Development of Vehicle Health Monitoring System (VHMS/WebCARE) for Large-Sized Construction Machine

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This paper describes the vehicle health monitoring system (VHMS/WebCARE) we have developed for large-sized construction machines.

Large-sized construction machines are continuously operated for many hours. Once they break down, it takes substantial cost to repair them. Besides, since repairing a large-sized construction machine takes much time, it significantly affects the machine activity rate. Therefore, construction machines, especially large ones, are required to be free of down time and capable of planned operation without interruption. In order to secure such machines, it is necessary to early detect any symptoms of machine trouble by physical examination, etc. and have the maintenance personnel take suitable measures without delay.

For monitoring and diagnosing large-sized construction machines, we have developed a system which supports diagnosis for the maintenance of large-sized construction machines, including prediction of machine trouble and estimation of machine life expectancy. This system consists mainly of a controller exclusive for collection of data for self-diagnosis of the operating condition of the machine and a data base which stores collected data so that the data can be effectively used for the diagnosis mentioned above.

Key words: *Large-Sized Construction Machine, Health Management, Monitoring, VHMS, WebCARE*

1. Introduction

(1) Background to development

It has been quite a while since the user need for a large-sized construction machine shifted in emphasis from an unbreakable machine to an environment-friendly machine equipped with a comfortable cab. In recent years, more and more users are calling for low-cost machines which are free of down time and which allow for planned operation.

On the other hand, the construction machine is required to have functions which self-diagnose its conditions and tell the diagnostic results to the machine operator and maintenance personnel so that they can prepare an optimum maintenance plan without delay.

The method that has been recommended most is to carry out prescribed periodical inspection and repair in a prescribed way. However, if some machine trouble occurred, there was no alternative but to rely on the experience of a skilled mechanic or diagnosis with the aid of suitable measuring instruments. Several attempts have been made to have the machine collect data and diagnose trouble for itself. However, it was impossible to detect symptoms of machine trouble beforehand and take suitable preventive measures.

On the other hand, electronic control systems using sensors and controllers are rapidly being introduced to construction machines too, making it possible for the machines themselves to monitor detailed information about their conditions without relying on the diagnosis based on the experience and intuition of skilled mechanics. In addition, with the progress of information technology (IT), it has become possible to utilize the mobile communication service that was formerly so costly that it could not be applied to the above purpose. Some of the construction machine makers, including our company, have started offering services for dynamic management of small and medium-sized construction machines.

(2) Vehicle health monitoring system for large-sized construction machines

The systems for small and medium-sized construction machines mentioned above are intended mainly for dynamic management. They are used to collect information necessary for remote management of construction machines. The information includes vehicle position, service meter and fuel gauge readings, and caution messages. They make it possible to improve the efficiency of control operations, such as the allocation of machines, hence benefit both rental companies and users that own or control many construction machines. For agents too, those systems are useful in efficiently allocating their service cars, mainly for the purpose of maintenance of construction machines.

In the case of large-sized construction machines, on the other hand, it is indispensable to analyze the physical condition of each individual machine. This calls for a system which is totally different in concept from the dynamic management system. Namely, for small and medium-sized construction machines, the ease of troubleshooting based on statistical processing of troubles and causes is called for, whereas for large-sized construction machines, which are much smaller in number, diagnosis based on specific data about each individual machine is required.

Large-sized construction machines are continuously operated for many hours. Once they break down, it takes considerable cost to repair. Besides, since repairing a large-sized machine takes much time, it significantly affects the machine activity rate. At 24 – 7 mines (i.e., mines which are operated 24 hours a day, seven days a week), the effect of machine breakdown is still greater. There, it is indispensable to tackle such extremely difficult tasks as predicting machine troubles and estimating machine life expectancy. In addition, since large-sized construction machines are used for a long period of time, the cumulative cost of maintenance becomes substantially high. There are even cases in which it exceeds the purchase cost. It has been known from a number of analyses made in the past that overhauling a machine before it breaks down is effective to reduce the cumulative maintenance cost. (The cost of repair after breakdown is 1.5 to 2 times higher than the cost of overhaul before breakdown.)

In view of the facts mentioned above, we have developed a monitoring & diagnostic system for large-sized construction machines. This system consists of Vehicle Health Monitoring System (VHMS) — a controller exclusive for continuous collection of data about the machine operating condition for health examination of the machine and early detection of symptoms of machine trouble — and WebCARE — a system which predicts machine trouble and estimates machine life expectancy from the collected data to help the maintenance personnel take suitable measures without delay.

2. Explanation of the system

(1) Purpose of the system

The purpose of VHMS/WebCARE is to cut the costs of inspection, maintenance, and repair of the machine throughout its life, reduce the downtime due to maintenance and repair, increase the machine activity rate, and contribute to the improvement in productivity. In order to attain this purpose, it is necessary to provide the service base with the following data as indicators of machine health conditions so that the service personnel can diagnose the machine and take suitable measures without delay.

A. The way the machine is used
B. The rigorousness of the condition under which the machine is operated
C. Estimated life expectancy of the machine

Namely,

- For how many hours has the machine been used (service meter/odometer)?
- When has the machine been used (key switch on/off, engine start/stop time)?
- How much work has the machine done (excavation load/transportation load)?
- How have the main components been operated (load map)?
- When and how troubles with the main components have occurred (trouble record, snap shot record)?
- Are there symptoms of trouble with any of the main components (trend data record)?

If the above information about machine conditions which could hardly be obtained in the field can be fed back on a real-time basis to the service base-the forefront of machine maintenance, it becomes possible to improve the level and speed of maintenance work dramatically.

(2) System configuration

This system consists of an onboard monitoring system (VHMS), a diagnostic data base, a data distribution network (WebCARE), and a communication system which links them together.

The VHMS Controller utilizes the Computer Area Network that links computers for electronic control of construction machines (these computers shall hereinafter be referred to as the controllers) and compresses sensor data obtained by the individual controllers and data subjected to primary processing before saving the data. The data accumulated in this way is automatically transmitted from a satellite communication terminal to the WebCARE data base via the ground station at the optimum timing.

Formerly, the conditions of construction machines were determined by periodical health examination using various instruments (PM clinic), oil analysis, maintenance and repair records, etc. By utilizing VHMS/WebCARE, it is possible to free the service personnel from the burdensome examination. As the monitor data are digitized and stored in data bases provided for the individual models and machine numbers, the service personnel can always monitor the latest data on the Web. The web screen displays detail data by, for example, a graph indicating a time-serial change, frequency of speed change, and error codes from the vehicle.

The general system configuration of VHMS/WebCARE is shown in **Fig. 1** and **Fig. 2**.

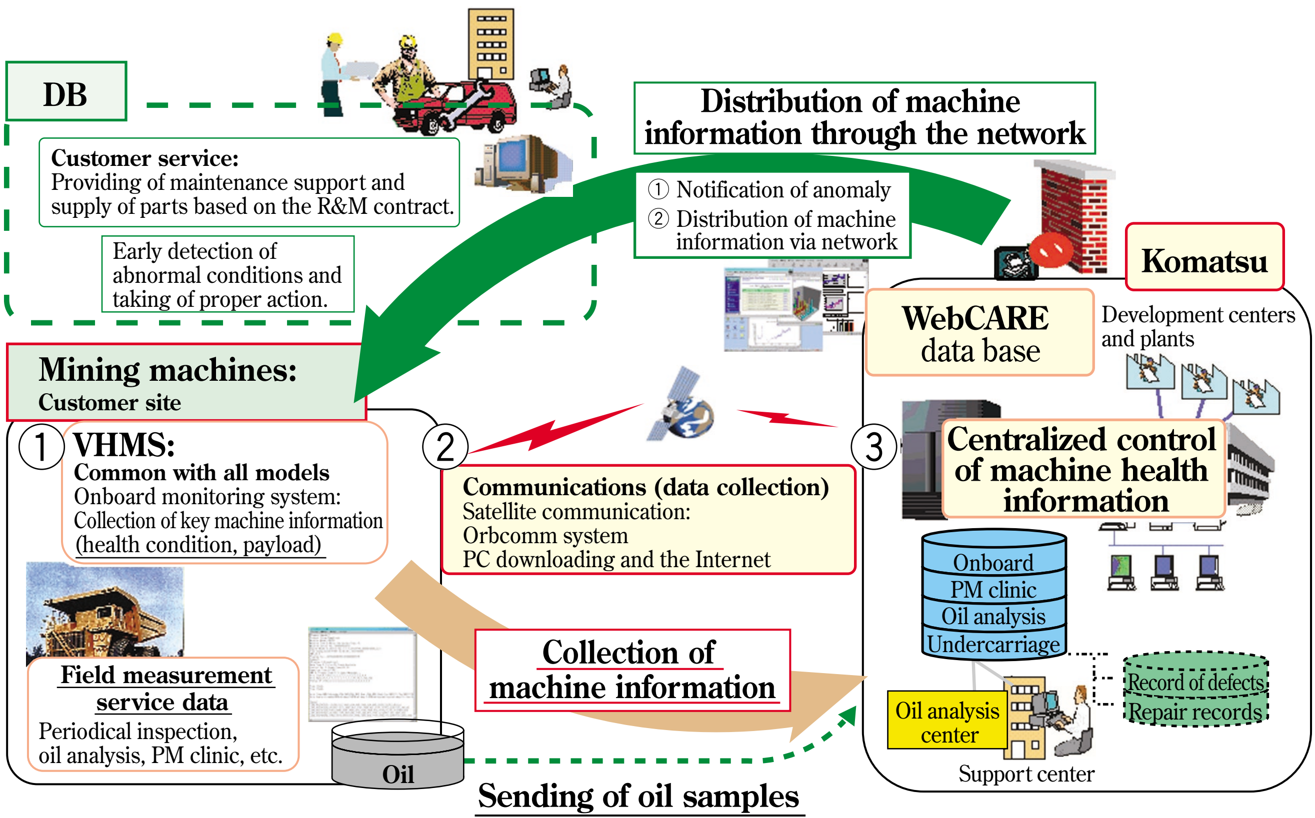

Fig. 1 Basic system concept (VHMS/WebCARE)

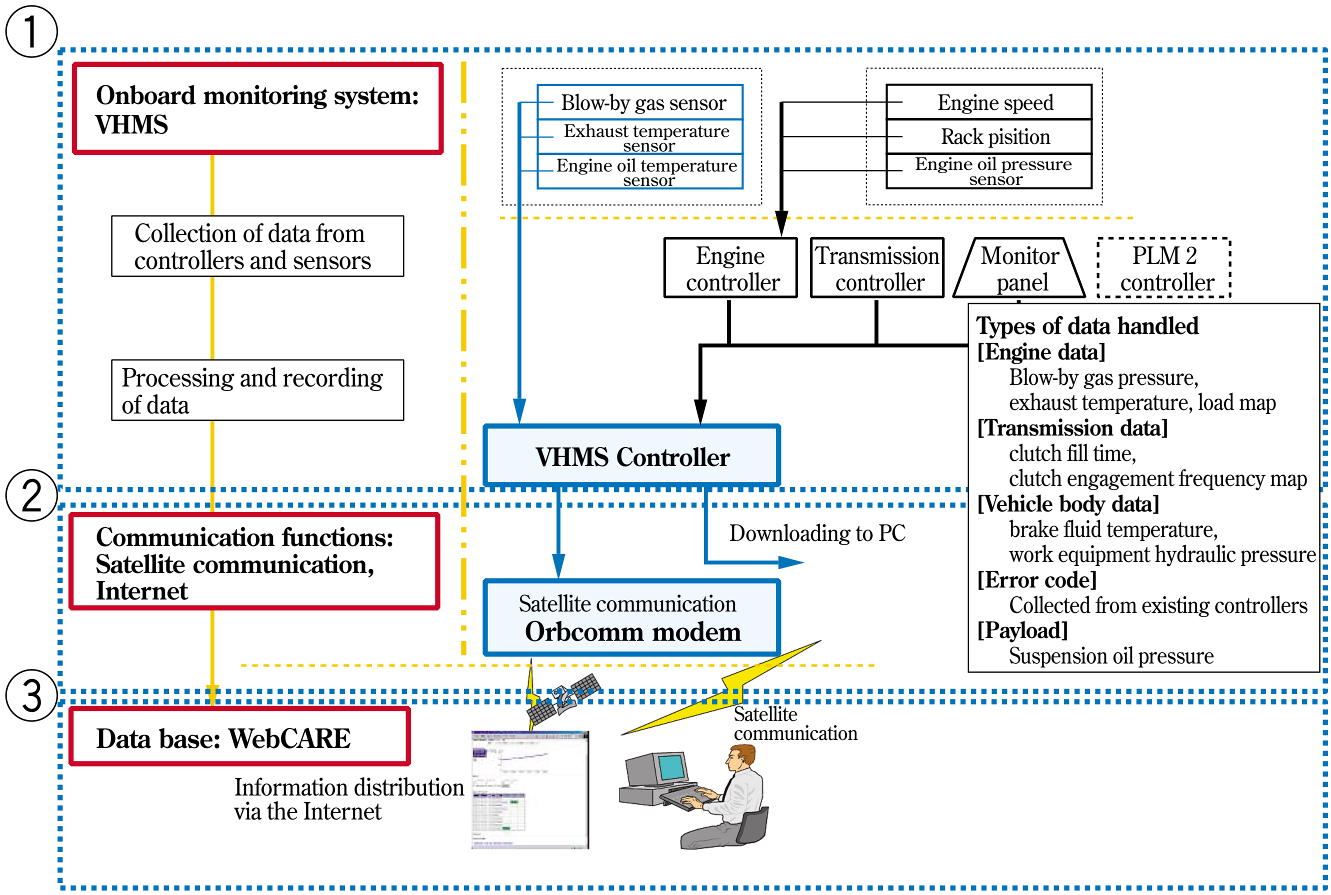

Fig. 2 Basic system concept (VHMS/WebCARE)

(3) VHMS Controller

The VHMS Controller is an onboard computer for collecting data and connected via a data communication network with the existing controllers for the engine, transmission gear, etc. There are cases in which other sensors are linked to the computer. Since there is no need to make any modifications to the existing controllers, the VHMS Controller can be installed even to an existing vehicle. By using the data communication network and VHMS, it is possible to collect necessary data not only from the Komatsu's original components but also from a Cummins engine which is a component of super-large-sized construction machines supplied from Cummins to Komatsu on an OEM basis.

The VHMS Controller receives signals from other controllers and sensors as required to perform various types of processing, such as giving the date, stratifying data according to the degree of importance, totaling, averaging, and maximization/minimization of data, preparing frequency distribution, and performing the flight data recorder function (saving time-serial data before and after some trouble), and stores processed data in its internal memory. Since it uses non-volatile memory, the data stored in the memory is not lost even when the switch is turned off or the battery is disconnected.

What the VHMS Controller monitors is limited to the main components which take much time and cost if they break down. Thus, the design concept is that the Controller leaves out unnecessary information as far as possible. Taking a dump truck as an example, the monitoring functions of VHMS are explained below.

The main objectives of monitoring can largely be divided into the following:

(a) Grasping abnormal conditions: Physical condition and aging deterioration of the machine.

(b) Grasping rigorous condition under which the machine is used: The load applied to the machine.

The former can be grasped from trends of the main parameters and time-serial changes of error codes, and the latter can be grasped from frequency maps of fuel consumption, etc. All this permits taking proper action as soon as data about abnormal operating condition is obtained. In addition, from the aging deterioration data and machine load information, it is possible to determine the optimum overhaul timing. A concrete example with an engine is given below.

① Engine monitoring

The Controller continuously accumulates and transmits the cooling water temperature and maximum, minimum, and average lubricant temperatures. Even if the temperatures are not so high as to cause an engine overheat, it is possible to detect unusual symptoms among the same fleet of vehicles (e.g., a machine whose lubricant oil is somewhat higher) by group control. In addition, the Controller accumulates and transmits a load frequency map and such trend data as blow-by gas pressure and exhaust temperature to allow for prediction of overhaul timing. This permits preparing necessary parts before a prescribed limit is reached. **Fig. 3** shows an example in which the life expectancy of an engine was determined from relevant data obtained. It shows that the overhaul period which was formerly 12,000 hours has been prolonged to 20,000 hours.

In order to establish items to monitor and diagnostic standards to follow, we carried out a long-term bench test to grasp cause-effect relationships and verified them by testing with actual vehicles. In the bench test, destructive tests were carried out on vehicles with various levels of parts, such as

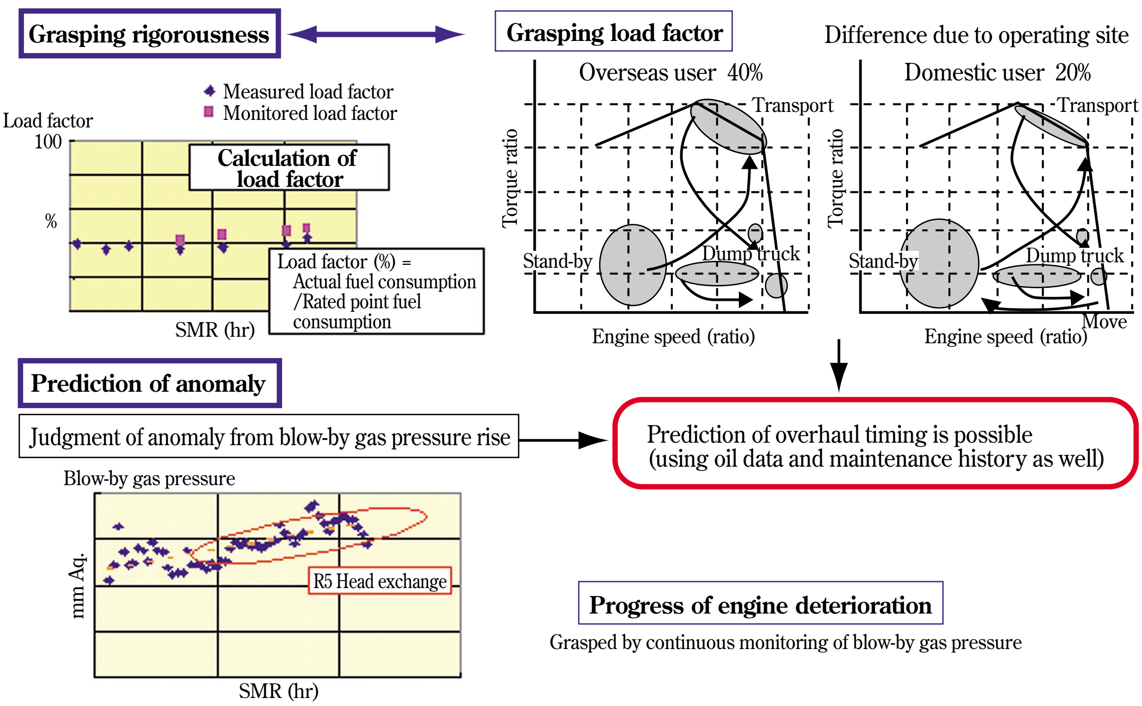

Fig. 3 Estimation of engine life expectancy

deteriorated lubricant, oil containing dust, and worn valve. After clarifying what breaks down in what mode, we developed a data base for diagnosis.

② Transmission monitoring

The transmission has many clutch plates as wearable parts.

The system precisely analyses not only the frequency of speed change but also the time required for engagement of the clutch, thereby constantly checking if the wear limit has been reached. **Fig. 4** shows an example of trend data obtained by monitoring the relationship between a transmission normally used and a transmission used very frequently.

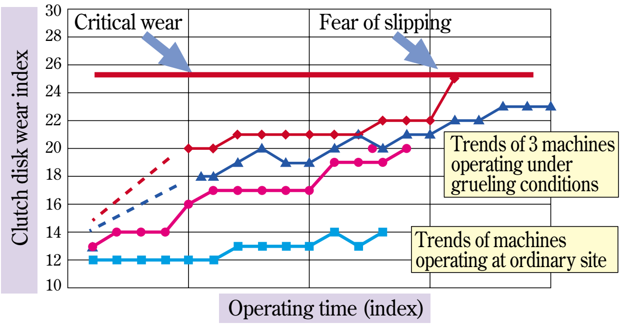

Fig. 4 Analysis of transmission overhaul timing

Like the engine, the transmission was also subjected to various tests using the expertise of our company which makes the main components for itself. As a result, we could establish a technique to grasp the transmission condition without measuring the amount of wear directly.

(4) Satellite communication equipment and antenna

For the satellite communication from the monitoring equipment to WebCARE, we decided to use a satellite communication which is a public infrastructure, like our KOMTRAX system that has already been installed on more than 4,000 small and medium-sized construction machines in two years. In order to spread our system throughout the world, it is indispensable to establish antenna technology for supporting the volume of data transmitted and the quality of communication and communication technology for uploading data at a cost which balances with the value of service. We could establish these technologies by monitoring information about test vehicles for more than two years and carrying out carefully-planned tests to determine the appropriate interval of data transmission, etc.

The satellite communication equipment is capable of radio transmission of data to the ground station installed in each individual country via satellites which turn around the earth on low orbits. From the ground station, the data is automatically transmitted to the Komatsu data base, WebCARE, via the Internet. Since low-orbit satellites are used for the data communication, a non-directive antenna may be used. There is no need to direct the antenna in one particular direction. This is suitable for construction machines which are changed in direction frequently. The fact that the same communication system can be used around the world also makes the system suitable for global operation. **Photo 1** shows the satellite communication equipment installed on a construction machine in operation in Phase II of the Kansai Airport Construction Project.

Photo 1 Satellite communication equipment mounted on vehicle

(5) Personal computer and software for data output

The data recorded in the VHMS Controller can be output to a personal computer by means of exclusive software. By so doing, it is possible to display data in the form of a graph and process/display the data as a standard CSV file (a string of data separated by commas) using Microsoft Excel, for example. In addition, by connecting the personal computer to the Internet, it is possible to transfer the data on-line to the WebCARE data base.

The types of data that are output to the computer include: date, service meter reading, engine speed, vehicle speed, atmospheric pressure, outdoor temperature, cooling water temperature, oil pressure, oil temperature, payload, machine trouble, etc. Displayed on the personal computer monitor screen are: a chronological list of items for machine troubles, load frequency map and trend graphs for temperatures, pressures, etc., and flight data recorder information (a detailed time-serial graph called a snap shot) when machine trouble occurs.

The snap shot can be manually obtained by a start switch. It permits examining the health condition of the machine without using any measuring instruments by performing a series of operations prescribed for each type of machine. With this, the conventional PM clinic which formerly required 60 minutes to prepare the measuring sensors, etc. can be completed in about 10 minutes, improving the efficiency of PM clinic dramatically. **Fig. 5** shows an example of PM clinic.

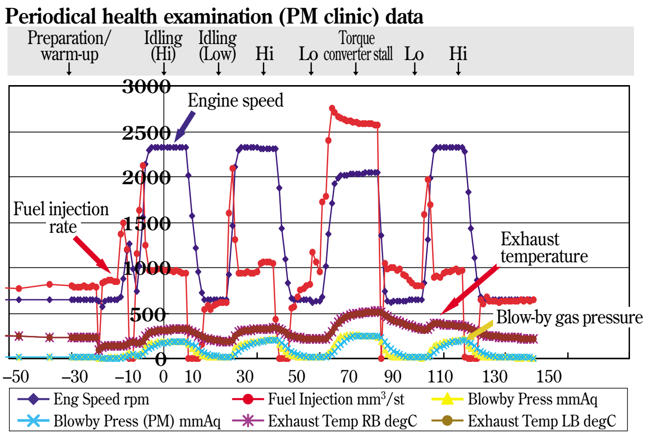

Fig. 5 PM clinic data

(6) WebCARE data base (central data base and server linked to the Internet)

The personal computer alone can display only the vehicle data that is input to it. When connected to WebCARE, however, it can display all the vehicle data around the world. In addition, both the data base and the server are linked to the Internet, allowing for access to them from any part of the world. The data base is protected by a sophisticated firewall to prevent data being damaged or lost by incorrect operation or malicious act. Needless to say, the password and the right to access are checked when access is made to WebCARE and the display of data is restricted to provide complete security. **Fig. 6** shows representative examples of screen display.

3. Results

(1) Effects of system development

We could develop a data base which is required to estimate life expectancy of the engine and other main components and detect symptoms of machine trouble by a combination of the VHMS Controller and WebCARE, thereby contributing much to the improvement of machine activity rate and the reduction of repair cost.

The VHMS/WebCARE is an inexpensive onboard system for overall health examination of construction machines. Because of this, it is installed as a standard system on large-sized construction machines, such as the dump truck, hydraulic excavator, wheel loader, and bulldozer (a similar system is being developed for certain models). Formerly, detecting symptoms of machine trouble required a considerable amount of cost (the onboard equipment alone costs several million yen per unit) and special technology (analytical computer program and engineer), hence was difficult to implement. Our new system permits analyzing huge volumes of data efficiently by incorporating our know-how into its algorithm and data base. It is positioned as the backbone of large IT-based construction machines in the future.

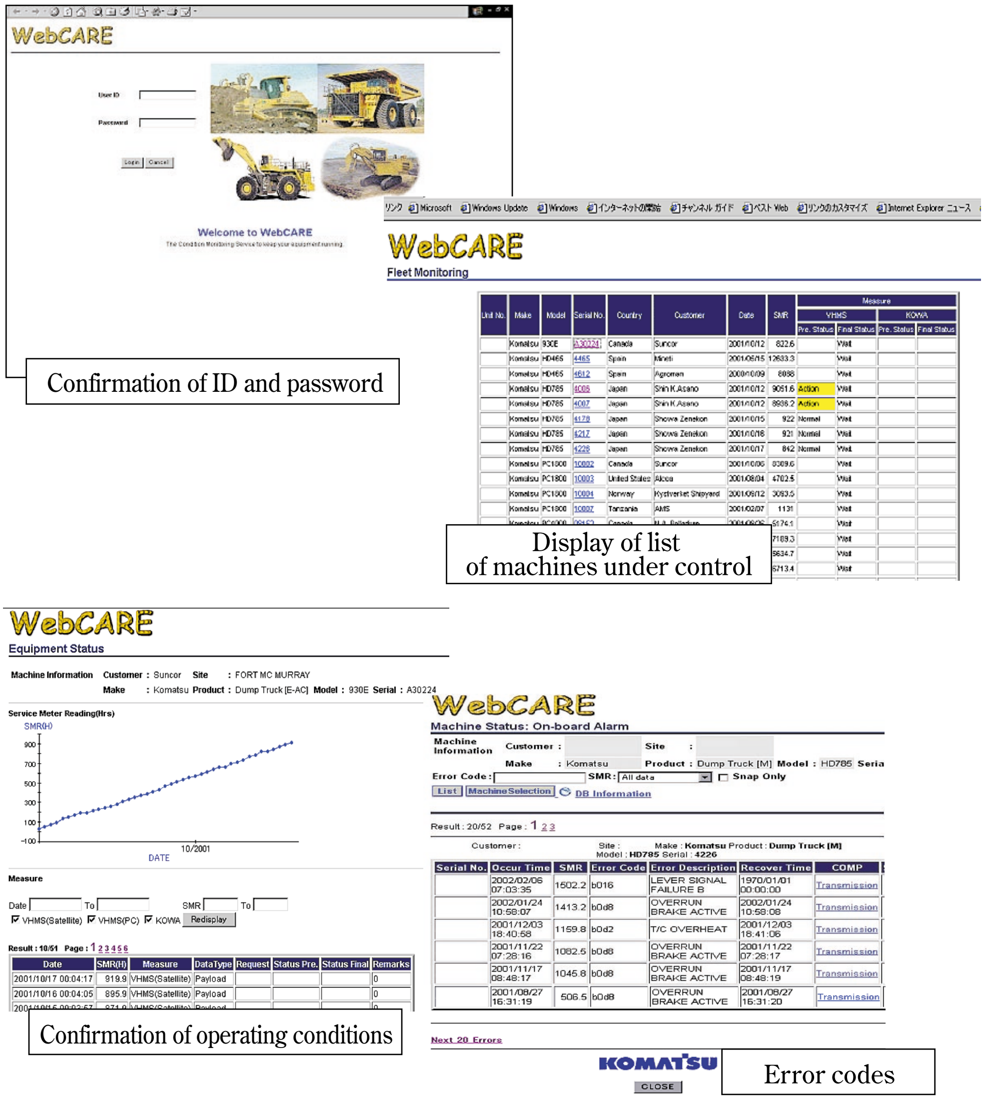

Fig. 6 WebCARE screens

(2) Improvement of machine activity rate and reduction of repair cost

Concerning the ultimate goal of operating mining machines at mines 24 hours a day, 365 days a year too, our system automatically transmits machine data by satellite communication equipment, hence does not affect the machine activity rate at all. Besides, there is no need to dispatch serviceperson to the field to collect necessary data, and VHMS is completely free of downtime. Since data is transmitted on a real-time basis, there is no time lag between the occurrence of data and the input of data. This means that it does not happen that important and emergency events are overlooked.

More than 70 construction machines which are equipped with VHMS require less maintenance cost than machines maintained by the users. Therefore, all the users have switched to a maintenance contract with their agents. For the agents too, they can attain planned cost by implementing preventive maintenance. In the past, for example, an analysis of data about the engine of a 120-ton wheel loader revealed an abnormal engine oil pump, thereby making it possible to prevent seizure of the engine right before it occurred, or frequent slipping of the tires of a 90-ton dump truck driven by a certain operator on a downhill was detected, when proper operational guidance was given to the operator, thereby making it possible to eliminate the need to repair the tires, power train, etc. Thus, the system is useful both to the users and the agents.

(3) Utility of data base

Data transmitted to the data base is instantaneously processed by the system that operates 24 hours a day, 365 days a year, and permits access to the processed data by WebCARE.

The same screens can be accessed from our service bases and construction offices at home and abroad. This has made it possible for all engineers specializing in machine design, manufacture, quality assurance, parts supply, repair and maintenance to share the same facts, knowledge, and experience and back up proper, speedy, and sophisticated machine maintenance work. The Internet that is free from national border and time lag allows for maintenance and repair support on a global basis.

As mentioned above, the primary effect of WebCARE is the improvement in quality and reliability of construction machines in operation. In the future, as data about construction machines in actual operating condition are accumulated, it should be possible as a secondary effect to further improve the construction machines and cut their costs in the medium to long run.

4. Future direction

Because of its nature, developing the present system required the cooperation of all the related fields — design, service, manufacturing, etc. In particular, the experience and wisdom accumulated in many years in the service field, such as the PM clinic and other health diagnostic techniques, were the backbone and prime mover of the system. In the future, we intend to improve the degree of perfection of the system, develop new systems for monitoring hydraulic machines, etc., enhance the data analysis functions of the server, and upgrade the link with repair records and other data held by other systems. Ultimately, we would like to come up with a system which allows for accurate estimate of machine life expectancy and efficient repair planning.

Introduction of the writers

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[A few words from the writers]

The writers have the feeling that the present system could be developed by the concerted efforts of all the persons concerned of the related departments — Service, Vehicle Body Development, System Development, Manufacturing, Test Laboratory. From the technical aspect, the system represents a fusion of construction machine and information technology (communication and data base). The writers could involve themselves in a very interesting system development project. In the future, they intend to further upgrade the present system.