Development and Deployment of KOMTRAX STEP 2

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More and more companies are taking advantage of information technology (IT) to expand their customer services and develop new businesses. In the construction machine industry, Komatsu was quick to utilize the Internet and mobile communication technology to develop a construction machine management system which it calls KOMTRAX. First the company successfully introduced KOMTRAX – a dynamic management system – to the rental machine market (STEP 1). Then the company made several improvements on the system, specifically adding new items to the menu of machine information provided by the system (STEP 2). Since two years ago, Komatsu has been promoting installation of KOMTRAX as a standard feature in Japan, first on its major models and then on its other models. At the same time, it has been building systems which are required for deployment of its overseas operations and used-machine business on a global basis. This paper describes the configuration and features of KOMTRAX and the onboard data terminal, communication infrastructure, and server that Komatsu has developed for the system.

Key words: *KOMTRAX, Dynamic Management, Satellite Communication, Ground Wave Communication, GPS, Position, Map, Operation Information*

1. Introduction

Today, information technology (IT), as represented by the Internet, GPS, and mobile communication, has become widespread among almost all generations everywhere. Komatsu tackled for years the task of incorporating IT in its construction machines and eventually came up with KOMTRAX.

KOMTRAX (Komatsu Tracking System) is an innovative new system that utilizes the most advanced mobile communication technology and ever-progressing Internet technology. This system has made it possible even for the people in the office to gain access to and use machine data that was formerly accessible only in the field, such as the current machine position, service meter (hour meter) and fuel gauge readings, machine trouble indications, and consumable parts replacement timings.

The navigation system that combines a GPS (Global Positioning System) and an electronic map has already become widespread in the field of automobiles. Now it can be used as a portable terminal too. The Internet and mobile communication technology have made remarkable progress hand in hand, allowing for higher communication density and speed and lower communication cost in terms of both hardware and software. The technological progress has made it possible to realize the long-cherished desire to remote-control traveling work equipment, production facilities, etc. In fact, the Internet and mobile communication technology are being increasingly used in operation control of delivery trucks and buses, inventory control for automatic vending machines, and production control at chemical plants.

In its research and development on electronics, Komatsu had been studying for more than 10 years a radio communication system which permits obtaining various data about construction machines operating at remote sites and which supplies those construction machines with control information. To develop such a system, the company had accumulated the key technologies. Because of large amounts of cost involved, however, it was difficult for the company to build wide-area communication infrastructure required for the system and maintain the infrastructure on its own. In recent years, as the remarkable progress and spread of IT mentioned above has made the necessary communication infrastructure available and the rapid increase in proportion of rental/leased construction machines has caused the need for dynamic management of construction machines to rise, the company could successfully develop the system.

2. Background to development

Several years ago, Komatsu developed satellite communication equipment and a terminal which can be linked to the network inside a construction machine. Tens of units were subjected to field tests to verify the viability of the terminal. Then, in the autumn of 1998, the company developed an onboard terminal with satellite communication equipment for advance introduction to the market through certain rental companies of the Komatsu Group. At the same time, the company developed a kit for mounting the terminal as an option on its major models. With the cooperation of users, the terminal was mounted on one machine after another. Thus, a new IT-based system for construction machines was born. Initially, the system was called a 'telemanagement system'.

At that stage, the information supplied by the system only contained the machine position, service meter reading, and operation map (STEP 1). The company started selling the system in earnest in November 1999 as the system proved effective in managing rental machines. The selling of the system to the other rental companies of the group was started at the same time. In addition, the company set about providing compensations for accidents and maintenance contracts utilizing the system.

In 2001, the company completed development of an onboard terminal with ground wave communication equipment. Then, the machine information obtained was increased to contain the fuel gauge reading, cooling water temperature, machine trouble indications, consumable parts replacement timings, etc. (STEP 2). In August of the same year, the company started installing the onboard terminal as a standard feature on its major models during factory shipment. At present, there are thousands of machines which are equipped with this terminal.

3. KOMTRAX

(1) System configuration

The system component that is mounted on the machine is an onboard terminal which incorporates radio communication equipment for either ground wave communication (Dopa, etc.) or satellite communication (Orbcomm low-orbit satellite) and a Komatsu's original CPU board for obtaining information from the network inside the machine, including information about the engine operation, calculating the current machine position from signals from a GPS satellite, and controlling the above radio communication equipment for communications with the ground control station.

On the other hand, the system component installed in the Komatsu Computer Center is the Komatsu web server (composed of a communication server, a data base server, and a web screen server). It decodes machine data received from the above onboard terminal via the communication infrastructure, stores the decoded data in the data base, and displays it on the web screen. Thus, it has the function of displaying machine information on the user's personal computer monitor screen via the Internet. The KOMTRAX system configuration for ground wave communication is shown in **Fig. 1**.

The Komatsu web server not only processes and displays machine data but also plays an important role in the maintenance and operation control of KOMTRAX. For example, in response to various inquiries from the user, the server analyzes the relevant events, isolates the factors in them, and analyzes the history of data that the server has transmitted and received. When the onboard terminal is installed on the machine during factory shipment, the server also provides a screen for controlling input and inspection by associating the machine information (model and machine number) with the onboard terminal information (product number and serial number). When the onboard terminal is installed on a machine after shipment from the factory, the server provides a control screen which permits the user to input from his personal computer the linkage between the onboard terminal information and the machine information.

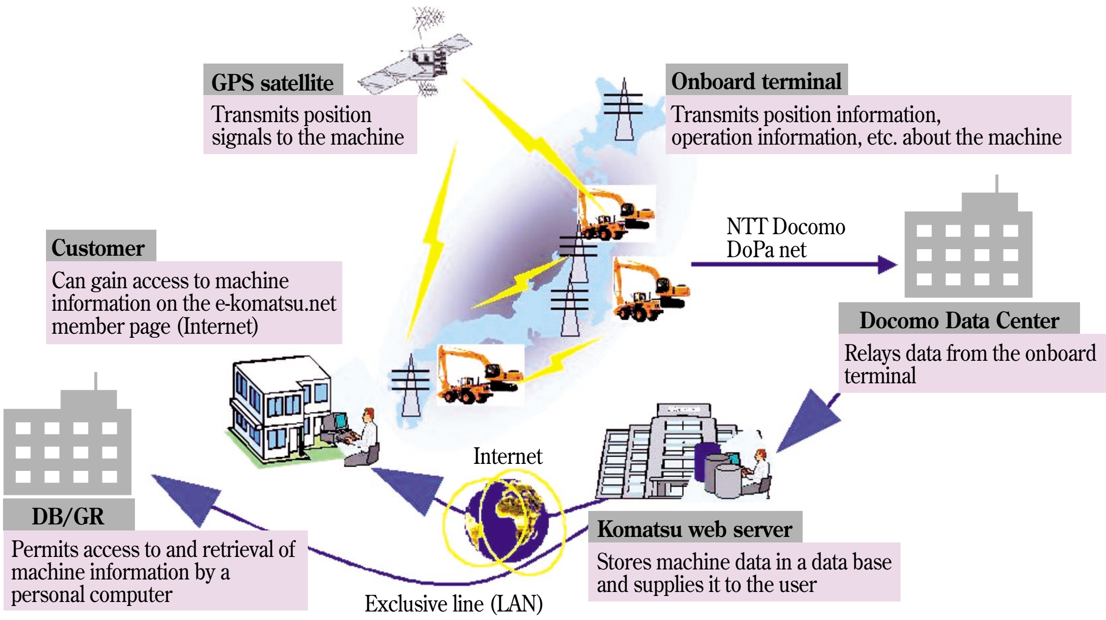

Fig. 1 KOMTRAX system configuration (when ground wave communication is used)

(2) Features of the system

(a) The system permits obtaining the latest machine information anytime.
The onboard terminal automatically transmits machine data. The timing and frequency of data transmission depend on the importance and volume of each individual data item. Since the system permits access to the data 24 hours a day, 365 days a year, the user can obtain the latest machine information anytime. In addition, since the system has a bidirectional communication capability, the onboard terminal can meet a request for data from the server.

(b) The system permits obtaining machine information regardless of the current machine position.
As long as the machine is within the communication service area, it is possible to obtain data about the machine by radio communication. If the machine is under unfavorable communication conditions (e.g., at an underground construction site or in a building), the data to be transmitted is stored in the onboard terminal till the communication environment becomes favorable.

(c) The user can obtain machine information at any place.
There is no need for the user to go to the place where the machine is used or stored in order to check the machine data. The user can gain access to the desired machine data and processed information via the Internet from a personal computer installed at any place. In the near future, it will be made easier to obtain the desired information even from a moving business car or service car.

(d) The system is completely secure.
Needless to say, gaining access to machine information from the client personal computer requires authentication of the user by means of the user ID and password. In addition, the SSL encoding technique has been adopted to prevent the leak of information along the way. Furthermore, when the user who controls the system considers it necessary, the import of a digital authentication key for the client personal computer is made an essential requirement.

(3) Comparison of communication infrastructures

In terms of service area, communication cost, antenna size, etc., data communication infrastructures available for mobile communications can roughly be divided into ground wave communication and (low-orbit) satellite communication. The salient characteristics of each type of infrastructure are shown in **Table 1**. In order to permit choosing the communication infrastructure suitable for a particular machine operation site, the company offers an onboard terminal appropriate to either type of infrastructure. No matter which infrastructure is chosen, the server permits the user to gain access to and control the machine information on a common web screen.

For ground wave communication, it is necessary to establish a direct bidirectional communication between the machine and fixed ground station. Therefore, in terms of the coverage of service area, ground wave communication is inferior to satellite communication. In fact, it can hardly be used in mountainous regions and remote rural areas. However, ground wave communication can be more favorable than satellite communication at construction sites in urban areas where the electric wave tends to turn around. Taking into account the communication speed, communication cost, real-time properties, etc., ground wave communication is a very useful infrastructure. On the other hand, satellite communication offers higher coverage of service area since multiple communication satellites are orbiting around the earth at relatively low altitudes. In addition, it can be used with the Internet on a global basis. (Accurately speaking, the service area depends upon the location of the ground station for satellite communication.)

In the case of satellite communications, the communication time depends upon the period, direction, and elevation of the orbiting communication satellites. **Fig. 2** shows the distribution of time required for data transmitted from the onboard terminal to arrive at the server in satellite communication (example in Japan). In Japan, a communication satellite comes flying over the land every 10 to 15 minutes on average. Therefore, the time distribution reflects that period (the time required for data processing by the ground equipment is included). It can be seen that more than 90% of data communication is completed when a second satellite comes over Japan.

Table 1 Comparison of communication infrastructures

Legend ◎: Excellent ○: Good ×: Poor

Type of communication infrastructure	Service area	Communication cost	Real-time properties	Universality
Ground wave communication	○	◎ Advantageous in mass data transmission/reception	◎	× Domestic use only
Satellite communication	◎ Offers high coverage and is applicable even in mountainous regions and remote rural areas	○	○ Depends on period, direction, and elevation of orbiting of satellites.	○

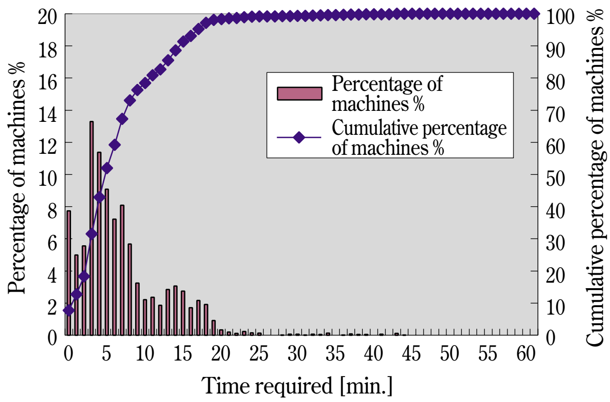

Fig. 2 Time required for data transmitted from onboard terminal to reach server in satellite communication (example in Japan)

4. Principal specifications and characteristics of system components

The principal specifications and technical characteristics of the individual system components of KOMTRAX are described below.

(1) Onboard terminal

The onboard terminal consists of Dopa ground communication equipment or Orbcomm satellite communication equipment, a CPU board for various types of control and serial communications with external devices, a power circuit, a GPS receiver for positioning, etc., all housed in a drip-proof casing. It serves as the interface between the machine and the communication infrastructure. The appearance of the onboard terminal is shown in **Photo 1**.

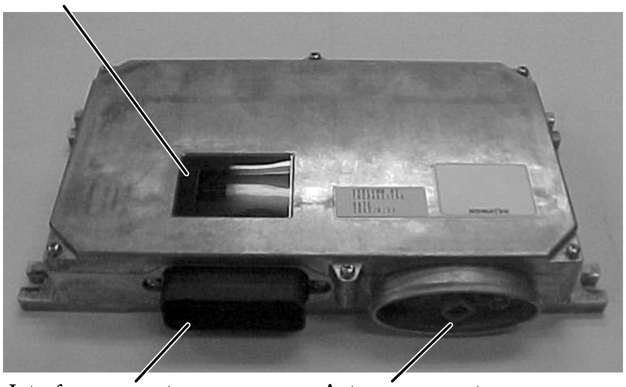

Photo 1 Appearance of the onboard terminal and connectors

The onboard terminal is provided with a row of LED lamps which indicate the communication condition and input signal conditions and a 7-segment LED which indicates the condition of inspection of the onboard terminal and the number of messages waiting to be transmitted. All this facilitates troubleshooting of the onboard terminal. In addition, the onboard terminal is so designed that it can stand use under extremely severe conditions which construction machines are often put under.

The principal specifications of the onboard terminal are shown in **Table 2**.

Table 2 Principal specifications of onboard terminal

Power supply		12 V DC or 24 V DC
Interface	Serial communication	RS-232C (3 lines/9 lines, max. 38,400 bps)
	CAN communication	Available
	S-NET communication	Available (Komatsu's original half-duplex serial communication)
	Digital data input	General data input, test data input, ACC input
	Digital data output	General data output
	Analog data input	Voltage input (0 to 30 V, 0 to 5 V)
Radio communication		Built-in Orbcomm satellite communication equipment or built-in Dopa ground wave communication equipment
Positioning system		GPS

(2) Communication antenna

Ground wave communication between the onboard terminal and the ground key station and satellite communication between the onboard terminal and a low-orbit satellite both require an exclusive antenna. The method of connection between the antenna and onboard terminal in each case is shown in **Fig. 3**. For ground wave communication, the antenna is so designed that diversity wave reception can be adopted to secure desired receiving performance.

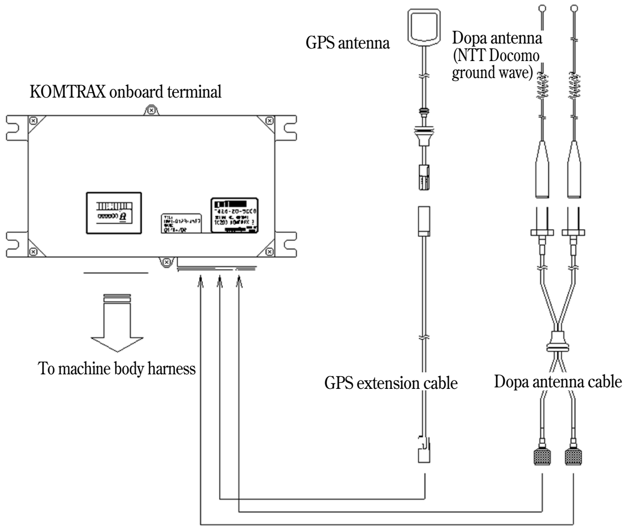

Fig. 3 Connection of antennas to onboard terminal

For a rod-type whip antenna available on the market, it is provided with a rubber mount to improve its vibration resistance. In order to facilitate installation of a communication antenna, the company has developed a sheet-type antenna which is comparable in performance to the whip antenna.

Idealistically, the antenna should be set up as high as possible and at a clear place. In the case of construction machines, special attention should be paid to the following.

- Set up the antenna where it will never make contact with the work equipment and where it is not obstructed markedly by the work equipment as it changes in position.
- Set up the antenna where the vibration acceleration is small.
- Observe the applicable regulations (e.g., ground clearance).

Unlike passenger cars, construction machines tend to remain in the same position for a long time. Because of this, if the antenna directivity has a wide dead angle, it makes it difficult to secure uninterrupted communication. It is, therefore, necessary to carefully evaluate the antenna directivity with the antenna installed to the machine.

The characteristics of antennas for ground wave communication and satellite communication, respectively, are shown in **Table 3**.

Table 3 Characteristics of antennas for communications

Item	Antenna characteristic values	
	Antenna for ground wave communication	Antenna for satellite communication
Antenna type	1/2 λ × 2 stages (sheet-type antenna available as option)	1/4 λ whip antenna (helical whip antenna reduced to 1/4 λ available as option)
Overall length	About 370 mm	About 510 mm
Frequency band (communication speed)	810 – 890 MHz, 920 – 960 MHz (9,600 bps)	Transmission: 148 – 150 MHz (2,400 bps) Reception: 137 – 138 MHz (40800 bps)
Plane of polarization	Vertical polarization	Vertical polarization
Directivity	Non-directivity within horizontal plane	Non-directivity within horizontal plane
Impedance	50	50
Gain	Max. 0 dBi	–3.86 dBi
Standing wave ratio	Max. 1.9	Max. 1.7

(3) GPS antenna

This antenna receives positioning waves from a GPS satellite to determine the position of a machine. The system employs a GPS antenna (attachable to a metallic surface by magnetic force) which is used with many navigation systems for automobiles. The characteristics of this antenna are shown in **Table 4**.

As in the case of the antenna for communication, the GPS antenna needs to be set up at a place which affords an unobstructed view of the sky so as to secure the GPS positioning accuracy (this also makes it possible to shorten the positioning time). Because of this, the GPS antenna is normally fitted to the cab ceiling with a magnet. At a clear place outdoors, it is possible to secure a positioning accuracy of 10 to 20 m. (In the days of STEP 1, the positioning accuracy was not better than about 100 m because the United States released selective availability (SA: the act of intentionally causing the positioning accuracy to deteriorate) in May 2000.)

(4) Server

The Komatsu web server consists of a processor for processing data in ground wave/satellite communications, a data base unit for storing machine data, a web display for processing data into accessible information, and a data transfer unit for transferring data to external devices. The web screen is accessible via the Internet and Intranet from all over the world. The data base unit is periodically backed up to provide against unexpected system failures. Thus, valuable data of the user are safely preserved. The server configuration is shown in **Fig. 4**.

(5) Client personal computer

This is a personal computer for gaining access to machine information supplied by the Komatsu web server. As long as the communication environment allows for connection to the Internet or Intranet, it is possible to use the KOMTRAX system. The requirements of the client personal computer are shown in **Table 5**.

Table 4 Characteristics of GPS antenna

Item	Characteristic values
Antenna type	Micro-strip
Size	45 × 45 × 14.5 mm
Frequency band	1575.45 ± 1.023 MHz (L1 band)
Polarization	Circular polarization
Antenna gain	Min. 2.0 dBi
Amplifier gain	25.0 – 37.0 dB
Installation method	Magnet

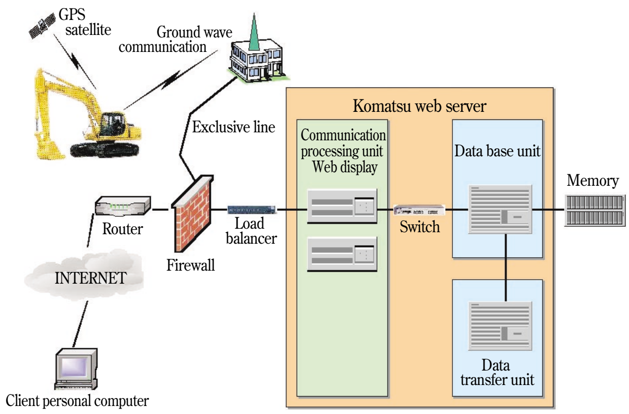

Fig. 4 Server configuration

Table 5 Requirements of client personal computer

Item	Requirements
CPU	*Pentium II 266 MHz or more
OS	**Windows95, 98, Me, XP
Browser	**Internet Explorer 5.01 or newer version
Hard disk capacity	50 MB or more when net-distributed maps are used
Memory	64 MB or more
Display	1024 × 768 dots, 256 or more colors
Disk drive	CD-ROM drive

* Pentium is a registered trademark of Intel Inc. (USA).

** Windows95, Windows98, WindowsMe, WindowsXP, and Internet Explorer are registered trademarks of Microsoft Inc. (USA).

5. Examples of information display screens

(1) Machine list control screen

This screen permits viewing all the machines under control (**Fig. 5**). By using this screen, it is possible to retrieve machines which meet specific conditions and to shift to the detailed information screen associated with those machines or the map screen that shows the positions of the machines.

Fig. 5 Machine list screen

(2) Detailed information screen for specific machine

Concerning a machine selected on the machine control screen, it is possible to see various types of information about the machine, including the machine position (longitude and latitude), address, service meter reading, and operating time. For certain models, this screen also provides additional information, including the fuel gauge reading, cooling water temperature, and machine trouble indications (**Fig. 6**). As the default, the machine operation data of the previous day is displayed on this screen. For machine trouble indications, the history of each of them can be displayed.

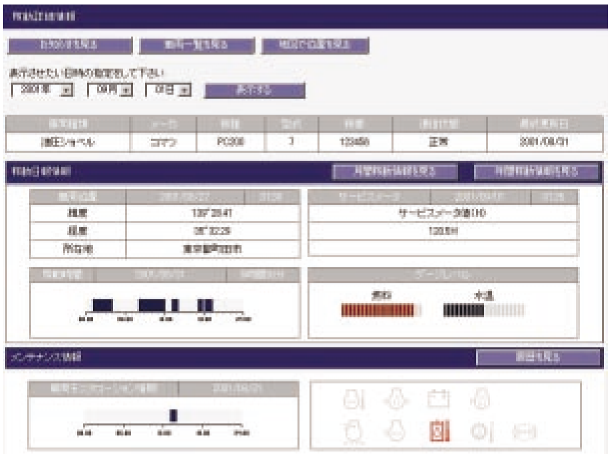

Fig. 6 Machine detailed information screen

(3) Operation information

Whether or not a particular machine was operated in a particular time zone is indicated by the coloring of a bar divided into 15-minute segments. Therefore, it is possible to grasp at a glance the operation condition of each machine on a daily basis (**Fig. 7**) and on a monthly basis (**Fig. 8**).

Fig. 7 Daily operation information

Fig. 8 Monthly operation information

(4) Guidance screen

This screen appears first when connection is made to the Komatsu web server. It displays the caution information and replacement timing information, prompting quick action on the part of the user (**Fig. 9**).

Fig. 9 Guidance screen

(5) Machine position

As the default, a 1/25,000-scale map is displayed (**Fig. 10**), indicating the position of the machine. There are six different scales, which can be changed as desired. This screen can be used to formulate a machine patrol plan and give shipping instructions to trailers. By using this screen together with the guidance screen mentioned above, it is also possible to issue a warning against the stealing of machines.

Fig. 10 Map screen

6. Future deployment

So far, the outline of the KOMTRAX system and the functions of the individual system components have been described. At present, we have systems which serve as the base of KOMTRAX. In order to make the most effective use of IT, however, it is indispensable to increase the proportion of user-owned construction machines of various models to which the onboard terminal is installed. In implementing group control of machines, it is important to clearly define data which are exchanged between different models and to standardize methods of obtaining and displaying data.

In addition, in order to implement dynamic management of machines which have been distributed all over the world, it is necessary to build a system which is capable of uninterrupted communication control of machines even when they are moved across national borders.

7. Conclusions

The KOMTRAX system with the existing functions is used in various ways. It has already produced remarkable effects in some fields.

- Monitoring the conditions of machines and providing timely service based on actual operating hours of machines.
- Preparing efficient transportation/service plans.
- Improving activity rate of rental machines by means of dynamic management
- Calculating rental charges based on actual hours of machine use.

In the near future, as more and more home electric appliances are being linked to the Internet to evolve to IT-based ones, construction machines now operating in the field will be freely linked to the Internet and evolve to intelligent construction machines, allowing the office and field to share the same machine information. At the same time, a new interface which eliminates the distance between the machine, user, and maker in terms of space and time will be developed.

Introduction of the writer

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[A few words from the writer]

The development of KOMTRAX was tough work. However, with our undaunted spirit free from the existing setups and with the aid of the talented technical staff of Komatsu, we could develop a viable system. In the future, we intend to upgrade the present system into one that will revolutionize the conventional ways of doing jobs.