Comparative Study of Experienced and Inexperienced Operators with Auto-controlled Construction Machine

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Abstract –

In the Japanese construction industry, it is predicted that during the next ten years, more than a million veteran technicians will retire, and a sudden shortage of experienced technicians will be inevitable. One way of countering this problem now being considered is the use of robotics technology to support inexperienced operators. To develop such systems, it is important to first quantitively compare differences of the working efficiency, working quality, operating methods etc. between experienced operator and inexperienced operator.

Hence, experiments were performed to compare how experienced operators and inexperienced operators execute base course material grading work using a motor grader. During the experiments, the time required to complete the work, and the finished height at a pitch of 1 m were measured in order to quantitatively identify working efficiency and working quality. To clarify operating methods, the line of sight of the operators during work was measured. Moreover, similar comparative experiments were performed with the introduction of MC to verify its impact on experienced and inexperienced operators.

Keywords –

Construction machine; Experienced operator; Inexperienced operator; Machine control

1 Introduction

In recent years, the number of young people entering the Japanese construction industry has been decreasing, and the veteran workforce is aging [1] (Figure 1). It is predicted that during the next ten years, more than a million veteran technicians will retire, and a sudden shortage of experienced technicians will be inevitable. The same patterns have appeared among construction machine operators, and a sudden shortage of experienced operators is predicted. One way of countering this problem now being considered is the use of robotics technology to support inexperienced operators. This means using robotics technology to perform some aspect of construction machine operation to assist inexperienced operators so that they can execute work at the same performance level as experienced operators. As a robotics technology that automates some of the operational work, machine control (MC) has already been introduced in motor graders and bulldozers [2][3]. MC refers to a system

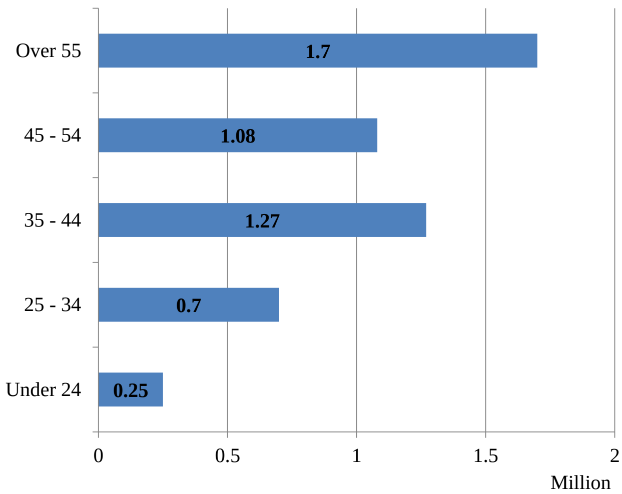

Figure 1. Labour force population by age group in construction industry (2015)

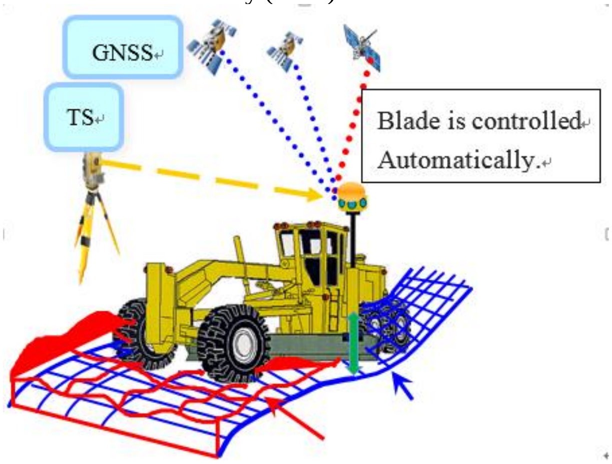

Figure 2. Machine control (MC)

that uses Total Station (TS), Global Navigation Satellite System (GNSS), etc. to identify the position of a construction machine, and calculates the discrepancy between the design value and the actual position of the working device (blade, etc.) so that the working device is automatically controlled in real time to remain in a position that conforms to the design value (Figure 2 [2]). It is presumed that expanding this kind of robotics technology to other types of machines and other types of work would be an effective measure of countering the future shortage of experienced operators. To develop such systems, it is important to first quantitively compare differences of the working efficiency, working quality, operating methods etc. between experienced operator and inexperienced operator. However, while differences between these two classes of operators have been partially verified, for excavation by hydraulic excavators for example [4][5], these differences have not yet been quantitatively confirmed. In order to evaluate the present state of MC and develop it further, it is important to also clarify the effects of MC on working efficiency, working quality, and on the operators. No studies that quantitatively clarify such effects of MC have been conducted.

Hence, experiments were performed to compare how experienced operators and inexperienced operators execute base course material grading work using a motor grader. During the experiments, the time required to complete the work, and the finished height at a pitch of 1 m were measured in order to quantitatively identify working efficiency and working quality. To clarify operating methods, the line of sight of the operators during work was measured with reference to the line of sight measurements used in the field of automated driving [6][7]. Moreover, similar comparative experiments were performed with the introduction of MC to verify its impact on experienced and inexperienced operators.

2 Outline of the Experiments

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A subgrade with a width of 6 m and total length of 65 m (straight: 45 m, curved: 20 m) was prepared, and a motor grader was used to experimentally grade the base course material (M40) so as to generate a 30 cm thick layer on the subgrade. Each operator used the same motor grader (KOMATSU DG655) to perform the work, once without MC ("normal operation"), and once with MC ("MC operation"). The view of the experiment is shown in Figure 3.

2.2 Operators

The ten operators shown in Table 1 performed the experiment. Operators A, B, C, and D were experienced operators with at least 15 years of experience, and operators E, F, G, H, I, and J were inexperienced operators with less than 10 years of experience.

2.3 Measurement of the Data

The following data were collected:

(1) Working time: time from the start of each work

Figure 3. The view of the experiment

Table 1. Operator

	age	Year of experience	
A	57	35	Experienced Operator
B	52	33	
C	37	17	
D	36	16	
E	31	9	Inexperienced Operator
F	30	8	
G	24	6	
H	24	2	
I	23	5	
J	22	1	

Figure 4. Finished height measuring points

until the height at the measurement points (every 10 m) was within 1 cm of the designed height (Japanese standard).

(2) Finished height: height at a pitch of 1 m along three measurement lines—center, right, and left—after completion of the work, measured by TS (Figure 4).

(3) Operator's line of sight: operator's line of sight during the work. This measurement was taken with an eye tracking system (NAC, EMR-9, Figure 5), and only during the operation of operators A, C, E, G, and H.

(4) Operator's heart rate: the heart rate of each operator during work was measured by a heart rate monitor (EPSON, SF-850, Figure 6) , and only during the operation of operators A, C, E, G, and H.

3 Results of the Experiments

3.1 Working Time

Figure 7 shows the average actual working times of experienced operators and inexperienced operators for normal and MC operation. The actual working times include only the time spent grading, and do not include time spent backing up, or measurement time.

According to Figure 7, in the case of normal operation, the working time of inexperienced operators is approximately 1.8 times that of experienced operators, which shows that the working efficiency of inexperienced operators is much lower than that of experienced operators. For this reason, it can be surmised that the future shortage of experienced operators will have a serious impact on the construction industry, and that it is necessary to implement countermeasures such as the introduction of robotics technology.

In the MC operation, working time of inexperienced operators was approximately 40% shorter than it was when they performed normal operation, while the working time of experienced operators was almost the same for normal operation and MC operation. For this reason, it can be inferred that MC had a considerable effect on inexperienced workers, and that introducing MC could enable inexperienced operators to work at a working efficiency equal to that of experienced operators. Meanwhile, there was almost no difference between the normal operation working time and MC operation working time of experienced operators, revealing that MC had little impact on the experienced operators.

3.2 Finished Height

As an example of the results, Figures 8 and 9 show the measurements of finished heights for operator D (an experienced operator) and operator J (an inexperienced operator). The horizontal axis of the figure represents the working length (total length: 65 m) and the vertical axis represents the difference between the measurement data and designed (target) height.

Figures 8 and 9 show that it is possible to estimate working quality based on the discrepancy between

Figure 5. Eye tracking system

Figure 6. Heart rate monitor

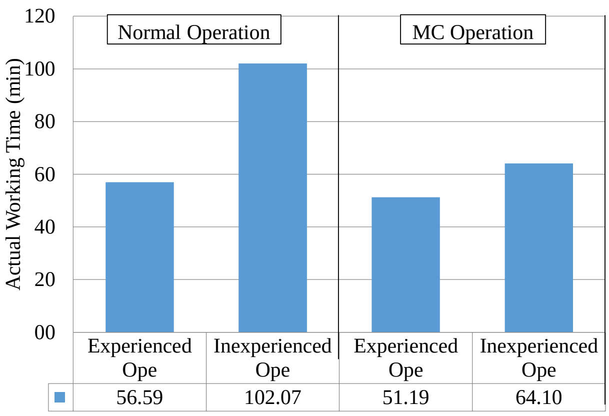

Figure 7. Actual working times

actual height and target height. It can be presumed that the working quality of the normal operation by operator D is better than that by operator J, and that the working quality for the MC operation by operator D and that by operator J are not very different.

To quantitatively represent working quality, all the finished height measurement data obtained for experienced operators and for inexperienced operators are represented by frequency polygon (frequency line graphs) in Figures 10 and 11. The figures also indicate the standard deviations.

According to Figures 10 and 11, in the case of

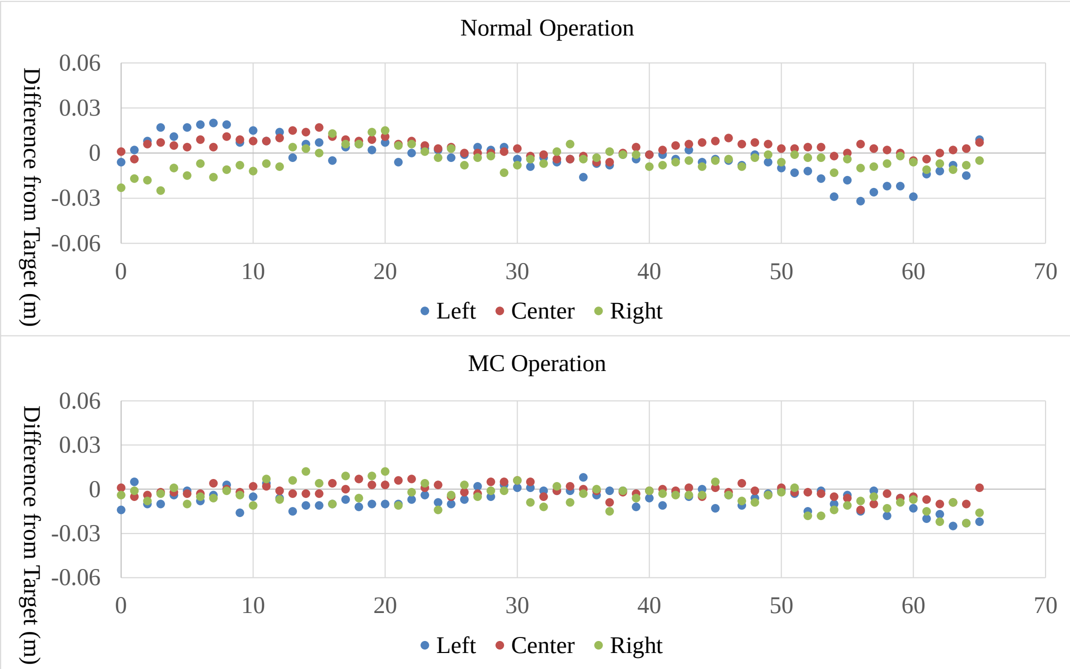

Figure 8. Finished height of operator D (experienced operator)

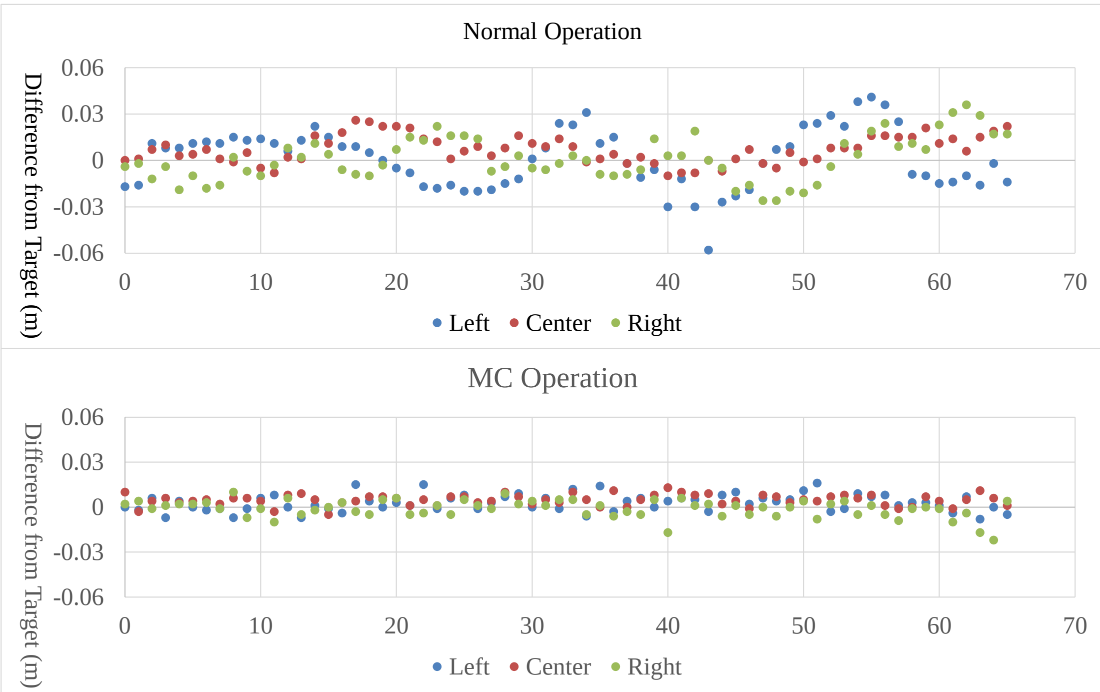

Figure 9. Finished height of operator J (inexperienced operator)

normal operation, the standard deviation of inexperienced operators is approximately double that of experienced operators, indicating that the working quality of inexperienced operators is much lower than that of experienced operators. For this reason, it can be stated that, as shown by the working time results in the previous section, the future shortage of experienced operators will seriously impact the construction industry, requiring countermeasures in the future, such as those based on robotics technology.

The standard deviation of inexperienced operators in MC operation was approximately 50% lower than it in normal operation, while the standard deviations of experienced operators in normal operation and MC operation were almost equal. Similar to the working time results shown in the previous section, this reveals that MC has a considerable effect on inexperienced operators, and that introducing MC could enable inexperienced operators to work with an working quality equal to that of experienced operators. While the effects of MC on experienced operators would be minimal.

3.3 Line of Sight of Operators

In order to organize the line-of-sight analysis data, the view of the operator is divided into three as shown in Figure 12, “near (the blade)”, “forward,” and “other” (outside the range of Figure 12, at monitors, etc.). And the time ratio of looking at each is shown in the Figure 13. Unfortunately, line-of-sight data during MC operation for operators C and G could not be obtained.

According to Figure 13, in the case of normal operation, the percentage of time that operators A and C (experienced operators) were watching “near (the blade)” were about 70%. On the other hand, that of operators E, G, and H (inexperienced operators) were 80% and 90%. From this, it is presumed that the inexperienced operators concentrated primarily on the area “near (the blade)” that was grading the base course material, and could not identify the state of the surroundings, but that the experienced operators paid attention to the area ahead, permitting them to predict the course the machine would travel smoothly and work high-quality.

In the MC operation case, the percentage of time that operators E and H (inexperienced operators) paid attention to the area “near (the blade)” fell substantially. This presumably occurred because, thanks to MC, they did not have to pay much attention to the blade operation, giving them opportunity to observe the

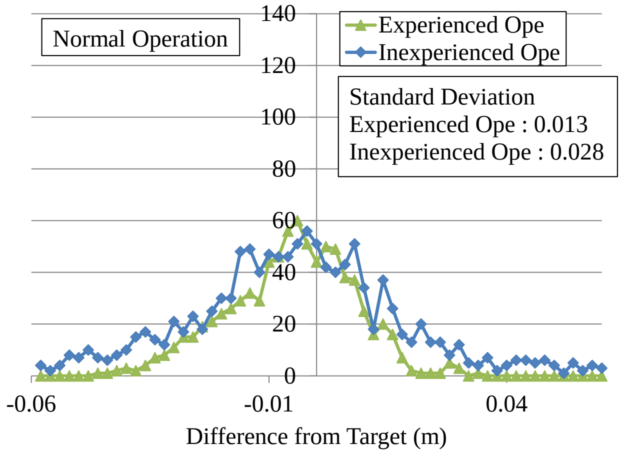

Figure 10. Frequency polygon of finished height data in normal operation

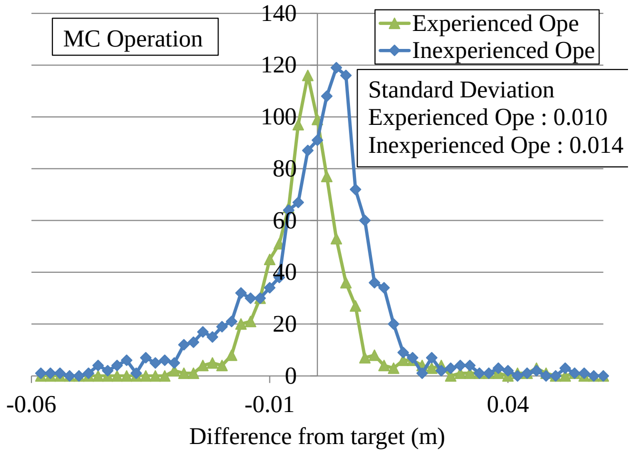

Figure 11. Frequency polygon of finished height data in MC operation

Figure 12. Operator’s view

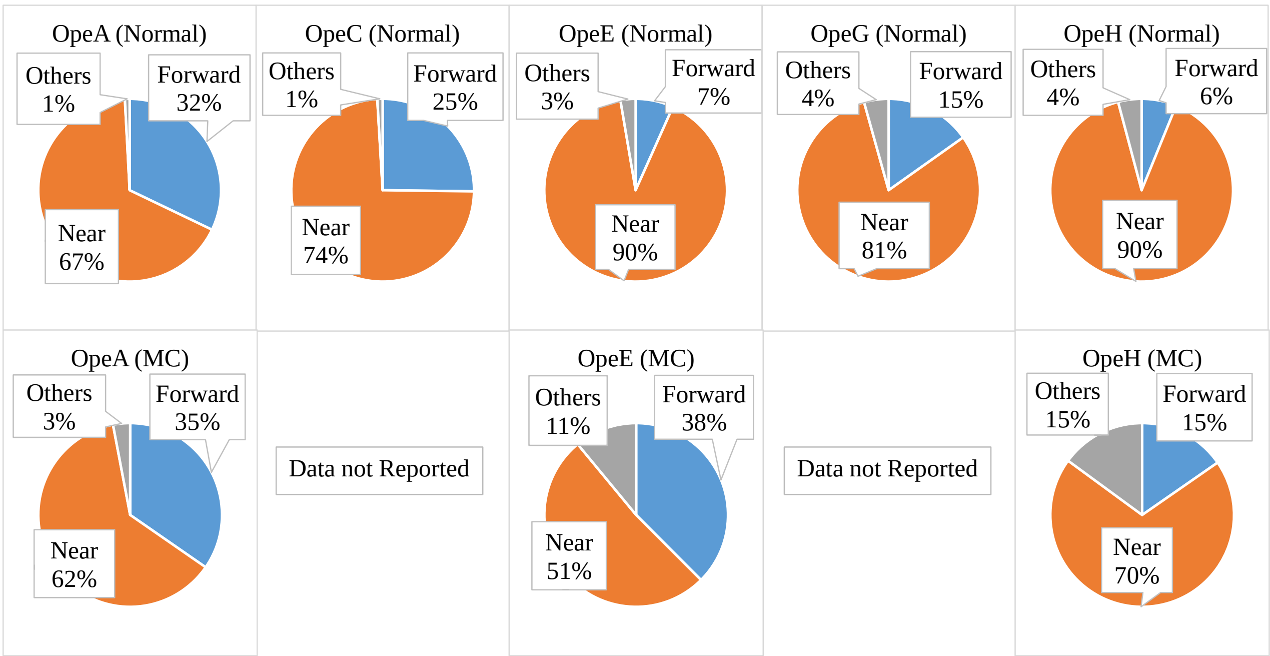

Figure 13. Time rate of looking

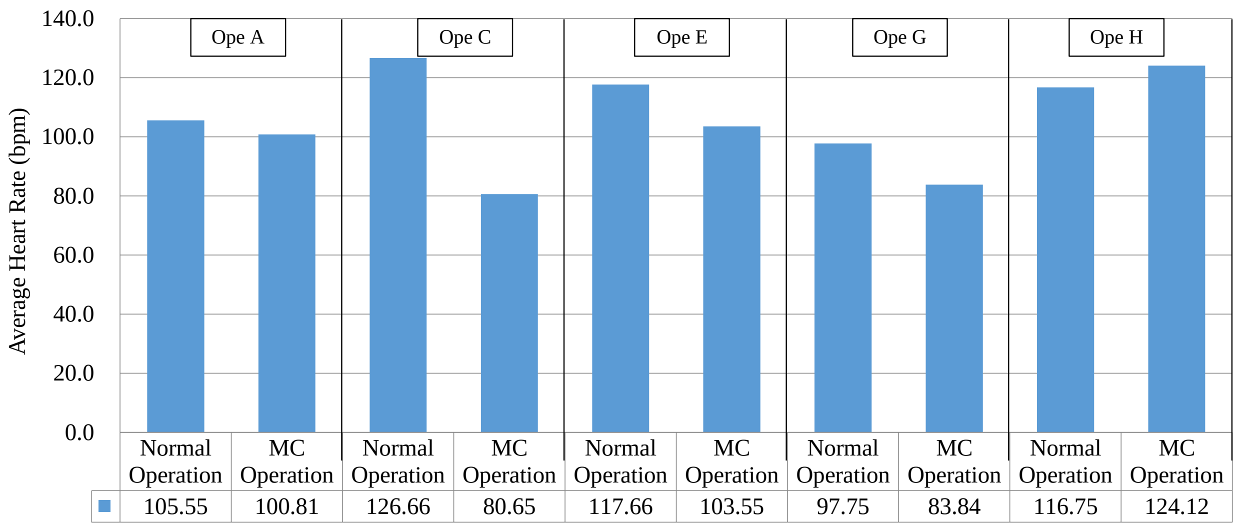

Figure 14. Average heart rate during operation

surroundings. For this reason, it can be stated that the introduction of MC would not only permit inexperienced operators to smoothly perform high-quality work, but it would also permit safer operation as they pay more attention to the surrounding conditions.

Meanwhile, it also shows that like working time and finished height, the line of sight of experienced operators would not be greatly affected by MC.

3.4 Heart Rate During Operation

To verify the effects of MC on operator mental burden, operator's heart rate during operation was measured. The average heart rate during operation are shown in Figure 14.

According to Figure 14, during MC operation, the average heart rate of all operators except operator H were lower than they were during normal operation. It is difficult to draw a conclusion based solely on heart rate, but results suggest that the introduction of MC could lower the mental burden of both experienced and inexperienced operators.

4 Summary

This study compared the working result of experienced operator and inexperienced operator when grading base course material using a motor grader. And also this verified the impacts that MC would have on both operators too. The results illustrated the following points:

(1) In the case of normal operation, the working time and finished height standard deviations of inexperienced operators are approximately double those of experienced operators, revealing that the working efficiency and working quality of inexperienced operators are much lower than those of experienced operators. This shows that the future shortage of experienced operators will have a serious impact on the construction industry, and that it is necessary to implement countermeasures such as the introduction of robotics technology.

(2) According to the line-of-sight analysis results, inexperienced operators concentrated only on the area “near (the blade)” that was grading the base course material, and thus they could not observe the surrounding conditions, experienced operators paid attention to the area ahead of the machine and predicted its travel path to smoothly perform high-quality work.

(3) MC had a considerable impact on the working time, finished height standard deviations, and line of sight of inexperienced operators, and the introduction of MC could permit inexperienced operators to achieve working efficiency, working quality, and safety equal to that of experienced operators.

(4) In the case of experienced operators, on the other hand, MC had only minimal effect on working time, finished height standard deviation, and operator line of sight.

(5) Introducing MC could lower the mental burden on both experienced and inexperienced operators.

The aging of experienced technical workers, and the oncoming shortage of these workers in Japan’s construction industry poses serious challenges. This study has clearly shown that if the situation remains unchanged, it is highly likely that the construction industry will be seriously impacted. It has been confirmed that the use of MC or other robotics technology would be an effective way to counter these problems. In the future, we wish to continue conducting research intended to introduce robotics technology in machines other than motor graders. And also we wish to research to fully automate these machines instead of automating only some machine operations.

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