Study on the level concept of autonomous construction in mechanized construction.

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Abstract –

With a focus on mechanical earthworks, automation of limited operations is progressing with regard to driving operations such as hydraulic excavators, bulldozers, and compaction rollers. The Ministry of Land, Infrastructure, Transport and Tourism is promoting public works that positively utilizes automated construction equipment and the like for the purpose of improving productivity at construction sites.

In the future, it is expected that the scope of automation of construction machinery will expand due to further technological advances such as AI and IoT. In that discussion, it is instructive to note that the classification of automation driving in automobiles serves as the basis for discussion of technology diffusion. Regarding automated construction machinery as well, in considering the promotion of the introduction of this technology into society, we believe that it is useful to formulate a concept at the autonomous construction level.

In this paper, while referring to cases such as classification of automation driving in automobiles, while paying attention to the differences between automatic running of vehicles and autonomous construction of construction machines, a conceptual draft of the level of autonomous construction by construction machines is proposed. In addition to showing the results of the study, the additional study issues that became clear in the study process are shown.

Keywords –

Autonomous, Construction, Level concept, Construction machine

1 Present situation for ICT in mechanized construction field and necessity of roadmap or concept of level for realization of automatic construction

1.1 Short history of introducing construction machinery and Machine control.

Mechanization of construction work has progressed in crane work and earthwork. After the Meiji Restoration, electric shovels were developed in Japan in the 1940s and were mainly used in large-scale earthwork sites [1].

In Japan, the mechanization of construction work has been rapidly promoted since the Second World War. In order to improve the supply capacity for the enormous demand for infrastructure, the construction machinery used by the United States during the war were paid off to japan government and construction industry, and then and then through technical cooperation with overseas companies, domestic construction machinery manufacturing took place again. Nowadays, several construction machinery manufacturers in Japan are competing to contribute to mechanization of construction sites in the world (Figure 1, [1]) [2],[3].

Since the 1980s, in the midst of rapid anxiety about the aging of the working population, automation and autonomy were sought for earthwork, which was the

Kobe Steel (1930) Komatsu(1943) SCM(1961) Hitachi(1965))

Figure 1. Example of construction machinery manufactured by a Japanese manufacturer [1]

most mechanized construction field.

Around 1990, hydraulic excavator manufacturers developed and commercialized semi-automatic hydraulic excavators. Operating a hydraulic excavator is a difficult operation in which the operating levers of the boom, arm, and bucket are moved simultaneously. However, with this semi-automatic product, the system automatically assists the hydraulic valve by the operator only operating the arm operation lever, and the bucket blade edge moves linearly for shaping.

Unfortunately, the economic downturn caused a recession and many workers returned to the construction site, so these did not lead to large sales.

Then, taking advantage of the spread of GNSS technology, an information presentation technology was developed that assists construction machine operators to visually confirm the difference between the cutting edge and the topographical design information. In the 2000s, these were called machine guidance systems in Japan and have been introduced in hydraulic excavators and bulldozers. (In Europe, this is called “Machine Control”.)

Nowadays, semi-automated technology and its combination are used to provide hydraulic excavators and bulldozers that assist shaping operations at any place in the construction site

Figure 2. Concept of future vision for construction work [9]

using 3D design information and real-time position information. In Japan, this is called 3D machine control [4]-[7].

Also, within a limited environment, trials have been made to automatically construct embankments by operating a plurality of such construction machines programmatically [8].

The Ministry of Land, Infrastructure, Transport and Tourism of Japan has set a future vision of realizing automatic construction in order to increase the production per worker in the construction field amid the rapid aging of the population (Figure 2, [9]).

1.2 Present situation for ICT in mechanized construction field and necessity of roadmap or concept of level for realization of automatic construction.

On the other hand, there are some differences in the understanding and evaluation of the actual situation of the developed semi-automated level among the parties concerned. Both the overestimation and the underestimation have caused cases in which the introduction of users is hindered and the policy making of the administrative agencies promoting the utilization becomes difficult.

The public works orderer wants to utilize these technologies to facilitate the supervision and inspection work such as step confirmation during construction. However, there are concerns that such misunderstandings will cause difficulties.

Please note that the content presented in this paper is not the official view of the Japanese government at this point, but is a report at the stage of consideration as a national research institute.

2 Investigation study on roadmap and technical level concept classification of automation driving

First, we reviewed the progress of the study on the roadmap for realizing automation driving in Japan (Figure 3, [10])

In Japan, the “Autopilot Study Group” established by the Ministry of Land, Infrastructure, Transport and Tourism held discussions and compiled the “Driver Assistance System Advancement Plan” in 2013. After that, with the Cabinet Secretariat as the secretariat, the Prime Minister's top meeting: Advanced Information and Communication Network Society Promotion Strategy Headquarters was launched, and at that meeting the roadmap for realizing automation driving is being

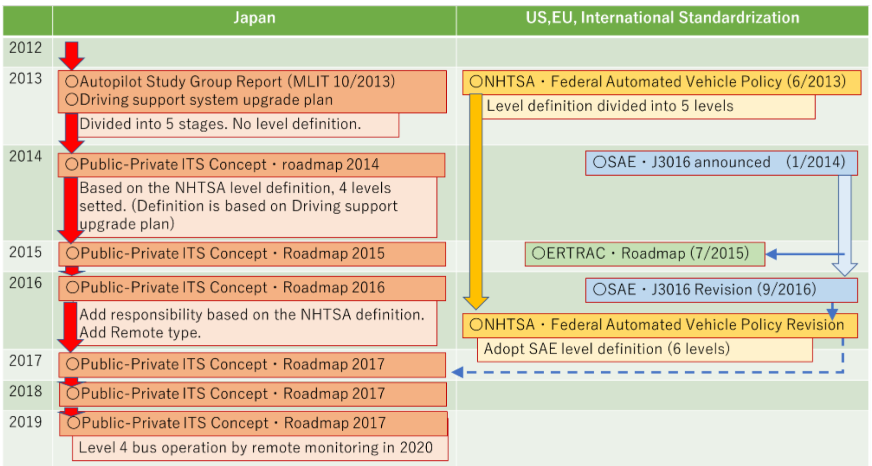

Figure 3. Movement around definition of autonomous driving level [10]

discussed. At that meeting, the first version of the “Public-Private ITS Concept/Roadmap” was formulated in 2014.

In the discussion there, the definition by the US Department of Transportation NHTSA and the discussion on the ERTRAC/Roadmap were investigated, and the definition of automation driving was referenced. With the aim of defining the concept of level classification and refining the scope of the roadmap, representatives of automobile manufacturers, government officials, and other parties continue to hold discussions and update the roadmap every year. Discussions and revisions were also held in response to the drastic revision of SAE/J3016 in 2016.9.

In Japan, a system that automatically stops the traveling vehicle by detecting people or objects was introduced due to the technological development of several manufacturers. For that reason, the terms "safe driving support system" and "automation driving system" existed before. The discussion of correspondence and consistency between those terms and the terms defined in the discussions such as NHTSA was an important issue.

In addition, a service was offered to reduce automobile insurance costs in response to the introduction of these systems. For this reason, the concept of responsible relationship between the driver and the safe driving support system installed in the automobile was also discussed.

In automation driving, what role the driver and self-driving car should share, and how to organize the components of the task of driving were important subjects of the discussion.

In the 2016 revision of SAE/J3016, these issues were organized as DDT, OEDR, DDT fallback, ODD, etc.

The roadmap for automation driving in Japan also follows this concept.

These conceptual arrangements have contributed greatly to clarifying the evaluation of technical contents as well as the definition of automation driving (Table.1, [11]).

Based on these discussions, revisions to the concept and roadmap of automation driving in Japan have been made. This has led to deepening of discussions and progress of work mainly in the following points.

・Clarification of manufacturers' priority development products and enhancement of management strategies
・Discussion from the perspective of how automation driving can help solve social issues
・Clarification of use cases that should be preceded
(* Mobile services in depopulated areas (Level 4 bus operation by remote monitoring, etc.)
・Discussion on how much resources the government should devote to the social introduction of self-driving cars.

Table 1. Elements Concept [11]

Element		Definition or Meaning
DDT	Sustained lateral and vehicle motion control	Sustained lateral and vehicle motion control
	OEDR (Object and Event Detection and Response)	The subtasks of the DDT (dynamic driving task) that include monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events (i.e., as needed to complete the DDT and/or DDT fallback
DDT fallback		Complete action or Response to when DDT operation is difficult to continue (i.e. Transiton to Minimal Risk condition)
ODD (Operational Design Domain)		The specific operating domains in which the ADS (Automated driving systems) is designed to function.

(*Positioning of advanced driving systems for safe driving, etc.)
・Revision of relevant laws and regulations by the government
(*Revision of technical standards for automobiles and consideration of new formulation)
・Adjustment of existing laws and regulations for experiments in real environments
(* Clarification of necessity of road use permission rules by police, review to enable experiments of remote monitoring vehicles)

3 Conceptual study of autonomous construction level in construction machinery that is becoming more automated

3.1 Arrangement of element concepts that are the basis of level division

-The survey and consideration in the previous section confirmed that the role played by the roadmap is effectively useful for the social introduction of technology. In addition, useful points were confirmed regarding the roadmap and level conceptual studies for the automation of construction work.

In particular, it is effective to sort out the concepts of DDT, Vehicle control motion, OEDR, Fallback, and ODD, and we took steps to sort out this point of view regarding automation of construction work.

Table 2. Elements Concept of Automation construction and comparison with Automation driving one

Automation driving		Automation construction		
Element		Element name		Definition or Meaning
DDT	Sustained lateral and vehicle motion control	TASK	Control work device	Control of work device of construction machine (including movement of construction machine)
DDT	OEDR (Object and Event Detection and Response)	TASK	OEDR	Detection of the changes of work objects and terrain shapes and procedure changes due to changes in them
DDT fallback		Task fallback		What to do if the construction machine system cannot control the task (Site Condition change, Changes in soil quality etc)
–		Work area setting / Task allocation		Construction execution planning or setup
ODD (Operational Design Domain)		ODD		(Site Condition change, Changes in soil quality etc)

Table.2 is the corresponding concept that we have examined (Table.2).

Here, as a new element, we propose to add "Work area setting/Task allocation" separately from “DDT”.

It is because that we define automatic construction in mechanical earthworks as changing the existing terrain to the terrain shape shown in the design drawing of the area without human intervention.

If you think in that way, the construction setup will emerge as the next necessary element after the above Task (corresponding to DDT) and fallback.

For example, if the automatic excavator digs the ground all the way to the surface of the design shape, the dump may create a slope that cannot carry the soil. In order for the work to proceed properly, it is necessary to determine the order of the excavation work positions of the excavator and the depth at which each is to be excavated in stages.

In addition, when performing construction with a bulldozer, just because the ground at that point needs to be excavated, the construction does not proceed simply by pushing down the cutting edge. If you do not set up a plan for where to push the soil and carry it, that is, the traveling route, the work will not proceed.

From this perspective, we added the construction setup as the adding new element.

However, we recognize that there is room for further discussion on these points. For example, an already developed car navigation system is responsible for searching for the movement from the current position to the destination in automation driving. And this car navigation is outside the scope of the roadmap (Figure 4, [12]).

Considering the current location as the current topography and the destination as the design drawing, considering how to reach it is equivalent to route selection, so there may be a way of thinking that the construction setup is outside the roadmap.

Since the proposals in this paper are tentative, we expect many opinions.

3.2 Tentative plan of level division concept in automatic or autonomous construction

Based on the above concept of functional elements and whether they are shared by people or systematization, we propose the level divisions concept (Table.3).

The outline of the six levels and the descriptive definition of each level follows the table of automobiles. Of course, this division depends on the combination of the realization of each element, so the level division also changes depending on how the element is considered.

In addition, between level2 and level3, we set level2.9 as the realization of automation with a single construction machine among the components of level3.

It is level 3 after level 2 when it is classified as a commercial level. However, among the development factors required before reaching Level 3, automatic excavation of hydraulic excavators is being realized in research. We think that it is necessary to realize Level 3 after Level 2 in order to have a significant meaning in practical use. However, level 2.9 may also be useful as a practical category when performing embankment compaction as a single task.

In addition, referring to the discussion on the roadmap for automation driving in Japan, we described the technologies that have already been realized and the technologies that are expected in the future at each level.

In Japan, the semi-automatic control of the shovel is called MC, and please note that it is different from Europe. In Japan, a system that gives guidance to operators is called MG.

The automatic embankment construction system at the dam site realized at Kajima corporation was set to level 3, but this may be a point of discussion.

Furthermore, similar to the discussion on the roadmap for automation driving in Japan, the safety equipment introduced to prevent accidents where construction machinery comes into contact with people on-site was not included in the table. This is an area where it seems to be highly effective as a utilization destination of AI for image analysis based on deep learning, which has undergone remarkable technological innovation these days. However, this is because the highest level was organized from the viewpoint of a realization route to autonomous construction that does not involve people on-site.

We think that this point is also subject to debate, depending on how to utilize the roadmap and considering the possibility of human intervention at the site of autonomous construction.

Table 3. Level Concepts of Automation or Autonomous Construction

Level	Name or Narrative Definition	Task: Control work device	Task: OEDR	Task fallback	Work area setting / Task allocation	ODD	Product
0	Non automation The work area of each operator is determined by the instruction of the foreman, and each operator controls construction machine in the allocated area, using finishing stake as a guide.	Operator	Operator	Operator	Foreman/ On-Site Agent	n/a	
1	Work Support The foreman (or on-site agent) divides the work range, and in that work range, each operator controls construction machine based on work device position information obtained from sensor and inputted 3D design digital data.	Operator (with position information support)	Operator	Operator	Foreman/ On-Site Agent	Limited	Machine Control In Japan, called “Machine Guidance”
2	Work Device Control Assistance The foreman (or on-site agent) divides the work range, and in that work range, the operator controls construction machine basically, the control system assist its control based on work device position information obtained from sensor and inputted 3D design data .	Operator and System	Operator	Operator	Foreman/ On-Site Agent	Limited	“Semi-auto” In Japan, called “Machine control” [4]-[7]
2.9	Work Device Control Automation The foreman (or on-site agent) divides the work range, and in that work range, control system controls construction machine to work based on work device position and current terrain information obtained from sensor and the inputed 3D design digital data. When the work is completed, it is in a standby state automatically.	System	System (Monitored by Operator)	Fallback-ready Operator	Foreman/ On-Site Agent	Limited	Multiple realization cases at the research stage. (Hydraulic Excavator, Wheel Loader) [13],[14]
3	Semi-auto combination construction The foreman (or on-site agent) divides the work range basically, and system assist. And in that each work range, the control system controls construction machine to work, the operator supervise those machines. Automatic stop when it is difficult to continue appropriate work.	System	System (Monitored by Operator)	Fallback-ready Operator	Foreman / On-Site Agent and System	Limited	KAJIMA corporation “A4CSEL” called "Quad accel" [8]
4	Conditional automatic construction The system is used to perform work plans from the planned completion (design drawings) and work division to each construction machine in the work that consists of only specific conditions and specific work types. Each construction machine carries out work autonomously and autonomously.	System	System	System	System	Limited	
5	Automatic construction Automation of construction in all case.	System	System	System	System	Un-limited	

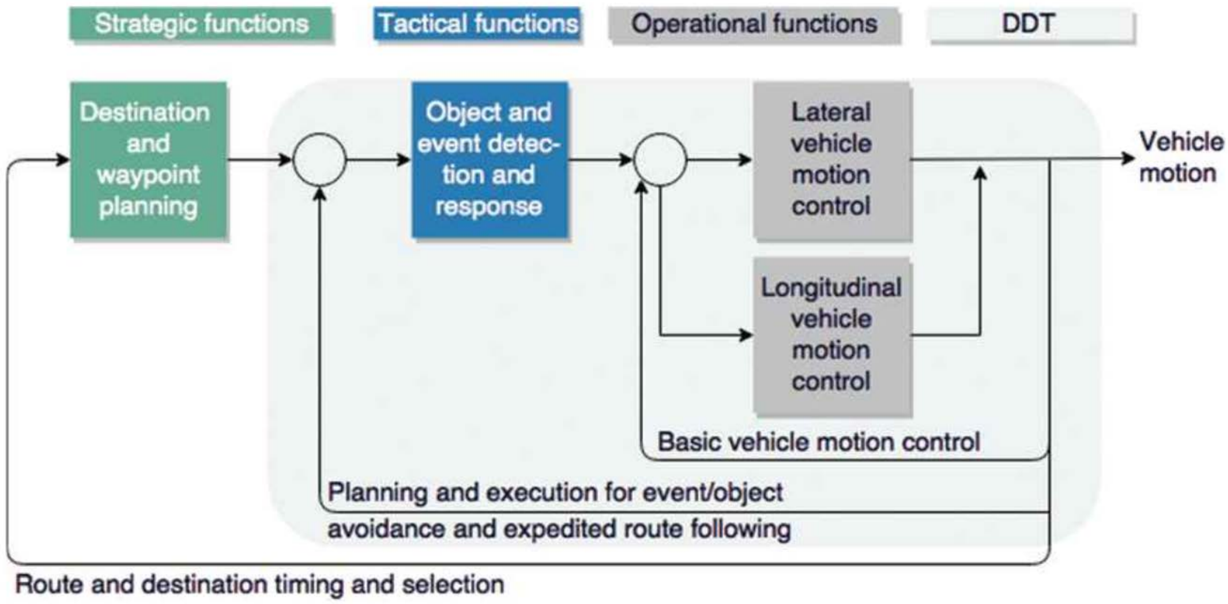

Figure 4. Functional component classification according to SAE J 3016 [12]

4 Additional study issues clarified in this study process

4.1 Need for automatic generation system of construction execution setup (Between Level2 and Level3)

At the construction site, the person in charge of the construction and the work team leader who receives the work instructions from the person in charge of the construction decide the work place and work goals for the day and work plans. Further, in many cases, detailed work preparation is left to the operator himself, and his know-how has not been formalized. It became clear that a solution to this point was required.

Note that a large amount of learning data is required when it is assumed that this problem will be solved by AI.

NILIM is considering the need for an approach by AI as a system to realize this function. In addition, we are conducting activities to collect on-site data as learning data for construction setup creation support AI. This will be announced in another paper (Figure 5).

4.2 Necessity of roadmap composition with "improvement of safety at construction site" as policy objective

The goal of the autonomous construction movement in Japan is to let the machines do what they can do, as a countermeasure for labor shortages in the construction industry.

However, the cause of the labor shortage in the construction industry is that the construction industry is dangerous. Further, in order to realize a completely safe machine earthwork, it is beneficial to construct an on-site environment where people do not mix with heavy equipment. This final goal matches the definition of automatic construction set above.

Also, by setting a roadmap with safety as the main goal, it is possible to put the technology of safety measures at the time of contact between people and construction machinery on the roadmap.

The above-mentioned person detection technology will be required when a third party enters the construction site even if autonomous construction is realized in which workers and construction machinery do not coexist in the future.

Due to these advantages, it is useful to construct a roadmap that aims to realize safety in order to realize automatic construction.

4.3 Necessity of refining the level concept when assuming development

In this level conceptual study, autonomous construction of machine earthworks was assumed, and it was expanded to other types of work in level 5. However, in addition to this positioning, the work of earthmoving also differs depending on the type of machine adopted, so it is necessary to make detailed the level classification that assumes them.

To this end, it may be useful to proceed with the discussion from the perspective of developing the hierarchy of ideas that correspond to the original ODD in more detail, based on the correspondence relationship of DDT.

(*We are aware that the Public Works Research Institute of the National Research and Development Agency is working on this point, and we are exchanging opinions. I would like to ask you to continue your studies.)

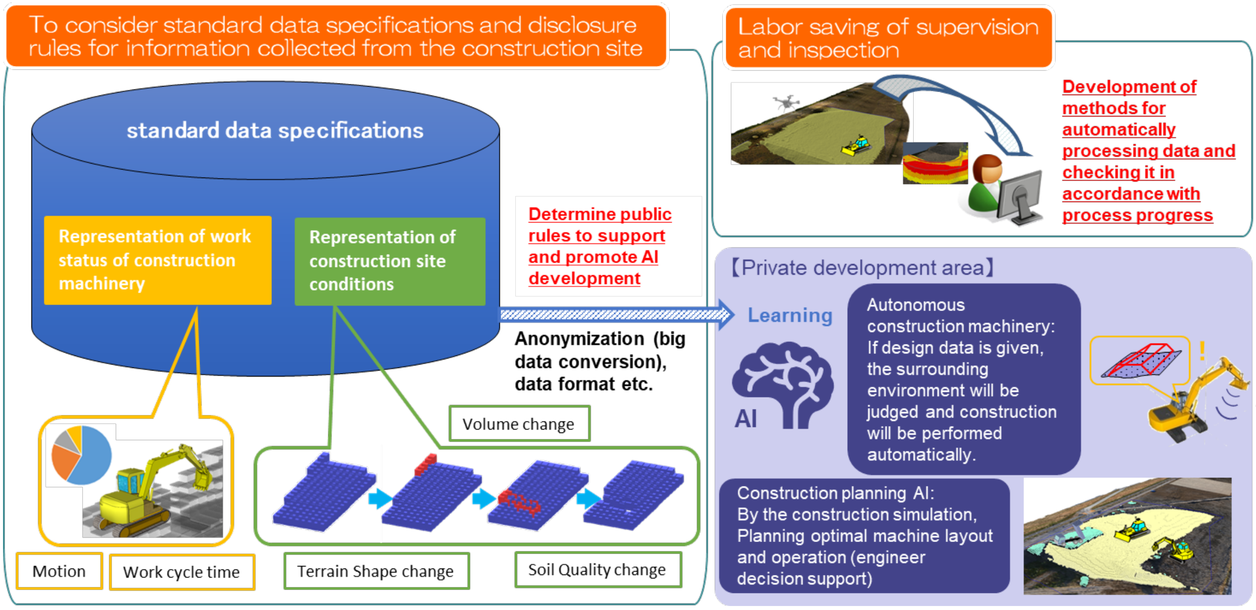

Figure 5. NILIM project outline

4.4 International terminology issues

In addition, there are some confusions among Japanese stakeholders due to differences in terms such as MC in Europe and Japan.

In the future, when broadly discussing the roadmap and the concept of level, it is necessary to make efforts to organize the term definitions between countries.

However, it may be difficult to make a complete agreement because there are differences in the construction sites and backgrounds of construction in each country.

5 Conclusion

① The following effects were confirmed as the roles of the automation driving realization roadmap.

1) Clarification of manufacturers' priority development products and enhancement of management strategies
2) ・Discussion from the perspective of how automation driving can help solve social issues
3) Clarification of use cases that should be preceded
4) (* Mobile services in depopulated areas (Level 4 bus operation by remote monitoring, etc.)
5) Discussion on how much resources the government should devote to the social introduction of self-driving cars.
6) Revision of relevant laws and regulations by the government
7) Adjustment of existing laws and regulations for experiments in real environments

② Based on the discussion on automatic operation, we created a draft of Level classification based on the concept of functional elements in automatic construction and the current technical situation. As a concept of functional elements, the category of 3) is newly added.

1) Task (Concepts corresponding to "DDT")
   ① Control work device
   ② OEDR (Object and Event Detection and Response)
2) Task fallback
3) Work area setting / Task allocation : Construction execution planning or setup (Additional element candidates not in automation driving)
4) ODD (Operational Design Domain)

③ Based on the concept of functional elements of Automation Driving and the current state of technology, a draft for Level Concept was created.

④ The following additional considerations were confirmed from these processes.

1) Need for developing construction execution setup setup generation system. (Between Level2 and Level3)
2) Necessity of roadmap composition with "improvement of safety at construction site" as policy objective.
3) Necessity of refining the level concept when assuming development
4) International terminology issues

The definition of automatic construction, functional elements, and level conceptual divisions shown in this paper are all in the trial stage. Opinions from interested parties are welcome. In response to those, further discussion will be deepened in the future.

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