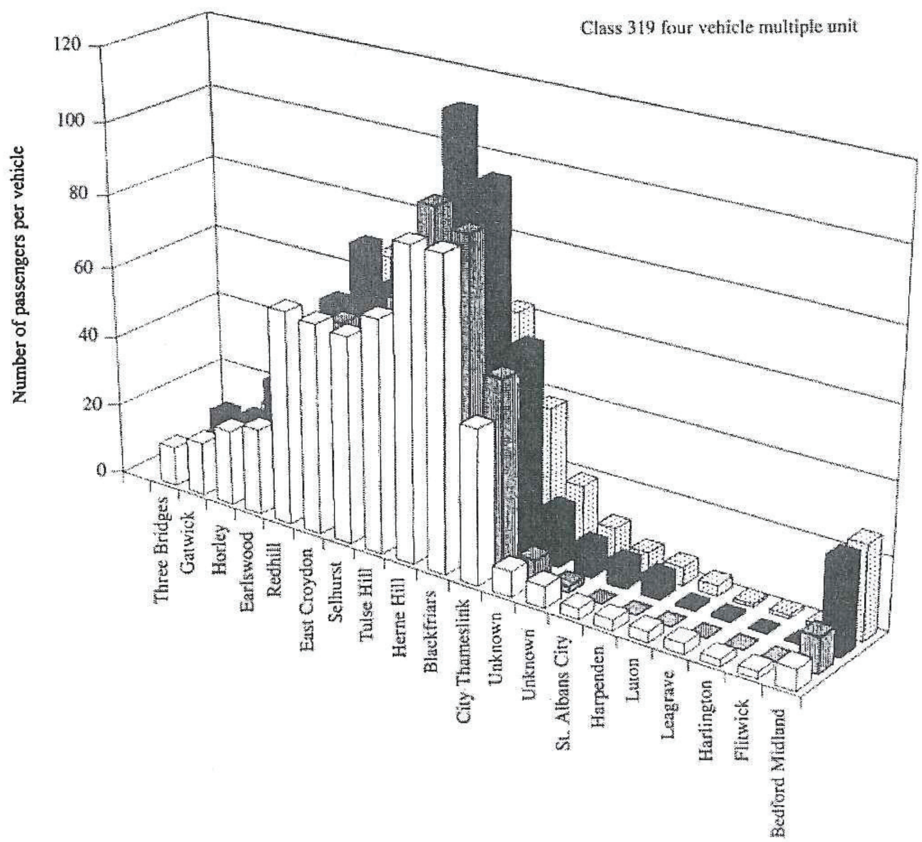

Fig. 7 Passenger vehicle load estimate

provide marketing information on customer loading ig. 7). The number of passengers is determined by the n-board detection system and is recorded along with late, time and the current station (via GPS). The information is routinely downloaded by cellular radio. Additional parameters can easily be included and some of these systems have been extended to include monitoring of traction, braking and door operation. So while the higher reliability of multiple unit vehicles makes SMR less economic, it may be done at marginal cost by integrating it with a customer load determination system.

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Diesel Locomotive Reliability Improvement by System Monitoring

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Abstract

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.

system monitoring for reliability diesel locomotives

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