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Research paper

An Analysis of the Threat Factors for the Autonomous Driving Robot on the Construction Site

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Abstract

Background/Objectives: Construction projects have limitations in improving construction efficiency through mechanization. Therefore, this study aimed to analyze the information needed to apply autonomous driving technology to construction equipment.
Methods/Statistical analysis: This study has identified the research trends of big information and autonomous driving technology through existing literature. This study collected information on locations and types of work that require site safety management through a questionnaire survey of experts.
Findings:This study focused on the types of information required for autonomous driving in earthwork environment. For this study, experts are engineers who served in the fields of building construction. The result disclosed that radius of operation of construction workers was the most dangerous and entrance of construction site was the least dangerous. Survey result on autonomous driving equipment speed indicated that equipment must come to a full stop within the radius of operation in each hazard area, drive under a normal speed at entrances, and slowdown in all other areas. Regarding potential accidents by autonomous driving equipment, the level of risk was highest for accidents within the range of equipment motion and lowest for equipment collision. When reviewed the result of hazard areas and accidents, it was disclosed that a direct collision between equipment and workers was most hazardous during earthwork. When categorized and analyzed accidents by worker and equipment, there was no significant difference. By the way, there is a difference between proper speeds when passing through workers and equipment.
Improvements/Applications: This study can contribute to the automation of the construction site by deriving the information type and the collection method for autonomous driving of the construction equipment.

Keywords: *earthwork, autonomous navigation, survey, earthwork equipment, hazard area*

1. Introduction

In manufacturing, efficiency and quality can be achieved through systematization and optimization of production lines. At the end of the 20th century, computer and information and communication technologies began to develop. The changes that the development of these technologies have influenced the construction industry include information, knowledge, technology intensification, and high efficiency[1]. In the case of construction projects, the mechanization of the construction site has been actively promoted and is recognized as a preliminary step to develop into the concept of construction automation. However, due to the necessity of the labor force for the construction business, there are limitations on the mechanization of construction [2].More recently, construction sites have introduced enhanced construction equipment and employed techniques more suitable for mechanized construction to resolve these issues and to pursue economy [3]. However, efficiency and productivity at construction sites have been subpar as the operating method of managers cannot keep up with developing technology. Especially, construction equipment takes up a significant portion of the construction cost, and construction cost and period may vary considerably depending on the equipment operating methods exerted by managers. Also, improper use of equipment has been the main cause of safety accident in construction sites. According to a 2014 KOSHA report, the construction industry was accountable for 21.4%of all safety accidents, closely following manufacturing industry. Of these, facility and equipment-related safety accidents made up 22.0%. The ratio of collision and other contact accidents involving construction vehicles constituted 24.9% of all such accident type [4]. Most of the accidents are due to construction equipment, especially vehicles and securing optimal path for them is in a construction site is vital to prevent safety accidents. However, this has proved to be extremely difficult, as each and every construction site is different in its own way. There are many risks involving obstacles on the equipment paths and slope and condition of terrain. It is also determined that intuitive equipment operation based on manager experience is an obstruction factor. Therefore, this study is to collect data in construction sites required for autonomous driving and analyze them, prior to research on automated route search system which automatically searches for optimal and safe routes.

2. Scope and Methods

2.1. Scope

This study focused on construction sites with irregular and atypical terrain. In general, earthwork is divided into Excavation, Loading, Haul, Placement, Compaction and Embankment[5]. The range of earthwork in this study is limited to site clearing, trench, drainage, back filling, banking, remaining soil handling, and sheathing work.The dimension of equipment was restricted to 1m x 1m x 1m with construction site data collection sensor during earthwork for application of autonomous driving system in construction equipment that require safety management.

2.2. Methods

In this study, the trend of studies on autonomous driving technology was investigated through literary review, followed by expert surveys on the risk factors to autonomous equipment driving within earthwork site and types of accidents prone with autonomous driving equipment. The survey questionnaire was comprised of short-answer questions to obtain open answers from the experts. The data collected were categorized and analyzed. Lastly, the result of the study was verified through a field study and determined applicability in the field.

3. Research Review Related Autonomous Navigation Technology

Regarding studies on optimal travel route search for construction equipment, there is one study on the early development of HUORS (Haul-Unit Optimal Routes Selecting system). HUORS is a transportation equipment route planning support system with variables such as terrain type, weight of equipment and weight of earth. The system developed in this study is comprised of field information input and GIS information utilization module, transportation time calculation module, and optimal route and total transportation time presentation module. This study is expected to have a substantial contribution to optimal route planning which significantly affects the productivity of earthwork equipment. However, there are limitations, including delayed route search time and being unable to incorporate field uncertainties [6].

Regarding studies on development of intelligent excavation robots, there is a study on 3D modeling sensor selection and field applicability. The study was conducted on the basis of building high price sensing system and delayed modeling speed due to noise from modeling result. In consideration of these concerns, specifications and strengths and weaknesses of developed 3D modeling sensor technology were analyzed for this study. Table 1 illustrates factors affecting 3D modeling during earthwork drawn after analyzing such issues with US and Japanese autonomous excavation robots.

Table 1: Factors Influencing 3D Modeling

Factors	Supplementary Details
Economic Feasibility	Price of hardware
	Price of software
	Price of customizing and Installation of 3D modeling sensor
Rapidity and Range	Quickness of data acquisition
	Acquisition of data with 10 meters in distance range
Accuracy	Accuracy of terrain model
	Resolution of terrain model
	Operation in night time
Installation	Installation difficulty on an excavator
	Sensor customizing difficulty
Durability	Accurate data acquisition under machine's vibration
	Waterproof
	Durability in harsh construction environment

Furthermore, a study was conducted which determined the weight of performances required in 3D modeling sensor technology through AHP analysis. The weight of accuracy was the highest at 0.49, followed by economic feasibility, 0.24, rapidity and range, 0.12, ease of installation, 0.09, and durability, 0.06. The quality and accuracy of a 2D laser scanner was considerably better than those of 3D modeling, and installation of 2D laser scanner will require a rotating instrument with precise and fixed rotational speed. Additionally, the scanner must be positioned on the excavating robot so that it can scan the surrounding terrain at a uniform density [7,11].

In the fields of development of autonomous driving cars, there is a study on driving environment recognition technology, autonomous driving technology, and electronic control system design technology. In his study, the author defined autonomous driving as 'next-generation intelligent technology that improves driving safety and accessibility by recognizing driving environment and providing assistance in driving or driving the car by itself'. The performance of the developed autonomous driving car was verified in a tournament. Further studies will be needed for the system to acquire information such as accurate car position and location and for the technology to be applicable in driving environment with moving objects [8,12].

4. Results and Discussion

There have been incessant research efforts on autonomous driving technology applicable on regular roads. The US National Road and Traffic Safety Administration (NHTSA) has defined five levels of autonomous driving: the US and Japan have achieved stage two in 2017, and Germany and Korea have reached stage two in 2018[9]. As the result, the technology is at commercialization stage, but it yet lacks information to be applied in a construction site. Principal reason for this is the distinction in driving environment between regular road and earthwork environment.Because earthwork is highly reliant on construction machinery equipment, work performance such as productivity and quality of the construction depends on the utilization of the construction machinery equipment and the ability to operate [10,13]. Besides, Unlike a regular road, the driving condition for construction equipment in earthwork environment is continuously changing, including location of obstacles and workers, which entails the autonomous driving equipment to gather real-time information more frequently. The information this study seeks to determine are type of accidents that may occur in earthwork sites and their level of risk. Construction accident types are difficult to simulate. What's more, because autonomous driving technology in earthwork environment is not yet perfect, it is important to identify risk factors in construction sites. Surveying was the most adequate research method for this study, and survey questionnaires were passed out to experts to determine type of information and their respective significance in development of autonomous driving equipment in construction sites. Figure 1 illustrates an example of a construction site for the sake of this study. The equipment developed in this study will pass through a number of areas from start point to finish point, including the radius of operation for back hoe, dump truck paths and other working areas. To complete autonomous driving technology in an earthwork environment, the equipment must recognize hazard and operate itself accordingly.

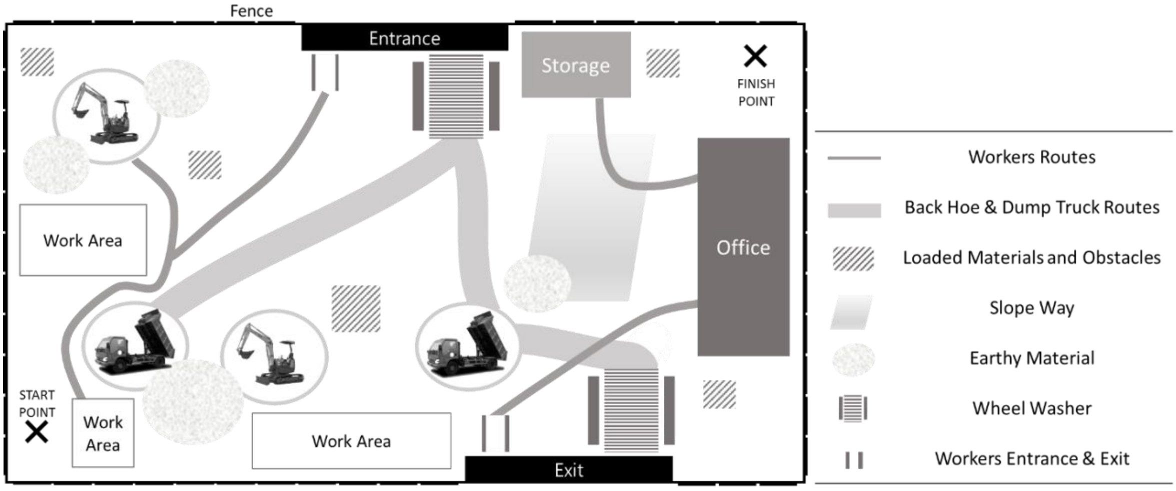

Figure 1: Example Construction Site

In order to determine the areas where autonomous driving equipment must recognize hazard areas and potential hazards, the following survey was conducted on experts. The questionnaire was scaled from 1 through 5 to accurately express hazard index for hazard area and safety accidents. A scale from 1 to 3 was given for equipment speed by area, where 1 required a speed limit of 30km/h, a typical speed limit in an earthwork site, 2 required a speed limit of5km/h, and 3 a temporary full stop. A video explaining how to fill out the questionnaire was shown to each and every expert before they answered. The survey questionnaires were distributed online and the questions were either open-ended or rating scale. The questionnaires were distributed to 78 experts in construction and a total of 32 questionnaires were received and analyzed. As for surveyee work experience, 18.75% had 5 years or less, 12.5% had 5-10 years, 9.38% had 10-15 years, and 59.38 had 20 years or more.

First, the questions were on the types of hazard areas that may affect autonomous driving equipment. Table 2 illustrates the result.

Table 2:.Survey Result on Hazard Area

Hazard area(n)	Risk level	Speed
Worker radius of operation(8)	4.38	2.88
Worker route (17)	4.24	2.59
Road and slope(31)	3.89	2.16
Equipment route (37)	3.38	2.19
Equipment radius of operation (15)	3.33	2.40
Passage and road (8)	3.25	2.25
Driving equipment route(3)	3.00	2.00
Obstructive spot(16)	2.06	1.81
Entrance and start point (3)	1.67	1.33

The risk level and speed values are mean values based on the respondents answers. The result disclosed that the risk level was the highest when driving an autonomous driving equipment around the radius of operation of workers. Future studies will have to focus on the equipment to prioritize worker radius of operation first. As for speed, driving the equipment under speed limit would not be a problem near entrance and start point but it must slow down or come to a full stop in all other areas. Because the speed values are significant in integer only, there needs to be a criteria for decimal points. Because speed is a very important figure in terms of safety by area, standard for driving under speed limit, driving slowly, and temporary stop will be defined as the following. Driving under speed limit is defined as 1.00 to 1.30, driving slowly as 1.30 and 2.30, and temporary stop as 2.30 or higher. Next, SPSS analysis was performed to compare expected proper speeds of autonomous equipment in radius of operation of workers and other equipment. Table 3 illustrates the result of analysis. The mean value of proper speed for autonomous driving equipment in the radius of operation of workers was 3.24km/h and that in the radius of operation of equipment was 7.7km/m. These numbers were the resulting figures after informing the respondents that speed limit in areas with no risk factors is 30km/h. It was evident that architectural engineers agreed that autonomous driving robot must slow down when passing through radius of operation of workers and other equipment.

Table 3:.Analysis on Equipment Speed by Hazard Area

Typeofarea	N	Mean	Std. Deviation	Std. Error Mean
Path way of Labors	17	3.24	7.28	1.76
Path way of Equipment	37	7.70	11.16	1.83

Next, t-test was performed on hypothesis 1 on the two situations above (speeds).

- H_1 : There is no difference between proper speeds when passing through workers and equipment.
- H_2 :There is a difference between proper speeds when passing through workers and equipment.

As shown in Table 4, t-values were -1.50 and -1.75, respectively, p-value of 0.037, confidence level at 95%. We can reject H_1.

Table 4:.Analysis on H_1

		Driving speed	
		Equal variances assumed	Equal variances not assumed
F		4.57	
Sig.		0.04	
t		-1.50	-1.75
df		52.00	45.59
Sig.(2-tailed)		0.14	0.09
Mean Difference		-4.46	-4.46
Std. Error Difference		2.97	2.55
95% Confidence Interval of the Difference	Lower	-10.41	-9.60
	Upper	1.48	0.66

When investigated different proper speeds at different areas in a construction site, it was determined that, on average, 4.84km/h was proper for sloped terrain and terrain with other such risks, and 0.63km/h and 10km/h when passing through radius of operation of workers and other equipment, respectively. Table 4 illustrates the result of analysis on H2.

Table 5:.Analysis on Speed by Area

		X	Y	Z	TOTAL
N		31	8	15	54
MEAN		4.84	0.63	10	5.65
Std. Deviation		50.8	1.77	12.68	8.19
Std. Error		0.91	0.63	3.27	1.11
95% Confidence Interval for Mean	Lower bound	2.98	-0.86	2.98	3.41
	Upper bound	6.7	2.1	17.02	7.88
Minimum		0	0	0	0
Maximum		30	5	30	30

(X: Sloped terrain, Y: Worker radius of operation, Z: Equipment radius of operation)

Lastly, ANAVA was performed on H_2, regarding the difference in speed by area for autonomous driving equipment.

- H_1 :There is no difference among proper speeds when passing through sloped terrain, worker radius of operation, and equipment radius of operation.
- H_2 :There are differences among proper speeds when passing through sloped terrain, worker radius of operation, and equipment radius of operation.

As shown in Table 5, F-value was 4.24 with p-value 0.02, confidence level at 95%. We can reject H_1. Table 6 is the result of SPSS analysis on H_2.

Table 6:.Analysis on H_2

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	506.245	2	253.12	4.24	0.02
Within Groups	3046.07	51	59.73	-	-
Total	3552.32	53	-	-	-

From the results of testing both hypotheses, it was concluded that the speed of autonomous driving equipment in earthwork environment must be established differently in different areas.

Next, the survey was conducted on type of accidents that may be caused by autonomous driving equipment in earthwork environment. Table 7 illustrates the result. Type of potential accidents were categorized into accident by negligence, accident due to lack of preparation, and accident due to unexpected event. The values (n) of accidents are the figures indicated in the survey answers.

Table 7:.Type of Accidents that May be Caused by Autonomous Driving Equipment

Category	Accident(n)	Risk Level	
Accident by negligence	Collision with worker (46)	3.76	3.52
	Collision b/n equipment (50)	3.36	
	Overturned (5)	3.00	
Accident due to lack of preparation	Accident due to work route (9)	4.11	3.81
	Accident due to equipment radius of operation (4)	4.50	
	Accident due to lack of organization (14)	3.43	
Accident due to unexpected event	Work delay due to unexpected event (12)	3.92	3.47
	Accident by environmental factor (6)	2.67	
	Collision with unidentified object (1)	3.00	

Similar to Table 2, Table 7 contains mean values of accident frequency and risk level of accidents, based on surveyee answers. There was no significant difference among the mean values by accident category, 3.52, 3.81, and 3.47, but the mean values of their subcategories do vary significantly. When interpreted the resulting values, it was determined that the risk level of accident due to equipment radius of operation was the highest at 4.50.

Based on the findings, SPSS analysis was performed on accidents cause by autonomous driving equipment by categorizing the accidents into harm to worker and harm to equipment. Table 8 illustrates the result of SPSS analysis on the basis of rating scale from 1 to 5. The result disclosed that the mean value of risk level for accident against worker was 3.93 and 3.15 against equipment. Accidents against worker had higher risk level, but the difference was not significant. Based on this finding, the weight of information gathering on workers and equipment in future studies should be equivalent to one another.

Table 8:.Analysis by Accident Type

Typeofaccidents	N	Mean	Std. Deviation	Std. Error Mean
Labor Accident	44	3.93	1.28	0.19
Equipment Accident	52	3.15	1.16	0.16

Based on the result, it is clear that the autonomous driving equipment must collect worker location information first. However, the risk level of accident in equipment radius of operation was the highest, indicating that equipment location information is also another vital piece of information.

When applied the result in Figure 1, the result in Figure 2 can be expected.

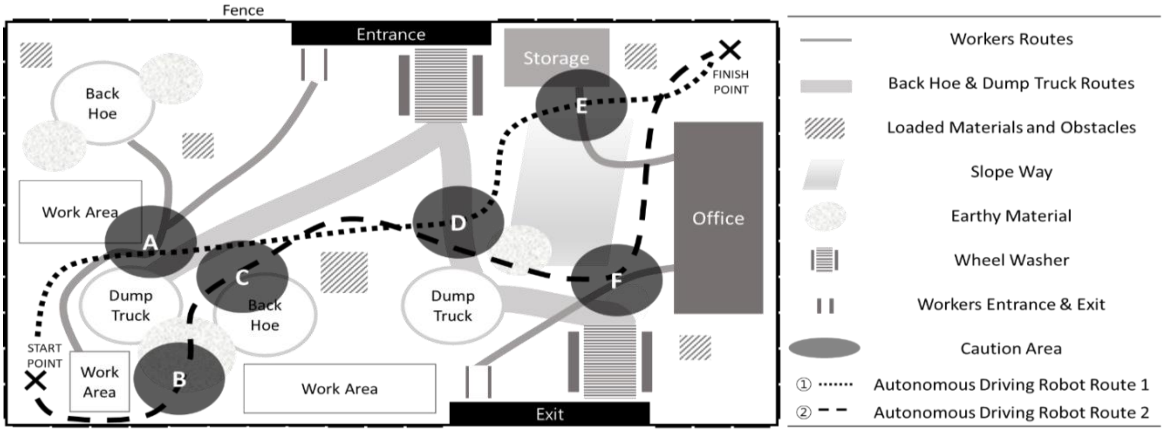

Figure 2:.Example of Autonomous Driving Equipment Route

Even in a same situation, the routes of an autonomous driving equipment may vary, and therefore, there are 2 different routes, 1 and 2. For 1, the following measures must be taken in areas A, B, C and D. Area A is a hazard area with worker route and dump truck radius of operation. Survey result disclosed that the risk level in worker routes was the highest at 4.38, and it was determined that temporary stops, 2.59, must be enforced in those areas. In addition, because the risk level of 'accident due to equipment radius of operation' was very high at 4.50, an autonomous driving equipment passing through this area must temporarily come to a stop and proceed with extreme caution. Area D is a dump truck route and may also be regarded as an equipment route. Risk level on equipment route was 3.38, which is somewhat higher than the median value 3. The measure to be taken by autonomous driving equipment in this area is 2.19, drive slowly. Accidents that may occur in area D include collision between equipment. Its risk level is very low at 0.36. Therefore, autonomous driving equipment must drive slowly when passing through area D but does not require extreme caution. If analyzed areas B, C, E and F in the same way, the measures to be taken by autonomous driving equipment in development can be sufficiently investigated.

The results of this study are as follows: (1) through expert surveys, we obtained information on hazard areas in earthwork environment by which autonomous driving equipment must recognize. The risk level was the highest within worker radius of operation. It was also disclosed that equipment must drive slowly or come to a full stop in all areas other than entrance and start point. Survey result was arranged by categorizing accident types into accident due to negligence, accident due to lack of preparation, and accident due to unexpected event. Although there was no significant differences among the categories, but their subcategories did have significant differences. Next, accident against worker and equipment were categorized and SPSS analyzed. There was no significant difference in risk levels between the two categories. Next, SPSS analysis was performed on equipment speed in worker and equipment radius of operation. The result disclosed that autonomous driving equipment must drive at 3.24km/h and 7.70km/h in worker radius of operation and equipment radius of operation, respectively. It was disclosed that average speed on sloped terrain and in worker and equipment radius of operation were 4.84km/h, 0.63km/h and 10.00km/h, respectively.

Through this study, sufficient data have been collected for development of autonomous driving equipment applicable in earthwork environment. However, to apply autonomous driving technology in earthwork environment, more studies are needed on hazard recognition methods by autonomous driving equipment in hazard areas.

6. Conclusion

This study focused on types of information needed for autonomous driving in earthwork environment, prior to the development of autonomous driving equipment applicable in earthwork environment. Experts in the field of construction were surveyed. The result disclosed that worker radius of operation was the most dangerous area, and that the equipment must come to a full stop before passing through worker radius of operation and worker route. Also, it was verified that different speed limits must be applied in different areas of earthwork site.

It was determined that accident type with highest probability of occurrence was autonomous driving equipment colliding with a worker. The analysis on hazard area and accident types disclosed that collision with worker was the most frequent accident type during earthwork. However, when categorized accident type by accident against worker and accident against equipment, there was no significant difference. By the way there is a difference between proper speeds when passing through workers and equipment.

It is anticipated that the results of this study will be served as cornerstone in development of autonomous driving equipment in earthwork environment. Utilization of big data in construction sites also looks promising as well. However, further studies are necessary on how to input relevant information in equipment and preparing for standards for tested accident categories.

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