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Spatial factors affecting the loading efficiency of excavators

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ABSTRACT

Excavators are typical machinery in the construction industry, and have advantages when applied in various tasks. Among various tasks of excavators, loading a dump truck is a very important task that could be automated. However, most of the previous studies are focused on the excavation/digging operation, and the studies on the loading efficiency are limited. Therefore, the spatial factors affecting loading operation were identified and investigated with regard to the different types of the movements of the machine in this study. To observe changes in the loading time according to the affecting factors, two main hypotheses were examined as follows: 1) loading time changes according to the height difference and distance between the excavator and dump truck; and 2) loading time changes by the rotation angle. In order to verify the hypotheses, the movements of three excavators were studied under the different conditions of the spatial factors. We believe that the automation of loading operation for excavators can benefit from the results of hypothesis validation, and from the analysis of the detailed loading operation in relation to the categorized movement and the patterns of loading operation.

1. Introduction

As the scale of construction projects increases, construction machinery becomes much more important. Today it is an essential element to successful projects with its effective usage in various types of construction works. Fig. 1 shows the gross value added to machinery for each industry.

Fig. 1 shows that the construction industry has the highest rate compared to other industries, meaning construction machinery has a very important role within the industry. Excavators, among various types of construction machinery, are commonly used in the construction industry. Their versatility makes them applicable to various purposes, so they are in greater demand than other kinds of machinery, and that demand has been increased consistently.

With the strong demand from the construction industry, the needs for the automation of excavators were recognized, and numerous studies on the automation of excavators have been performed [2–4,7–9,12, 14–18]. For the research, the operational characteristics of excavators were analyzed, and the task plan and working pattern of experienced operators were extracted for automation. However, most of these studies were focused only on digging operation, and the remaining work was not covered. Among the tasks of excavators in earthwork, loading is accompanied by digging. Rowe and Shao et al. [8,14] broke down loading into dumping, rotating after dumping for scooping, scooping, and rotating after scooping for dumping to automate the loading operation. However, this has limits in practical applications because various work or site conditions are considered insufficiently.

Artificial Intelligence (AI) approaches have also been applied in relation to the productivity of earthwork machines including excavators [5,10,11]. Such approaches are suitable to improve the overall productivity (e.g. m^3/h) of a set of earthwork machines. The study focused on a specific task of a specific type of machine such as loading operation of excavator could also provide better understating of an input variable of such overall productivity estimation approaches.

Within this background, this study aims to provide effective working conditions for loading operations. The working condition is confined as to the spatial condition, and changes in the loading time are observed to determine the loading efficiency changes per spatial condition as described by Bernold [1] and Hall [4]. For precise observation of these changes, this study breaks down the cycle of excavation loading into detailed sequences by a timeline based on actual loading operation of excavation operators at construction sites. This study sets two hypotheses to verify the relationship between the loading time and spatial factors, and it records the time required for loading under construction and confirmed changes of broken down time. The hypotheses are proven based on the test results, and the observations made during the test are discussed.

The motivation of this research was to improve the productivity of an autonomous excavator developed in Korea [13]. Programming and/or giving intelligence to an automated excavator require the consideration of different spatial conditions. The result of this study can be used to improve the path planning of the body as well as the arm of an automated excavator for loading operation.

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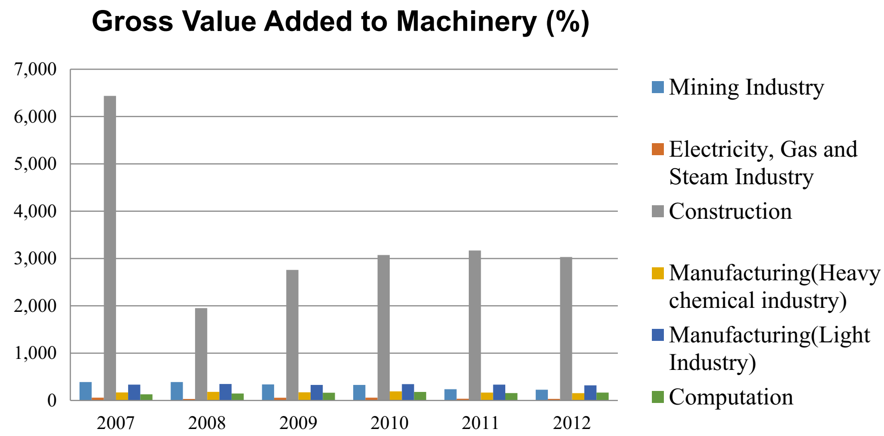

Fig. 1. Gross value added to machinery.
Indicators of Productivity, Bank of Korea, 2013.

Inexperienced operators usually develop proficiency through trial and error under different working conditions in the construction industry [1]. This prolongs the mastery period and thereby undermines productivity in construction projects. Considering the future lack of skilled operators due to aging [6], the result of this study can also be used to develop the guidelines for novices to learn machinery operation techniques.

2. Preparation for data analysis

2.1. Spatial factors affecting loading operation

The spatial factors after loading operation are largely divided into distance and angle. In the case of distance, there are horizontal distances and vertical height differences between excavators and dump trucks. In the case of angle, there are angles of rotation to the spot for dumping after scooping, and there is a directional angle between the manipulator of the excavator and the dump truck. Those factors were identified by site observation and are defined in Table 1 and Fig. 2.

2.2. Hypothesis

Based on the identified affecting factors, two hypotheses were set up as follows:

Hypothesis 1. Loading time will be affected by H, D, and L_{BD}.

It indicates how the height difference and distance are far apart in terms of locations for excavators and dump trucks. These impact factors influence the loading time because the positions of the boom, arm, and bucket differ according to the affecting factors when the excavator dumps soil into the truck bed. Also, H, D, and L_{BD} of the dump truck and of excavation minimize the operation time when the dump truck performs the loading.

Hypothesis 2. Loading time will be influenced by θ_2.

Table 1
Spatial factors affecting loading operation of an excavator.

No.	Spatial affecting factor
H	Height from ground to top of dump bed
D	Horizontal distance from center joint of excavator to back part of dump bed
L_{BD}	Length from boom joint to top back part of dump bed
θ_1	Rotation angle from dump truck to soil for scooping
θ_2	Rotation angle from scooping point to dump truck
θ_T	Angle between dump truck and excavator

After the excavator scoops the soil, it rotates the upper structure for dumping, and the rotation angle from scooping to dumping influences the dumping time. Generally, a smaller angle makes the loading time shorter. However, the excavator should raise the bucket higher than the truck bed to dump. To raise the bucket it requires a set amount of time so that the loading time is not reduced beyond a certain degree.

Fig. 3 shows two different loading cases according to θ_T. θ_T is the directive angle between the manipulator of the excavator and the dump truck, and it may influence the loading time. However, this study focused on the Hypotheses 1 and 2, and the analysis on θ_T is recommended for future study.

2.3. Loading operation analysis

Based on the hypotheses, analysis of the excavation and loading was performed for proper data collection. First excavation is performed with movement of four joints. It rotates around the center joint horizontally, and the boom, arm, and bucket dig or throw the soil vertically (Fig. 4). Both rotation and vertical movement of the boom, arm, and bucket can be performed simultaneously. As mentioned above, loading basically consists of dumping, rotating for scooping, scooping, and rotating for dumping. However, since the operator rotates the center joint horizontally while moving the boom, arm, and bucket vertically, the rotating part was again divided into horizontal rotation and vertical movement.

Table 2 breaks down the loading operation into detailed motion in this thesis. Also, the operator performs arbitrary gathering during loading to facilitate scooping, and performs work location movement for efficient loading. Thus, those motions were added in Table 2.

2.4. Data collection form

Through the analysis of the spatial affecting factors and loading work, a data collection form was established for hypothesis validation as shown in Table 3. The beginning and ending times of each motion are recorded because the time of each detailed motion should be considered individually, and horizontal rotation and vertical motion in rotation are recorded separately. Furthermore, the additional work time is recorded when it involves supplemental tasks such as stop, gathering performance, position change, and additional rotation.

3. Data collection and analysis

3.1. Data collection

Data collection was performed at three construction sites in order to investigate the relationship between the spatial affecting factor and the