Research on standardization of construction site time-series change information as learning data for automatic generation of work plan of construction machinery in earthworks.

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Abstract –

For earthwork, whether or not it will be possible to automatically generate a work plan for construction machinery has become the key to realizing autonomous construction of earthworks.

The use of AI is being sought by some researchers for the automatic generation of construction setups. Efforts are being made to utilize the results of construction work plan of construction machinery carried out by skilled engineers as learning data when searching for rules to reproduce construction work plan of construction machinery.

National Institute for Land and Infrastructure Management is considering acquiring work plans of construction machinery data in the MLIT ordering works, and to be going to provide these data. What is required for these data is to reproduce the history of construction progress and explain the reasons for deciding the construction work plan of construction machinery, and to provide those data in a format based on certain rules. We call this approach the examination of data standards for time-series change information at construction sites.

As a starting point, we examined the acquisition method of the topographic shape and the effective display format. We tried the Voxel display as a data format that makes it easy to grasp the amount of construction progress and to add attribute information to each construction point. On the other hand, some experts have pointed out the usefulness of the point cloud data and the surface data generated by connecting the point cloud data in the design of the drainage slope. This paper reports the initiative.

Keywords –

Work plan, Construction machine, earthwork, Learning data, AI

1 Introduction

In Japan, We, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has begun to promote the efforts to improve the productivity of construction sites by fully utilizing ICT at construction sites since 2015, under the name "i-Construction" (Figure 1, [1]).

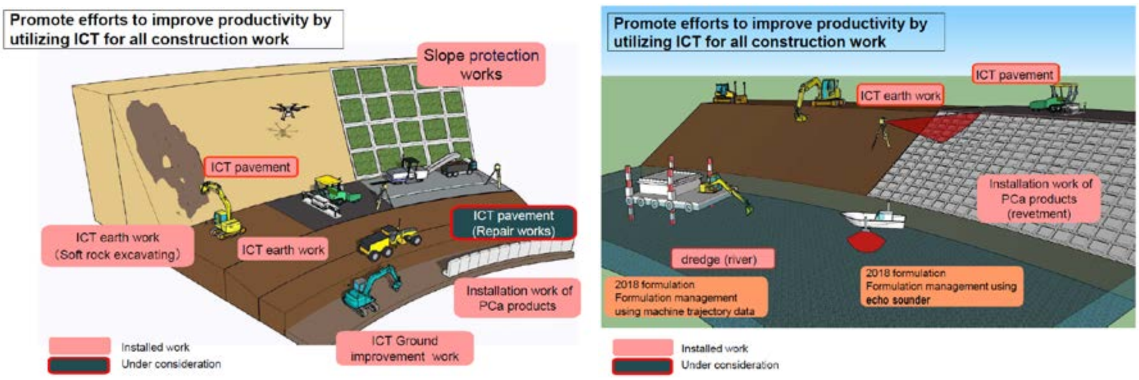


Figure 1. Examples of technologies targeted for introduction [1]

Since then, the following technologies have been utilized in earthwork, paving, dredging, etc.

- Efficient construction survey using ICT.
- A system that provides guidance to construction machine operators about work details.
- Construction machinery that automatically controls the blade edges of buckets and blades such as shovels, graders and bulldozers for shaping slopes and crowns of earthworks.

In the three years up to the end of January 2019, 2,287 cases of ICT utilization work have been carried out in the construction ordered by MLIT [2].

In addition, it is estimated that the amount of work done by humans has been reduced by an average of approximately 30% compared to the past by the full use of ICT in ground surveying, design data correction, construction, work form management/inspection, and electronic delivery [2].

We, National Institute for Land and Infrastructure Management (NILIM; Research department of MLIT) promotes the realization of AI construction machines that can automatically or autonomously construct, and that as a tool for further productivity improvement at construction sites. In order to do so, we started to study the data format for recording the time-series changes at the construction site and providing it in a widely usable form as the learning data for the autonomous construction AI (Figure 2). This paper reports the initiative.

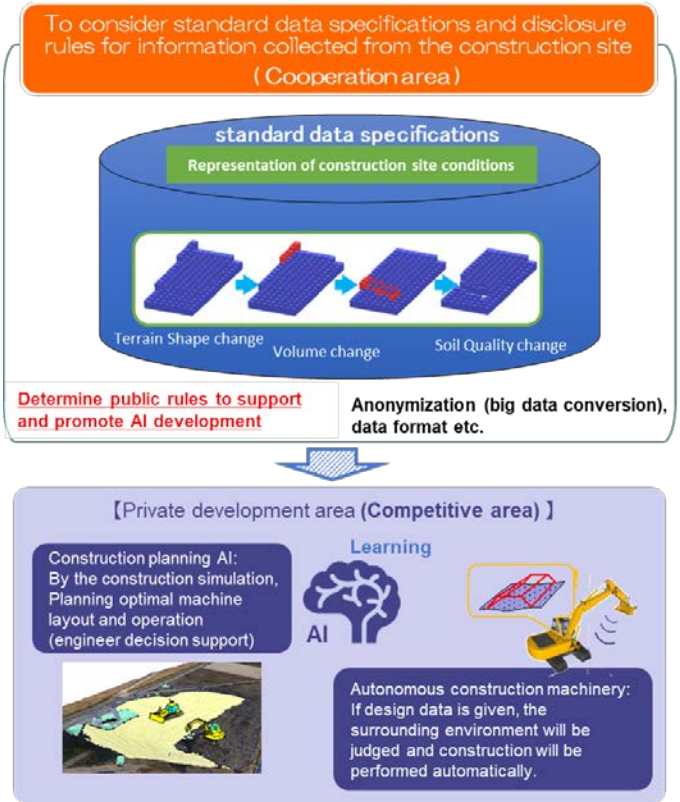


Figure 2. NILIM Project - Overall picture

2 Development status and key to realizing autonomous or automation construction technology

2.1 Current development status

As mentioned above, in earthmoving, semi-automatic control of buckets and blade edges such as shovels, graders and bulldozers has been realized and used for shaping slopes and tops of embankments [3]. Furthermore, some construction companies and construction equipment manufacturers are conducting experiments to operate combined construction of hydraulic excavators, vessel dumps, bulldozers, and vibrating rollers according to a human-defined program. In a closed environment where no one can enter, an excavator scoops up the sand in the sediment storage area, loads it into the dump vessel, moves the dump to the embankment point, dumps it, spreads the bulldozer, and compacts the vibrating roller. A series of work is being attempted [4].

And from a relatively long time ago, automatic calculation of the volume allocation plan has been realized. Compare the current topographic map with the blueprint showing the completed form and calculate the amount of cut and fill at each point. Then, using linear programming or some other method, calculate which embankment is to be filled with which cut so that the transportation cost of the soil is most economical [5].

2.2 The key to realization of autonomous or automatic construction; Development of “automatic generation of construction work plan of construction machinery”

However, based on this volume allocation plan, it is not so easy to calculate where to start and in what order to proceed. In order to move the soil, the difference in the earthmoving machine used (bulldozer, scraper, crawler dump, wheel dump) causes differences in transport efficiency and restrictions on the inclination of the moving path.

In addition, the local procurement costs (rental costs, transportation costs, etc.) of the earthmoving machinery itself to be put into the field will change depending on the site conditions and machine availability information. Many of these constraints exist, and they change depending on conditions such as the weather and economic environment, so if you perform an exact calculation, you will end up with a large-scale model.

When planning these steps with a computer program, it is necessary to examine every possible pattern of the work sequence, evaluate all the patterns, and select the optimum work sequence. This is a so-called "combinatorial optimization problem", and its calculation requires an enormous amount of calculation time compared to the linear programming method used in soil volume allocation planning. Also, trying to reduce the computational cost of doing so requires a high degree of mathematical manipulation in assigning constraints.

So the bottleneck in automating all earthmoving is the step to achieve the automatic creation of work order plans to execute the volume allocation plan.

(As a program that partially supports work, in the work plan created by humans, the current situation is to calculate the required number of heavy equipment and perform a simulation applying queuing theory.)

3 Study on time series change information of construction site that should be collected as record data of construction execution setup

3.1 Purpose of this study

With the aim of realizing the automatic generation of construction execution setups, which was difficult to achieve with the conventional combination optimization approach, movements aiming for realization using AI are being sought. It is an approach such as using the construction execution setups actually performed by existing humans as learning data, and searching for work rules to reproduce the setups itself.

In order to support this approach, it is necessary to record the actual construction history of the earthwork and collect all the data that would explain the reason for the construction. In addition, it is useful to set certain rules for data collection and data format in order to provide such data in a usable state.

To achieve this, NILIM has begun studying a data standard for time-series change information at construction sites, assuming that this data will be provided.

3.2 Time series change information of construction site to be considered for collection

The most basic information that NILIM considers as time-series information at construction sites (Table 1) is the initial topography and final topography, and the history of changes in topography between them. And, as the constraint information that may have been used when selecting the change process, the ground conditions, usable materials and equipment (size and number of excavators, bulldozers and dumpers, embankment materials, etc.), the maximum number of days allowed for construction, and construction costs.

We will report the results of research and consideration on how to acquire the topographical shape data in Section 3.3, other data in 3.4, and how to link them after 3.5.

Table 1. List of Time series change information of construction site in this paper

	Perspectives of influential elements	Fine details	DATA	Format (unit)	Acquisition timing
Condition of construction machinery	Information for construction machinery management	Machine asset ledger	Construction machinery management records	Text or Numerical value	Annual, renewal
	Position and operating status of construction machinery	Construction machine operation records, location information, location history of work device, etc.	Working time	Date、Time	Secound
			Location log	Latitude/Longitude/Elevation	Secound
			Operating log	Text or Numerical value	Secound
			Fuel consumption	Numerical value (L)	Day, Hour, Minutes
			Machine sensor log	Text or Numerical value	Secound
	Construction machine maintenance information	Failure code, maintenance history, etc.	Error log	Text or Numerical value	On maintenance or troube occurring
			Maintenance records	Text or Numerical value	On maintenance
	Information for productivity management	Cycle data, payload data, etc.	Construction volume per hour (Calculated by combining other data)		
			Bucket loading capacity	Numerical value (m^3)	On operatiing
Topographical data	Soil volume	Cut volume	Design/Estimation cut volume	Numerical value (m^3)	When starting work
			Actual cut volume	Numerical value (m^3)	On machine operation, UAV surveying
		Fill volume	Design/Estimation fill volume	Numerical value (m^3)	When starting work
			Actual fill volume	Numerical value (m^3)	On machine operation, UAV surveying
	Area	Total area	Design/Estimation area	Numerical value (m^3)	When starting work
			Execution area	Numerical value (m^3)	On machine operation, UAV surveying
		Area for each setting area (construction section)	Design/Estimation area	Numerical value (m^3)	
			Execution area	Numerical value (m^3)	
	Terrain shape	Surface or polygon	Terrain shape or its change	Point cloud、Latitude/Longitude/Elevation	
	Transport distance (outside, inside)	Bull, dump, heavy dump, various scrapers, etc.	Transport distance	Numerical value (km、m)	When starting work
(Geological data)	Soil quality	Clay, silt, sand, gravel, soft rock, hard rock, etc.	Soil type	Text or Index	When measuring
	Rate of change	Loosening rate L, Compaction rate C	Loosening rate	Numerical value (%)	When measuring
			Compaction rate	Numerical value (%)	When measuring
	Specific gravity	1.4〜2.1	specific gravity	Numerical	When measuring
	Trafficability	Cone index	Cone index	Numerical	When measuring
	Ripperability	Number of nails	Number of nails	Numerical	When measuring
	Water content	Need for improvement, improvement/aeration yard	Water content	Numerical	When measuring
	Groundwater level	Workability	Presence or absence of groundwater and spring water	0/1	When measuring
(Meteorological and hydrological data)	Considering the number of rainy days and cold regions by region	Area and Weather	Weather	Text or Index	Automatic acquisition/manual input
			AMEDAS data (Regional rainfall information system in japan)	Text or Numerical value	Automatic acquisition
			Cold regions/snowy regions	Text or Index	Automatic acquisition/manual input
	Rainy season/dry season, dry season/normal season		※Present meteorological conditions of the area from past data of AMEDAS		
Construction Site Constraint data	Construction amount limit per day	Cut soil volume (transported soil volume), embankment volume	Cut soil volume (transported soil volume)	Numerical value (m^3)	When starting work or work planning
			embankment volume	Numerical value (m^3)	
	Removal limit of leftover soil	Embankment acceptance conditions and transportation conditions	Limit dump number	Numerical value (number、t)	When starting work or work planning
			Available days/days	Date	
			Available time/number of hours	Time or Time zone	
			Construction volume per hour (Calculated by combining other data)		
	Leveling/adjusting work (cost considerations)	Pile up, landslide, procurable number	Limit machine number	Numerical valeu (Number)	When starting work or work planning
			Available days/days	Date	
			Available time/number of hours	Time or Time zone	
			Construction volume per hour (Calculated by combining other data)		
	Workable time for each area	Securing land, constraints on construction plans	Available days/days	Date	When starting work or work planning
	Workable time constraint	Subdivided according to season, neighborhood, soil disposal conditions, etc.	Available time/number of hours	Time or Time zone	When starting work or work planning
	Secure work space (area)	Separation of heavy equipment that can ensure safety	Machines selected, workload, construction days (process)	Days	When starting work or work planning
			Area of each work area	Area	
	Sky height limit	Overhead line, etc.	Sky height limit	Numerical value (m)、Latitude/Longitude/Elevation	When starting work or work planning
	Construction management standard value data	Quality control, performance control, test/attendance frequency, etc.	Quality control		When starting work or work planning
			Finiish form management		
			test/attendance frequency, etc.		
	Safety management data	Loadable weight of transport machine	Loadable weight of transport machine	Numerical value(%)	When starting work
	Adopting ICT construction equipment construction	3D groundbreaking survey	Organization of construction machinery and surveying equipment to be introduced locally	Text	
		ICT construction machinery		Text	
		3D survey management		Text	
		Others		–	
	Ground improvement	Method	Ground improvement or not	1/0	When confirmed
	Local Soil improvement	Required specifications, materials used, amount added, machinery	Local soil improvement or not	1/0	When confirmed
	Bring-in Soil improvement		Bring-in soil improvement or not	1/0	When confirmed
	Designated construction period		Economic process, last-minute process	Text	
	Limited cost		Limited cost	Text	
	Machines designated for use		Limited Machine for use	Text	

3.3 Survey of technologies for acquisition of basic information (terrain shape data)

The following is the technology for acquiring topographic shapes, which was verified on-site at this time. The description in parentheses at the end is a description of the applied site. The site will be described later.

- UAV photogrammetry (Site A)
- 3D laser scanner (Site B (terrestrial),Site C (with UAV))
- Location history of construction machine work device (Site A, B, C)

These techniques have come to be used for surveys before construction starts and finished work measurements in MLIT ordering work.

The purpose of this survey was to understand the following facts.

- Actual measurement technology that can be used according to site conditions
- Available data area for each measurement technology
- Possibility of extracting topographical shape changes from those data

The field survey was conducted at three sites. The site outline, equipment used, and measurement data are shown.

① Site-A (Figure 3)

At Site A, UAV photogrammetry (about twice a day) and working equipment position history of construction machinery (real time) were used. These are assumed to be the most basic (Figure 4).

The data from the working device position history of the construction machine is, for example, information regarding the history of the blade edge position of the bucket of the hydraulic excavator. The data obtained here is a collection of data on the bottom surface in each range separated by a mesh of a certain size when a series of work is completed at a certain fixed position. In other words, you can acquire and record as data even the breaks for each setup. Utilization of work device position history data seems to be a useful method for grasping work setup.

② Site-B (Figure 5)

From the trial survey at the site A, the usefulness of the working device position history data was confirmed in the scene of utilizing the terrain shape data for grasping the construction execution setup, but at the site B, the problem was also confirmed.

At Site B, it was a site where a steep hill was cut. In order to efficiently carry out the work of loading cut soil into the dump truck to transport the cut soil off-site, the construction company at this site uses the temporarily formed slope for the slope and pushes down the soil to the loading point.

The shape of the pushed-down clod cannot be grasped from the work equipment position history data of construction machinery, so it was necessary to directly measure the terrain

■Site A

Work Type	Embankment widening (River)
Work Outline	Embankment using earth and sand from outside
Machine Configuration	ICT Excavator, ICT Bulldozer, Excavator (normal)
Constructor	Matsuura Construction company (Saitama-pref)
Collaborator	Komatsu Customer Support

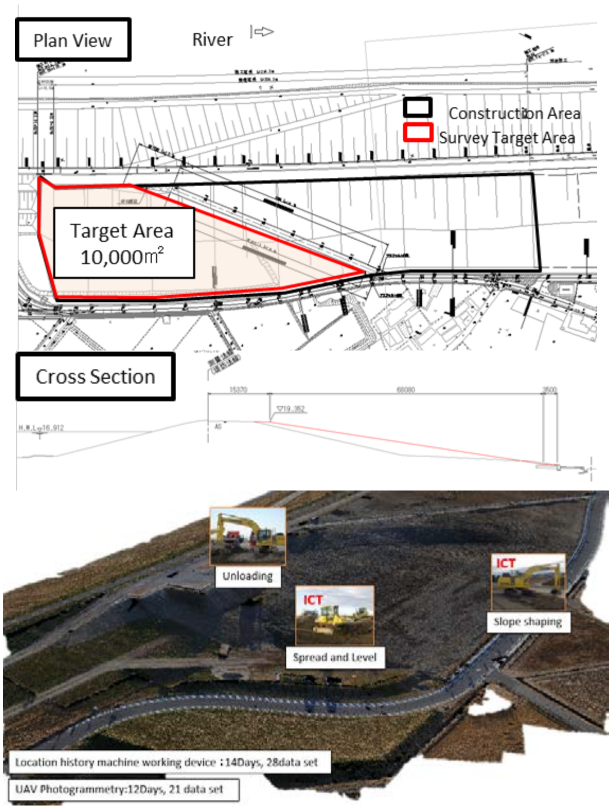


Figure 3. Site-A Outline of construction and measure

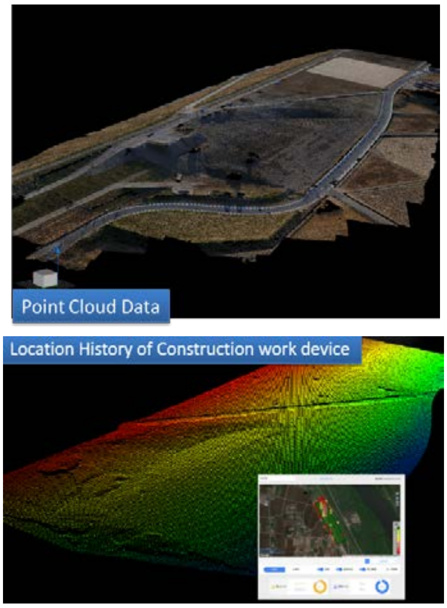


Figure 4. Comparison of point cloud by UAV photogrammetry and Location history of construction work device in Site-A

using UAV photogrammetry or a 3D laser scanner in order to perform this measurement. (Figure 6)

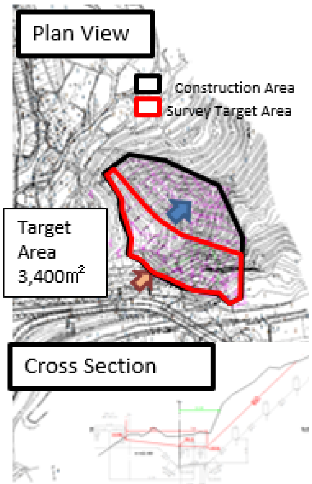
What was even more difficult at this site was the fact that there were roads with heavy traffic in the surroundings and the strong winds made it desirable to refrain from flying UAVs. Therefore, TLS (terrestrial Laser scanner) was used to obtain the topographical shape data.

It took a great deal of effort to change the installation position of the equipment at the site where the height difference was large, and the number of measurements was limited to 4 times per day. (It should be noted that the measurement operators commented that they do not want to carry out such measurements in the future.)

At such sites, it is considered effective to use construction machine-mounted camera images, acquired data from laser scanners, and stationary bird's-eye view camera image data to acquire site conditions.

■Site B

Work Type	Excavation, slope shaping
Work Outline	Excavation of hills, removal of sediment
Machine Configu -ration	ICT Excavator, ICT Bulldozer, Excavator (normal):2
Constru-ctor	Fukuue industry (Kagoshima pref)
Collabor -ator	Sitech Japan, Nippon Caterpillar



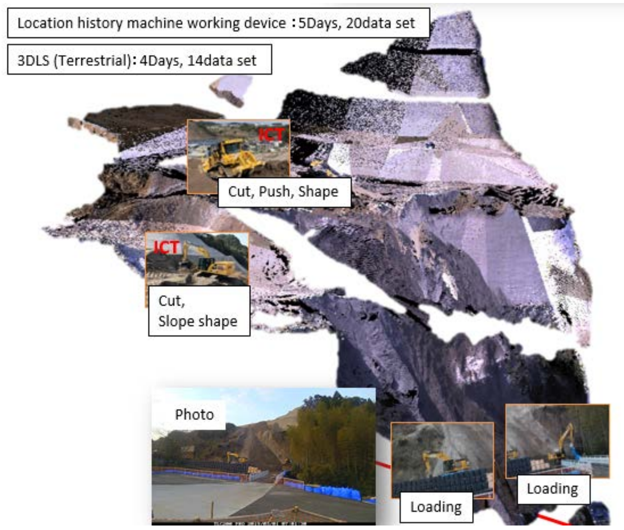


Figure 5. Site-B Outline of construction and measure

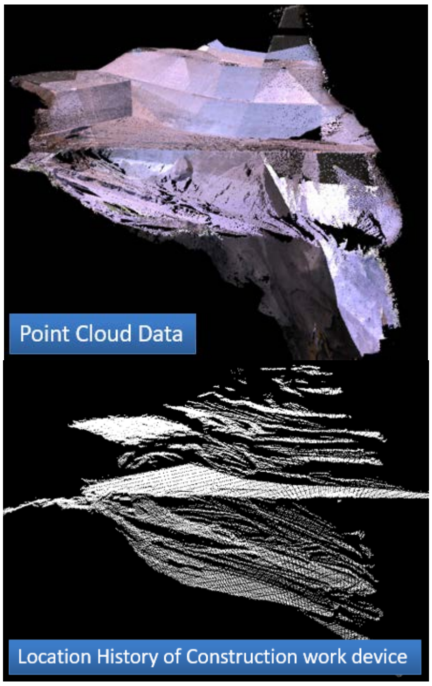
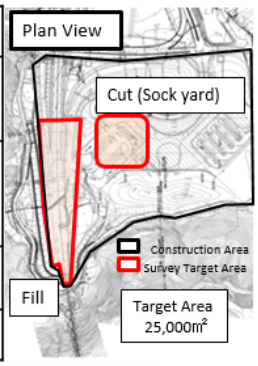


Figure 6. Comparison of point cloud by TLS and Location history of construction work device

③Site-C (Figure 7)

At Site C, we tried to obtain topographical shape data using a 3DLS with UAV. Unlike UAV photogrammetry, it was possible to obtain precise topographical shape data, but it cost about 8 million yen during the survey period. At present, it is difficult to use it from the viewpoint of application of grasping the construction progress. We would like to keep an eye on future technological trends.

Work Type	Road Embankment
Work Outline	Cut, Carry/Dump, Level and compaction
Machine Configu -ration	ICT Excavator, ICT Bulldozer, Articulate Dump(normal)
Constru-ctor	Choho construction(Nagano pref)
Collabor -ator	Kobayashi consultant



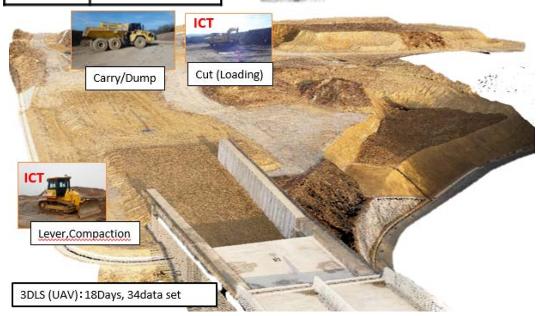


Figure 7. Site-C Outlines(upper) and Point cloud by LS with UAV

3.4 Survey on the actual status of data recording the progress of daily construction excluding topographical shape data

In grasping the construction execution setup, we investigated the existence of data that can be utilized to confirm from what viewpoint the site decided the machine selection and construction execution setup.

Although daily construction reports are prepared on site, it was confirmed that most of the sites are managed by handwritten or PC text information (Figure 8).

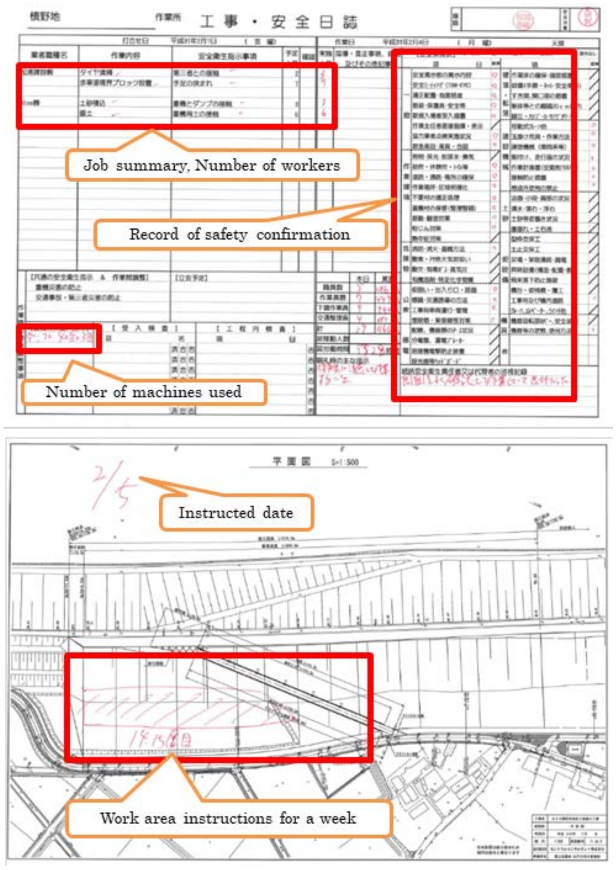


Figure 8. Examples of collected daily reports (upper) and construction instructions (under)

In many cases, the status of safety measures and quality control data are managed by inputting them in files of different styles such as Word and Excel. It is expected to utilize a platform that can handle these data.

System services have been started to centrally provide on-site construction management work, but their use is not yet widespread.

As one of the causes, it is assumed that it is due to the business practice when carrying out the construction work of the construction industry in Japan.

In Japan, the construction contractor, which is the main contractor, works with several companies that do the actual construction work. Also, the combination changes for each individual construction.

As a result, manual data entry can be efficient if different companies use different systems. It is expected that the system side will focus on this point.

3.5 Study on data structure and format of time series change information of construction site collected as record data of construction execution setup

It has been pointed out that the voxel format is useful as a display format of useful topographical shape data in planning the construction execution setup and grasping the progress of the construction.

These papers point out the significance of the following points when performing earthwork with hydraulic excavators and bulldozers [6]-[7].

- Whether the heavy equipment can be moved to the work location
- When planning work, the work volume can be easily grasped by grasping the work in voxel units.
- It is also possible to link quality information such as the material information of the voxel and the degree of compaction.

A further analogy is that when the construction procedure is reproduced later, it is possible to grasp the construction order by associating the starting order of each voxel.

An example of handling data in Voxel is analysis data by CT scan in the medical field. In CT scanning, X-rays are first applied to a fixed human body from various directions, and light is received on the opposite side to obtain transmitted X-ray data. Based on these data, we divide the body into each voxel, construct a simultaneous equation with the transparency of each voxel as a variable, and solve it. In this way, it is a technology that visualizes the internal conditions in three dimensions.

Technology is also being developed to convert the actual patient body data stored in voxel format for the surgery simulator. This has already been used in pre-surgical simulations at medical institutions in Japan [8].

Data retention in Voxel format may contribute to the application of these technologies to the construction side.

It is considered to be useful based on past research and precedents in other fields by converting the acquired topographic shape data into voxels and adding the necessary attributes.

3.6 Trial of data display in voxel display

Using the point cloud data acquired in 3.2, a trial of voxel modeling of the terrain shape was performed.

The voxel model referred to here is a representation of the terrain shape with a set of cubes. Each cube has x, y, z coordinates and is assigned a unique ID. In addition, the side length of a cube can be determined arbitrarily, so it is possible to reproduce terrains of various shapes.

Since this model is created based on the topographic surface data using 3D survey data, it has the feature that a rough ground shape can be visually grasped by the ground model.

Voxels are created by comparing the closest point cloud data with respect to the reference point cloud data and calculating the difference.

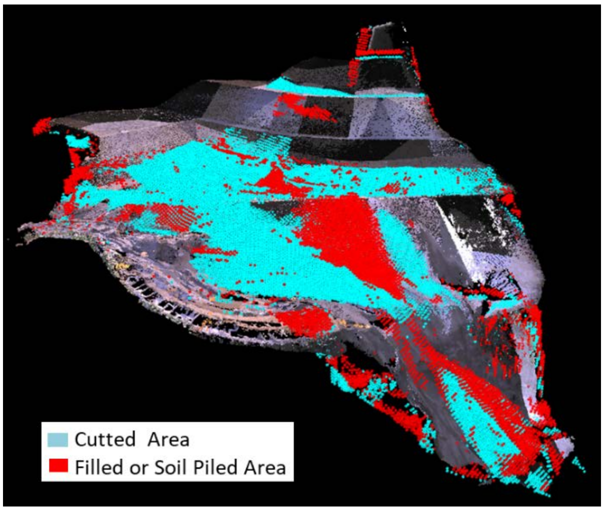


Figure 9. Change amount displayed as voxel on the point cloud data in Site-B

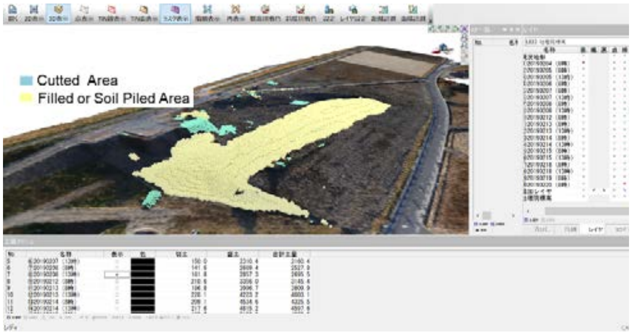


Figure 10. Change amount displayed as voxel on the point cloud data in Site-A

Figure 11. Continuous display of earthwork amount for each day in Site-A

Since software that has the function of changing the mesh width and height of voxels was used, it can be expressed as a cube or a rectangle.

In general, the voxel calculation method can be a one-point method, a four-point average method, a four-point columnar method, a topographic model (TIN) method, or the like. This time, the voxel has a specification that occurs when the difference volume exceeds 1/2 of the voxel volume, and the following method is adopted.

- Mesh width and height: 50 cm Output with voxels on all sides
- Voxel calculation method: 1 point method

By displaying the voxel data overlaid on the point cloud data, it can be seen that the construction part can be effectively extracted (Figure 9, 10).

In addition, the following is displayed separately for each lapse of time (Figure 11).

3.7 Additional discussion on the voxel size and data retention format based on the knowledge obtained from the exchange of opinions with a mechanical earthmoving company for the use of time-series change information at construction sites

Additional discussion on the voxel size and data retention format based on the knowledge obtained from the exchange of opinions with a mechanical earthmoving company for the use of time-series change information at construction sites

We presented these voxel modeled data and asked the construction company that specializes in mechanical earthworks to utilize the time-series change information of construction sites. As a result, the following points were received.

Table 2. Main opinions from earthmoving constructors

	Opinion content
1	I think expressing in voxels is good because attributes can be associated. <u>It is important to consider how the surface water flows. (This is also a provision of MLIT)</u>
2	As earthwork companies, the construction cost is not the best construction plan. In the face of various market constraints, we are planning to make sure that the equipment and human resources that can be arranged will be used without waste. It would be good if we could include things such as constraints.
3	If the construction process can be converted into data, it could be used as a basis for explaining the process to the orderer and for understanding the difficulty of the work.

Among the above points, from the viewpoint of the examination of the voxel model, the point that we should emphasize is that it corresponds to the provision of the inclination angle for drainage regarding the surface finish of earthwork during construction execution setup.

Based on this recognition, the factors affecting the topographical shape were extracted from the precautions for earthwork described in the construction standard specifications, which are applied to the construction ordered by MLIT (Table 3).

Table 3. Main provisions in MLIT specifications related to earthwork topography

Provision Name	Provision Content
1-2-3-3 Embankment	
2. Prevention of embankment sliding	When the embankment is carried out on the ground with the slope steeper than 1: 4, the flat step cutting (minimum width and height are 1.0m and 0.5m) must be carried out, and the embankment and the site board must be closely adhered to prevent the slide, except for the case where the instruction is given.
3. Finished layer thickness	In embankment construction, the finished thickness should be 30 cm or less and compacted flat.
6. Wastewater treatment at the end of work	When the contractor finishes the embankment work or interrupts the work, the contractor must provide a cross slope of about 4% on the surface and compact it evenly to ensure good drainage.

In order to be able to confirm these provisions or regulations with the voxel model, it is necessary to study the size of the voxel. Based on sampling theory, we need to be able to extract less than half the size of the observed object.

It may be necessary to display in a size different from the vertical and horizontal directions, such as 0.5 m or less in the vertical and horizontal directions and 0.15 m or 0.1 m or less in the depth direction, in order to address all of the points pointed out.

When utilizing time series change information at the construction site for accountability to the orderer, it is necessary to consider not only the display format of these data but also the data retention format of the actual voxel model.

Although it is a voxel model, the actual data format may also have a practical idea of having coordinate data of the center point of each voxel and linking the data to it.

The discussion on this point requires further study by grasping the following trends.

- Initiatives for intelligent compaction at FHWA
- Data handling cases in other fields (compared with data capacity from hand rig cases on a computer for large amounts of data)

4 Conclusion

The following findings were obtained in this research.

- Efforts to automate construction work plan of construction machinery will hold the key to the realization of automatic construction in the future.
- To realize the construction work plan of construction machinery support AI, construction history information as learning data is required.
- Construction history information consists of basic time-series data of topographical shape data, quality relations associated with it, and construction constraint data.
- The usefulness of the voxel format as a data display or data storage format.
- Through the trial of voxel display and the exchange of opinions with practitioners based on it, it is necessary to set the voxel size up to 0.5 m in width and height and 0.15 or 0.1 m in height direction along with the effectiveness of the point cloud data.
- Further investigation of data handling precedents in other fields such as consistency with similar efforts in other countries and medical care is effective.

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