# Proposal for Automation System Diagram and Automation Levels for Earthmoving Machinery

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**Abstract –**

**In Japan, earthmoving workers are aging rapidly, and more than one million skilled workers will retire at once in the near future. Thus, the mass retirement of these skilled technicians could bring a significant drop in production capabilities throughout the earthmoving industry. To solve this problem, it is expected that automatic construction systems using robotics technology will improve productivity at earthmoving field. To efficiently promote further advancements in earthmoving automation research, it is necessary to systematize the entire earthmoving construction and classify automation levels.**

**In this paper, we formed a team in collaboration with project owners, civil engineers, engineers of construction machinery manufacturers, and robotics researchers, and others. Then, with them, we attempted to formulate a "automation system diagram for earthmoving work" to systematize the entire earthmoving construction, and "automation levels for earthmoving machinery" to grasp the achievement of current technologies. It is anticipated that these will make it possible to give concrete shape to research aims and plans, and that automation research will proceed as a result.**

**Keywords –**

**Earthmoving machine; Automation; system diagram; level**

## 1 Introduction

The aging of workers in Japan's construction industry has been progressing rapidly in recent years. The percentage of construction workers aged 55 years or older, which stood at 24.2% in 1998, rose to 34.1% in 2017. Meanwhile, the percentage of workers aged 29 or younger, which was 21.6% in 1998, fell to 11.0% in 2017 (Figure.1, [1]). Moreover, looking at the number of construction workers by age group in 2015 (Figure.2, [2]), a reverse pyramid is created whereby the number is largest in the elderly group and becomes smaller with each descending age group. This problem is more serious in the earthwork field than in the building field.

From this, it is estimated that at least one million skilled technicians will retire in the near future. The production capabilities of skilled technicians (having at least 15 years of experience) is roughly 1.8 times that of less-skilled technicians (having experience of less than

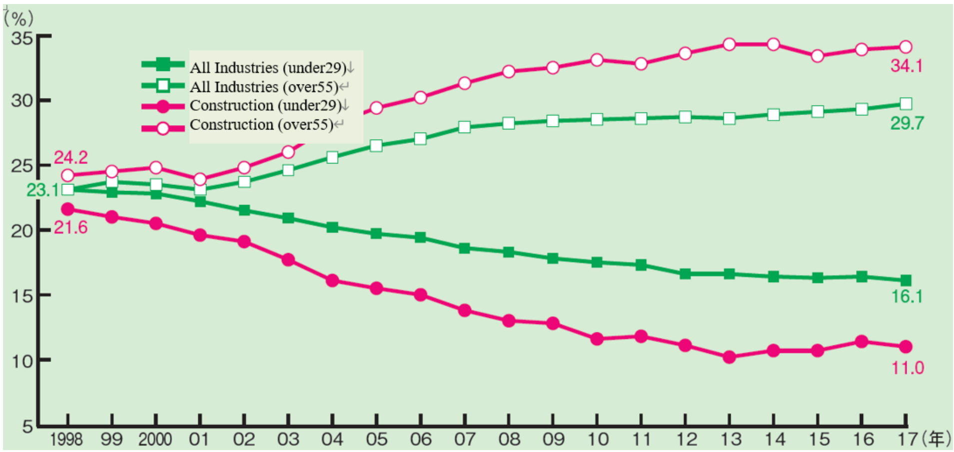



Figure 1. Number of workers [1]

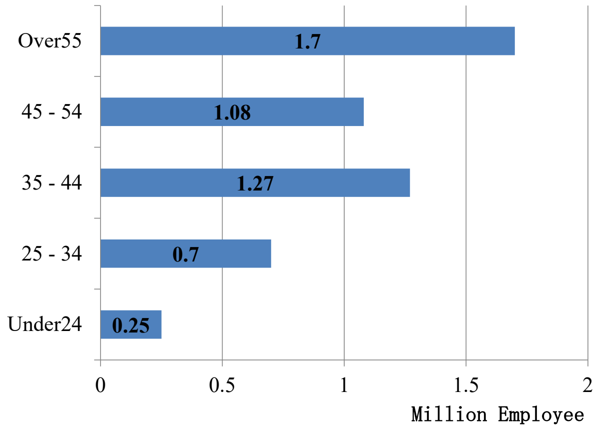



Figure 2. Number of construction workers (2014) [2]

ten years) [3]. Thus, the mass retirement of these skilled technicians could bring a significant drop in production capabilities throughout the earthmoving industry.

It is expected that one way of resolving this problem is to improve productivity by applying robotics technologies in earthmoving work. Specifically, it is anticipated that automating earthmoving work with robotics technologies will raise the production capabilities of less-skilled technicians and achieve manpower savings at earthmoving sites. A number of such automation technologies have already been studied and some are being put to practical use [4] – [11].

However, most of the research conducted so far has been limited to the automation of individual earthmoving machinery, and is far from the automation of the entire earthmoving work.

To efficiently promote further advancements in earthmoving automation research, it is necessary to clarify the research goal to be carried out next by understanding the scope that the current research occupies in the entire earthmoving work and the degree of achievement of the research. For that purpose, it is necessary to systematize the entire earthmoving construction and classify automation levels. There are some examples of these studies in the earthwork field [12] – [14]. However, these are discussed on limited conditions only, and overall examination by many category researchers (for example, owner, contractor, robotics engineer, etc..) is insufficient.

In view of this, we, the authors, formed a team in collaboration with project owners, civil engineers, engineers of construction machinery manufacturers, and robotics researchers, and others. Then, with them, we attempted to formulate (1) a "automation system diagram for earthmoving work" to systematize the entire earthmoving construction, and (2) "automation levels for earthmoving machinery" to grasp the achievement of current technologies. It is anticipated that these will make it possible to give concrete shape to research aims and plans, and that automation research will proceed as a result.

This paper presents one such proposal that we studied toward this end.

## 2 Study of a vision and an automation system diagram for earthmoving work

Earthmoving work involves various types of work, for example embankment work, cutting work, slope work, and soil improvement. earthmoving sites are comprised of the some types of work that are required there. For example, if a site is for road construction, it will be comprised by embankment work, cutting work, culvert work, and pavement work, etc..

Additionally, types of work are largely divided into components termed "construction," "construction planning," and "inspection." "Construction" is the execution of actual work by earthmoving machinery and people; "construction planning" includes the ordering, arrangement, and scheduling of personnel, machinery, and materials; and "inspection" is the task of inspecting daily operations and final products to determine if they meet specifications.

Furthermore, there are elements that comprise each of the components of "construction," "construction planning," and "inspection." For example, "construction" in embankment work that is part of road construction is mainly comprised of the four operations using various types of earthmoving machinery shown in Table 1. In the case of "construction planning", it is comprising elements include "effective arrangement of machinery, workers, materials, etc." "appropriate ordering" and "coordination of various types of machinery". While in the case of "inspection," it is comprising elements include "measurements of layer thickness, as-built form, density, etc." and "pass/fail judgments."

Figure 3 provides an outline of the study detailed above. It is an "automation system diagram for earthmoving work."

We presented "road construction" and "embankment work" as examples for this diagram. However, it is possible to prepare diagrams for various types of work by changing necessary components and elements.

## 3 Study of automation levels for earthmoving machines

Next, we conducted our study with the goal of proposing "automation levels for earthmoving machines" necessary to grasp the performance of current technologies.

Here, we studied with the following approach, referring to the previous research [12] – [14].

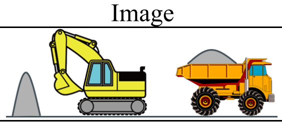
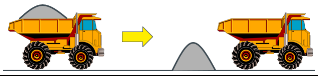
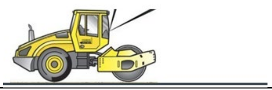
- "Construction" and "construction planning" are considered to be separate. This is because, as mentioned in the previous chapter, they are separate in the system diagram.
- Remote control is not included as an intermediate step to autonomous. This is because, remote operation is the

same as boarding operation, except that only the operation location is different.

Then, we decided to use the levels for motor vehicles, for which similar automation levels already exist, as a reference.

It should be noted that, in order to simplify our study, we narrowed it to the work of "excavating and loading by hydraulic excavator" in embankment work within road construction.

Table 1. Elements of construction (ex. embankment work)

| Operations | Image |
|---|---|
| Excavation and Loading (Hydraulic Excavator) |  |
| Transportation and Dropping (Dump Truck) |  |
| Spreading (bulldozing) (Bulldozer) |  |
| Compaction (Compactor) |  |

### 3.1 Study of levels of driving automation for motor vehicles

The Society of Automotive Engineers (SAE) of the United States has issued a standard for levels of driving automation vehicle called SAE J3016 that has become the international mainstream. On this SAE J3016, the level is divided by whether "(1) vehicle motion control," "(2) object and event detection and response (ODER)," and "(3) dynamic driving task fallback (DDT fallback)" is handled by a person (driver) or by a car (system), and whether "(4) operational design domain (ODD = conditions)" is limited or not (Table.2, [15]).

Using these levels as a reference, we first decided to substitute items (1) to (4) above to achieve compatibility with earthmoving machinery.

### 3.2 Item substitution

**(1) "Vehicle motion control" → "earthmoving machine control"**

Here, we focus on earthmoving machine control. In the case of a hydraulic excavator used in embankment work, for example, this refers to commanding the excavator to move, excavate, rotate, drop soil, etc.

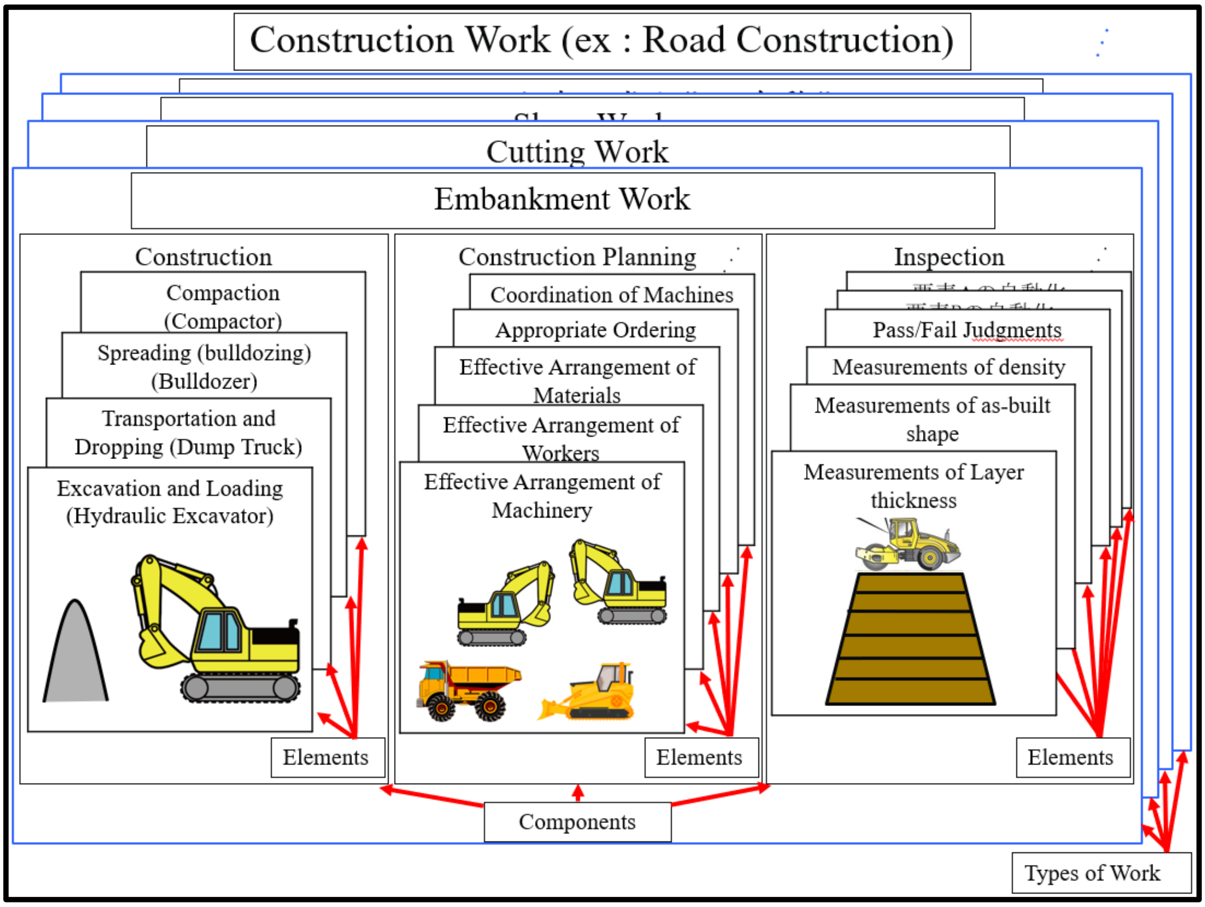


Figure 3. Automation system diagram for earthmoving work

**(2) "Object and event detection and response" → "detection and judgment for high-efficiency construction"**

This is the conscious (or unconscious) detection of surrounding information and judgment by the operator to improve construction efficiency. For example, in the case of a hydraulic excavator used in embankment work, this refers the detection and decision of optimal machine position, optimal excavation operation, optimal soil drop position, etc., based on conditions around the machine (e.g., locations of other machines, condition of materials).

(3) **"Dynamic driving task fall back" → "Response when autonomous operation is difficult to continue"**

This refers to response to unexpected events that make continuous automated driving difficult. In the case of a hydraulic excavator used in embankment work, for example, such events include obstacles within excavated materials, load spillage from the bucket, obstacles encountered while moving, deviation from course, etc.

(4) **"Operational design domain" → "site condition limitations"**

This refers to whether or not to limit the conditions of the construction site. Examples include topography (e.g., size or slope of worksite, etc.), ground (firmness, surface conditions, etc.), targeted material (type [such as sand or clay], moisture content, etc.), and weather.

Table 2. Levels of Driving Automation [15]

| Level | Name | Narrative definition | *DDT* | | *DDT fallback* | *ODD* |
|---|---|---|---|---|---|---|
| | | | *Sustained lateral and longitudinal vehicle motion control* | *OEDR* | | |
| ***Driver* performs part or all of the *DDT*** | | | | | | |
| 0 | No Driving Automation | The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems.* | *Driver* | *Driver* | *Driver* | n/a |
| 1 | Driver Assistance | The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*. | *Driver* and *System* | *Driver* | *Driver* | Limited |
| 2 | Partial Driving Automation | The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system.* | ***System*** | *Driver* | *Driver* | Limited |
| ***ADS* ("*System*") performs the entire *DDT* (while engaged*)*** | | | | | | |
| 3 | Conditional Driving Automation | The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately. | *System* | ***System*** | *Fallback-ready user (becomes the driver during fallback)* | Limited |
| 4 | High Driving Automation | The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene.* | *System* | *System* | ***System*** | Limited |
| 5 | Full Driving Automation | The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene.* | *System* | *System* | *System* | **Unlimited** |

DDT : DYNAMIC DRIVING TASK
ODER : OBJECT AND EVENT DETECTION AND RESPONSE
ODD : OPERATIONAL DESIGN DOMAIN

### 3.3 Study of automation levels

Table.3 shows the results of our study of automation levels for the work of "excavating and loading by hydraulic excavator" based on the items presented in the previous section are shown.

In this levels, we focused solely on the element of "excavating and loading by hydraulic excavator." However, it is possible to propose automation levels for other element and other machines by changing the details of the work, the specifics of problems, limiting conditions, and other factors.

It should be noted that remote operation is not considered in these levels, as mentioned above. Although the operator will get off the earthmoving machine at one of the levels, we decided not to specify that level. In other words, the operator can engage in either onboard operation or remote operation at levels 1 to 5. SAE J3016 is the same in this regard.

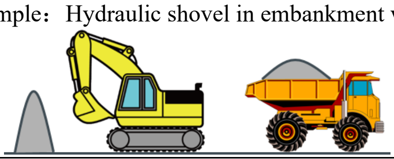
## 4 Conclusion

In this study, we discussed with many category researchers, project owners, civil engineers, engineers of construction machinery manufacturers, and robotics researchers, and others. And through this study, we successfully proposed draft versions of an "automation system diagram for earthmoving work (Figure 3)" and "automation levels for earthmoving machines (Table 3)." We believe that referencing these outcomes will make it possible for all researchers to understand the scope that the current research occupies in the entire earthmoving work and the degree of achievement of the research. And it will be possible to clarify the research goal to be carried out next.

For example, based on the outcomes of this paper, "Autonomous Hydraulic Excavator", which is researched recently [10][11], are autonomous research only for a "Hydraulic Excavator" element in "construction" component (Figure 3). And it corresponds to "automation level 1 (Table 3)". Thus, as future research and development policies, it is possible to propose an advancing the automation level or an automatization other elements or components (Figure 4). It can be expected that this will effectively promote further advancements in earthmoving automation research.

Additionally, no single correct definitions exist for the diagram and levels mentioned here, and interpretations will vary depending on the viewpoint. It is therefore inappropriate

Table 3. Levels of Automation for Construction Machines

| Level | Name / Definition<br>Example: Hydraulic shovel in embankment work<br> | Construction Machine Control | Detection and Judgment for High-efficiency Construction | Response when Autonomous Operation is Difficult to Continue | Site condition limitations |
|---|---|---|---|---|---|
| 0 | No automation | Human Operator | Human Operator | Human Operator | Limited |
| 1 | Automation of individual behavior<br>Automation of locomotion / excavation / turning / releasing<br>(Automation of each operation can be individual)<br><br>Excavation position, bucket point, release point, each optimal operation, completion judgment, etc. can be instructed by a human operator. | Human Operator and System | Human Operator | Human Operator | Limited |
| 2 | Automation of series operation<br>Automation of series operation. Move→Excavate→Turn→Release<br><br>Excavation position, bucket point, release point, each optimal operation, completion judgment, etc. can be instructed by a human operator. | System | Human Operator | Human Operator | Limited |
| 3 | Automation of detection and judgment for high efficiency work<br>The system determines and executes the optimum excavation position, optimum bucket point, optimum release point, optimum operations, completion judgment, etc. for high efficiency construction. | System | System | Human Operator | Limited |
| 4 | Trouble shooting<br>Example : Load collapse, sudden obstacle, etc. | System | System | System | Limited |
| 5 | Open the limited scenario | System | System | System | Unlimited |

For example, "Autonomous Hydraulic Excavator" [10][11] are autonomous research for **HERE**.
And "automation level" is **1** (Table 3).

Then Next research,

- Advancing the automation level
- Automatization other elements or components.

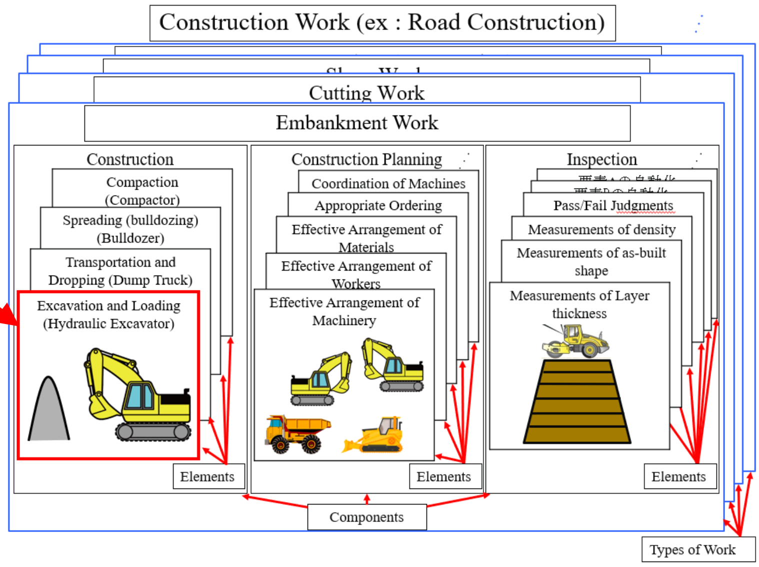



Figure 4. An example of understanding the position and level of current technology and setting the next goal

to immediately view them as universal standards. However, we believe that concretely conceptualizing the performance of current technologies and R&D aims by illustrating proposals and stimulating discussion by presenting studied processes are extremely meaningful endeavors. We would like to see the outcomes described herein be at the forefront of discussions among researchers.

We hope that the outcomes presented in this paper will be of assistance to researchers and engineer who aim to autonomous earthmoving construction.

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