Technical paper

Productivity Improvement by Visualization of Construction Machinery Operation

Minoru Shimizu

Satoki Matsumura

Labor shortage has been a serious problem in worksites operating construction machineries. To secure the production amount while maintaining the quality, the productivity improvement through manpower reduction, greater efficiency, and sophistication in production is necessary. We would like to report the study and the applicable cases of the productivity improvement by visualization of construction machinery operation utilizing ICT/IoT implemented for this problem.

***Key Words**: Visualization of operation, ICT, IoT, guidance monitor*

1. Introduction

In Japan, the population started to decrease with its peak 128.06 million in 2010 and aging is in progress at a rapid speed. The productive age population providing precious labor force is expected to decrease by nearly 1% every year for 20 years until 2030. In the “i-Construction” project for productivity improvement of construction sites promoted by the Ministry of Land, Infrastructure, Transport and Tourism, the proposal of “Making construction sites a most advanced factory” is one of its “three viewpoints”. In factories’ production sites, “improvement activities” to grasp and visualize the moment status of production processes and review how to reduce man-hours and costs have usually been conducted. With the progress of Industry 4.0 and ICT/IoT, these activities have rapidly been sophisticated. We are working on the activities to improve the productivity in the construction machinery operating worksites by applying these manufacturing engineering-based improvement activities which have been implemented in the factory manufacturing sites.

2. Visualization system for construction machinery operation

2.1 Background and aims of development

Komatsu’s construction machineries are equipped with various sensors and have the “KOMTRAX” system accumulating information transmitted from construction machineries in the server via the communication satellite lines or the mobile phone lines. However, the information KOMTRAX provides is summary data in a day and not for a moment grasp like the visualization for manufacturing process conducted in the factory production sites. For example, as you see that “The fuel consumption is not good” but do not know “when, where, in what operation” the fuel consumption is not good, it is difficult to consider a concrete improvement measure for the productivity improvement. To solve such problems, we have developed and constructed “the visualization system for construction machinery operation” which accumulates detailed operation data available from the construction machineries in the cloud server and analyzes them.

2.2 Entire picture of visualization system

This visualization system (**Fig. 1**) collects the sensors’ data of the construction machinery with 10 Hz by attaching an IoT device (a tablet terminal) to the machinery and performs calculations with the collected data for the machinery operation (travel, scooping, etc.) and the payload values by using the edge terminal. The collected data and the calculated data are transferred to the cloud via the mobile phone line. The system automatically analyzes the big data accumulated in the cloud by using the BI tool to visualize the operation status of the construction machinery. The data is collected by accessing to the CAN network mounted on the vehicle. The detailed vehicle CAN data to be used for the vehicle control can be collected by attaching the terminal. The hardware required for the data collection is a commercially-available tablet PC easy to be attached to the existing vehicles. The required specifications are shown below, and the hardware does not dependent on any specific tablet.

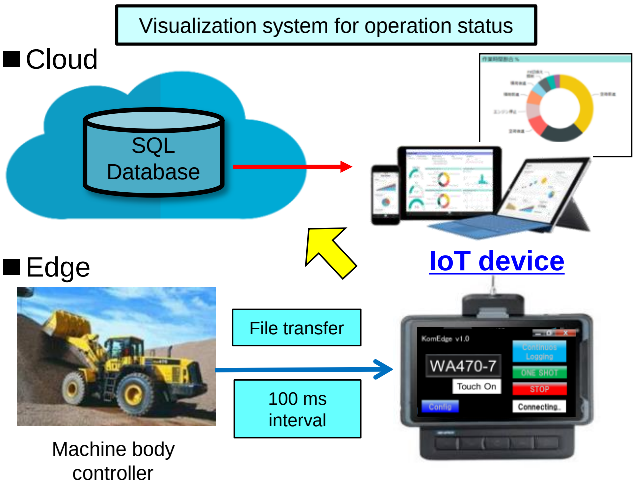

Fig. 1 Visualization system for operation

2.3 Concrete example of visualization

Fig. 2 is a concrete example of the visualization. We can see the ratio in the working time with the construction machinery by job classification (travel, scooping, etc.). With such information showing the moment ratio in the man-hours by operation and visualizing the ratio of valuable work (scooping, traveling with load) and supplemental work (idling, traveling with no load), it becomes possible to consider how to improve the operations. It is the same activity as the method to grasp moment man-hours and improve production processes implemented in the factory manufacturing sites. The collection of the detailed operation data of the vehicle realized this.

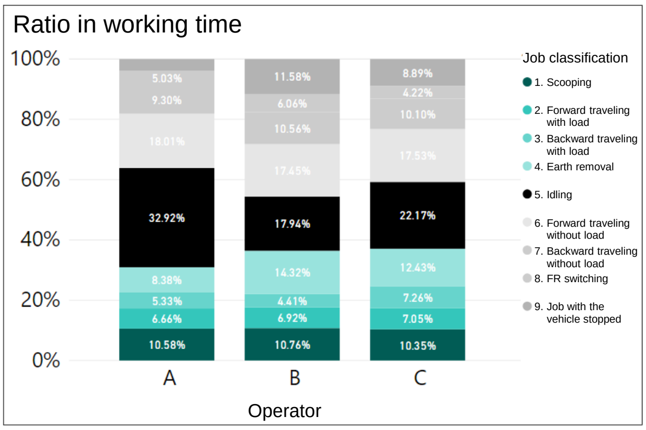

Fig. 2 Concrete example of operation visualization

2.4 Case of improvement

Here we introduce an improvement activity actually implemented by utilizing the visualization system for construction machinery operation. We explain it with the "wheelloader" (**Fig. 3**) as a construction machinery. The wheelloader is a construction machinery with the tire drive system which is mainly used in loading and transportation of earth, sand and crushing. With the results from the collected operation data of the wheelloader, when it was found that an operator had a larger accelerator pedal depressing amount (he always travelled with depressing the pedal to the maximum) compared to those of other operators, his accelerator depressing amount was reduced by 12.4% by providing recommendations such as moderating the accelerator depressing amount and appropriate switching of the travel mode in uphill traveling (**Fig. 4**). As for an operator who had a long cycle time for scooping to loading, his cycle time was reduced by 10% by the visualization of his travel route with the GPS information and the recommendation to have an appropriate travel route when he had unnecessary routes.

Fig. 3 Wheelloader

Such activities should be implemented to establish the improvement effect in the worksite by not only providing recommendations but also continued monitoring with the operation data to check if the operations are actually improved. Also, it should be shown that the production amount does not decrease. For example, when we give a proposal to "moderate the accelerator pedal depressing amount", customers always have a concern that "the production amount may decrease". However, if we can show that the production amount does not decrease when the machine travels with 80% of the accelerator pedal depressing amount by presenting the data, the site supervisor of the customer company can proceed with the operation with understanding. When construction machineries are not the key in the production process in the worksite, such a case are surely possible. With improvement activities like this, we had the results improving the users' fuel consumption (L/H) by 15-20%.

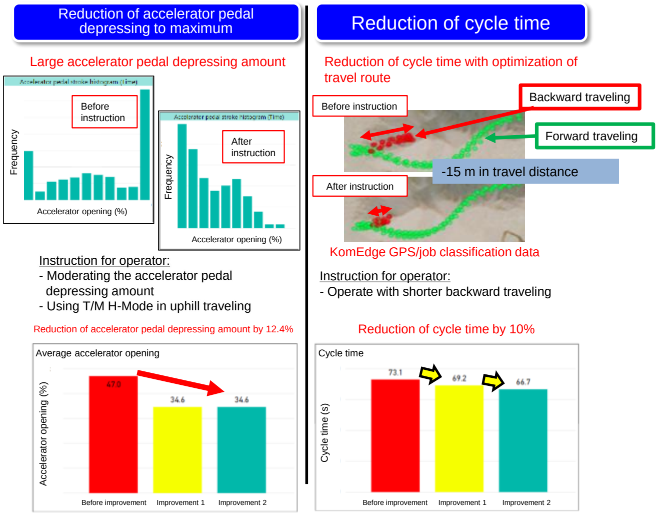

Fig. 4 Case of improvement with wheelloader

3. Visualization of scooping skill

3.1 Background and aims of development

In our activities described in the section 2, we acquired some cases in which the productivity in the worksites was improved by utilizing the detailed operation data, but a problem became clear at the same time. While the improvement was successful in "travel" of the construction machineries, it was difficult in "scooping" operation, which is scooping the earth, in spite of spending more cost. **Fig. 5** and **Fig. 6** show the ratios in the fuel consumption and the fuel consumption amount by job classification. As it is clear with **Fig. 5**, scooping is the highest load work with the worst fuel consumption and its ratio in the fuel consumption amount is also high. **Fig. 7** is the graph plotting the scooping time (s) and the fuel consumption amount (mL) of each scooping operation. It is clear that there is a strong correlation between the scooping time and the fuel consumption amount in scooping. It means that if the scooping time is short, the fuel consumption amount is small. **Fig. 8** is the graph plotting the scooping time (s) and the amount of scoop soil (ton). From these scooping data, we find that the scooping work with short scooping time (small fuel consumption amount) and large amount of scoop soil is "high-productivity scooping work". By comparing this "high-productive" scooping work and "low-productive" scooping work, we find that there are differences between the operations (**Fig. 9**). It is difficult to convey such differences in skill to operators and establish the operation improvement with them. That is the reason why the improvement in the scooping skill is difficult. To solve this problem, we developed "the operation guidance monitor", a tool to visualize the differences in the scooping skill for the operation improvement.

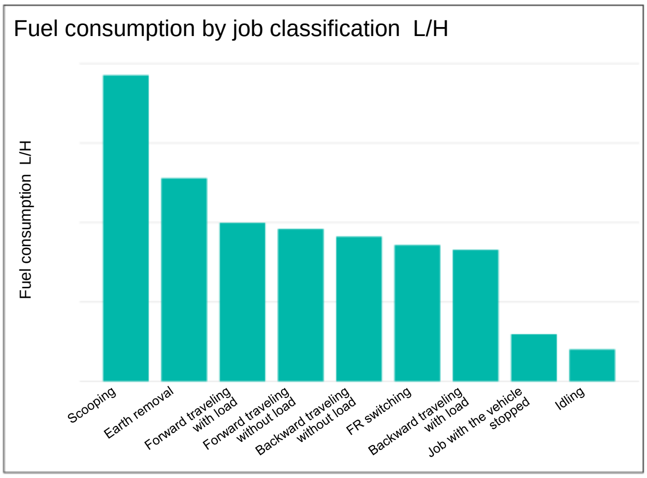

Fig. 5 Fuel consumption by job classification

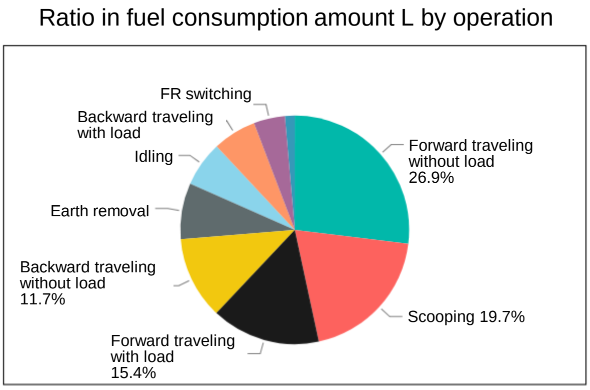

Fig. 6 Ratio in fuel consumption amount by job classification

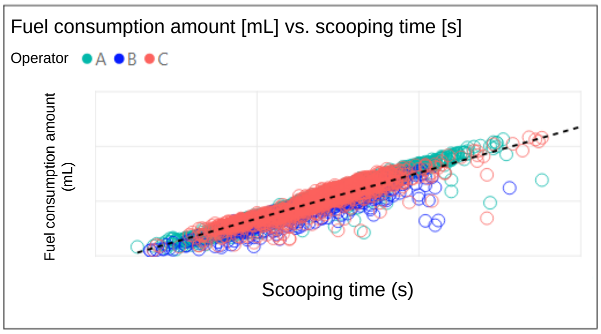

Fig. 7 Fuel consumption amount and scooping time

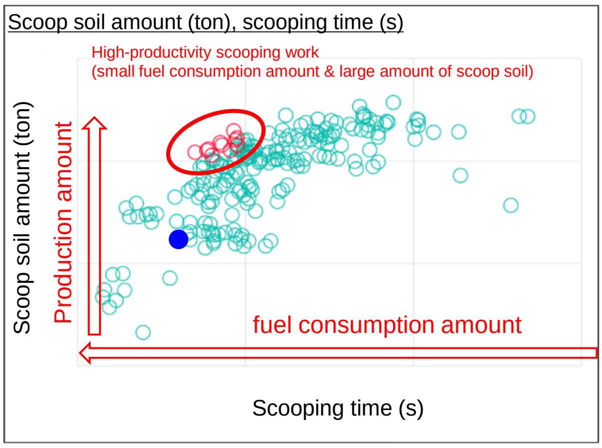

Fig. 8 Scoop soil amount and scooping time

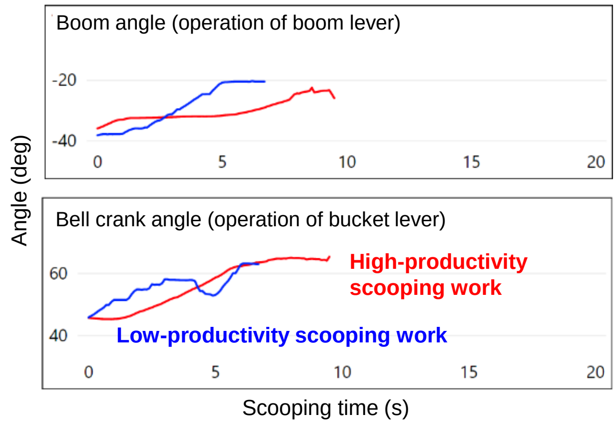

Fig. 9 High-productivity scooping work and low-productivity scooping work

3.2 Operation guidance monitor

Here we describe the "operation guidance monitor" (**Fig. 10**) visualizing the differences in scooping skill. The monitor extracts the scooping data with short scooping time and large-amount scoop soil as high-productivity scooping data from the scooping data collected by worksite based on the idea from **Fig. 8**. It generates a model operation (teacher operation data) from the extracted data. And then it visualizes the difference in skill between the generated teacher operation data and the actual operator's scooping operation, and a monitor for improving the operator's operation is provided. The bar indication at the right center of the monitor in **Fig. 10** shows the difference between the operator's operation (of the bucket lever, the boom lever and the accelerator) and the teacher operation data by color. The bucket lever and the boom lever are the levers to operate the work equipment of the wheelloader. The boom lever is to change "the boom angle" and the bucket lever is to change "the bell crank angle" (**Fig. 11**). The red color indicates that the operation is too large compared to the teacher operation data. Yellow indicates that it is too small, and green indicates it is almost the same as the teacher operation data. The waveform at the upper right in the monitor indicates the transition of the bucket penetrating angle against the ground. The white line is the teacher operation data and the blue line is the operator's operation. At the upper left on the monitor, the scooping score from 0 to 100 is indicated. The scooping score is determined with the amount of the difference in the scooping time and the amount of scoop soil from the teacher operation data. The score is indicated every time a scooping operation is performed. The teacher operation data is also updated every time a scooping operation is performed. Therefore, as the scooping operation is continued to be performed by various operators in the worksite, better teacher operation data can be obtained.

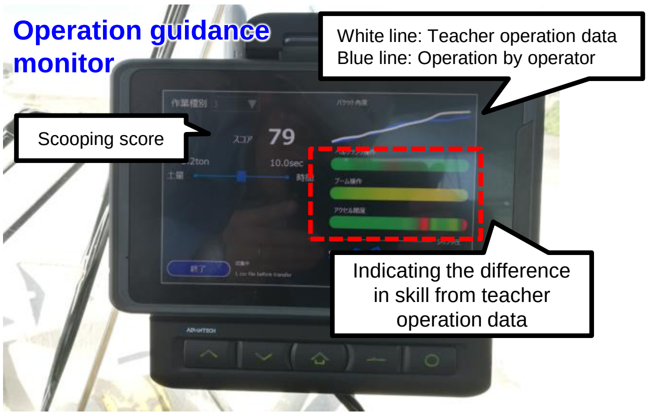

Fig. 10 Operation guidance monitor

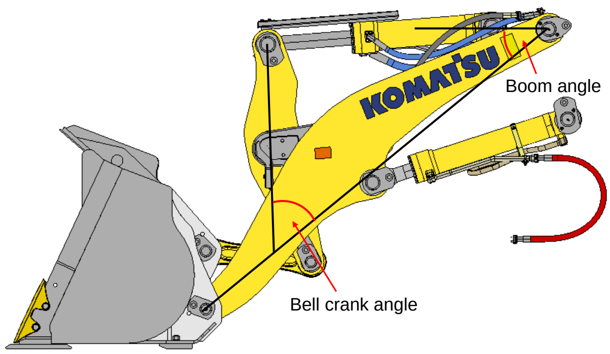

Fig. 11 Boom angle and bell crank angle

3.3 Method of visualization of difference in scooping operation

Each scooping operation has different scooping time, so that the operations cannot be simply compared. Therefore, the data of the operations should be regulated for the comparison (**Fig. 12**). Here is the explanation in detail. At the time t (0 to T) in the scooping section, the accelerator openings S (t), the boom angle is AngB (t), and the bell crank angle is AngC (t).

The boom angle and the bell crank angle are the angles of the work equipment of the construction machinery. As the scooping time T (time taken for scooping) varies by scooping operation, the accelerator opening, the boom angle, and the bell crank angle are converted to the values in the ratio in the scooping section as 100%. To make the number of the data in the section same, n = 100 data at 100%. With the scooping section k = 0 to n, calculate AngB (k) and AngC (k) from S (t), AngB (t), AngC (t) for each scooping. The calculation is made by interpolating S (t), AngB (t), and AngC (t) with time t = r * k (r = T/n) when k = 0 to n. When k = 0 and n, the values are those with t = 0 and T respectively. When 0 < k < n, the values are linearly complemented with the formulas below.

When t' = k * T/n and the definition below are made:

timeBfr =

(the closest time of acquired data less than t')

timeAft =

(the closest time of acquired data more than t')

S (k)

= S (timeBfr)

+ (t' - timeBfr) * {(S (timeAft) - S (timeBfr)}/(timeAft - timeBfr)

AngB (k) and AngC (k) are calculated in the same manner.

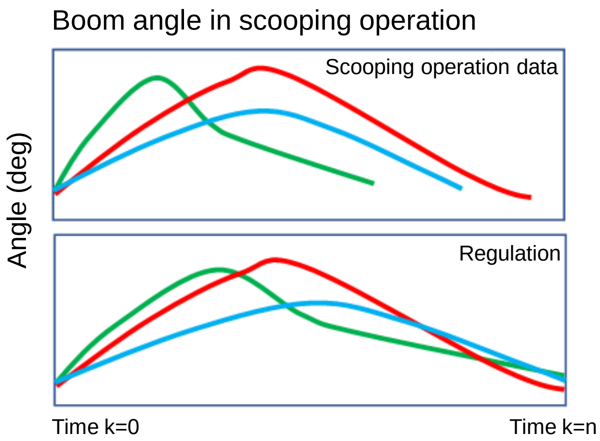

Fig. 12 Regulation of scooping operation data (example: boom angle)

3.4 Case of improvement

We conducted the tests of operation improvement in a customer's worksite by using the operation guidance monitor. We used the operation guidance monitor for the new operators (six operators) training in scooping skill. As the test method, the operation guidance monitor was attached to the construction machinery and the experienced operator in the worksite and Komatsu's test driver performed the scooping operation first to generate the teacher operation data. Using the generated teacher operation data, the scooping training for new operators were implemented for three days. The result is shown in **Fig. 13**. The improvement in the scooping time and the fuel consumption amount is recognized with all of the six operators. The reduction of the scooping time by 19% and the fuel consumption amount by 15% in average was obtained as the result.

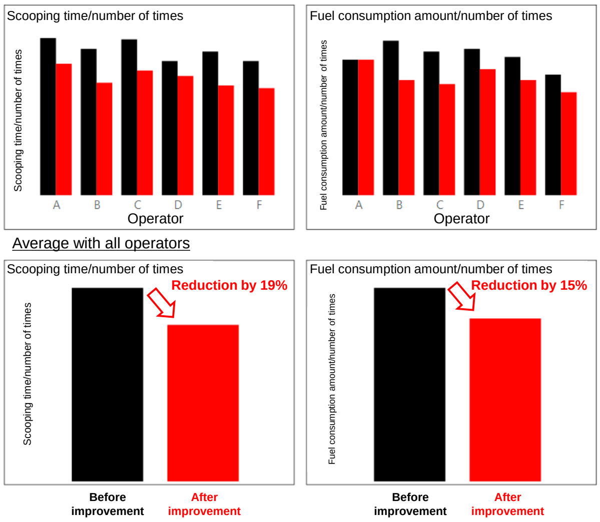

Fig. 13 Result of the test of new operators' scooping skill improvement

Here we describe the details of the improvement of the scooping operation. **Fig. 14** shows the monitor display of the new operators' operations before the improvement. It shows the accelerator opening (accelerator pedal depressing amount) in yellow. It means that the operation amount is not enough compared to the teacher operation.

Fig. 14 Operation guidance monitor display

As shown in **Fig. 7** too, there is a strong correlation between the scooping time and the fuel consumption amount. So, to reduce the fuel consumption amount, the scooping time should be reduced. Regarding the travel operation, a large accelerator pedal depressing amount affects the fuel consumption, but in the scooping operation, it can make fuel consumption amount reduced and high-productivity scooping by operating the machine in a short time. With the monitor display, the operator can see that his accelerator pedal depressing amount is not enough for the scooping operation and find how to improve it. **Fig. 15** is the waveform graph of the accelerator pedal depressing amount of before improvement and after improvement. It is clear that the accelerator pedal depressing amount is increased after improvement. **Fig. 16** shows the result of the work equipment angle (bell crank angle) of before and after improvement. It clearly shows that the work equipment angle of the operators after the improvement are almost the same as the teacher operation data. We interviewed the operators after the test of the scooping skill training using the operation guidance monitor. We got opinions from them that the system is excellent as it not only judges the operations with scores but also shows what operation is required for the improvement.

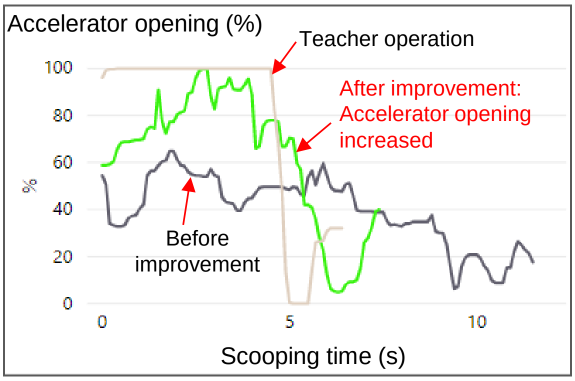

Fig. 15 Accelerator opening

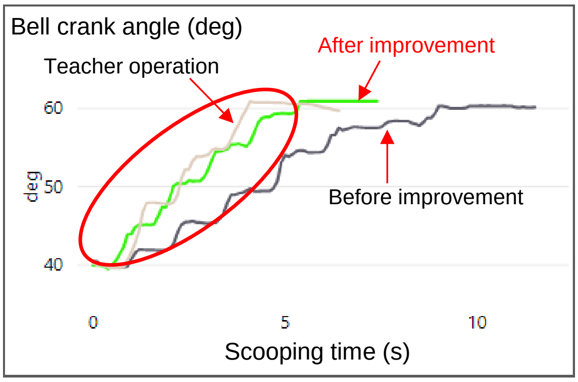

Fig. 16 Angle of work equipment (Bell crank angle)

4. Conclusion

Here is the results obtained in the research and development of "productivity improvement by visualization of construction machinery operation".

(1) We developed the system to collect the detailed operation data from the construction machineries and visualize the operation status. We conducted the activities for improvement of worksite operations by numerically analyzing operations such as travelling and scooping.

(2) For the scooping operation which is at a high difficulty level in skill improvement among the construction machinery operations, we developed the operation guidance monitor to visualize the differences in skill and confirmed that it is effective for the improvement through the user tests.

References

[1] Hiroshi Komiyama, Kazumsa Ozawa, Kazuyoshi Tateyama, Risa Tanaka, Kazuhiko Toyama, Kumi Fujisawa, "i-Construction Committee Report", 2016

Introduction of the authors

Minoru Shimizu
Joined Komatsu Ltd. in 2011.
Manufacturing Engineering Development Center, Production Division

Satoki Matsumura
Joined Komatsu Ltd. in 2001.
Manufacturing Engineering Development Center, Production Division

[A comment from the authors]

We hope that the worksites with construction machinery operation utilize ICT/IoT and their productivity is further improved in the future. To contribute to it, we need to understand the worksites with construction machinery operation and grasp their potential problems, and would like to proceed with the development of ICT/IoT to solve such problems.