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Viability Analysis of Innovative Surface Stripe Removal System

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Abstract

Colored markings on surfaces travelled by cars, trucks and even airplanes not only provide visual guidance to the operator but also leave space for emergency vehicles. The marked road stripes on the roads should be timely or suddenly repainted in accordance with road maintenance, reconstruction, and other environmental situations. When the road surface marking are removed and remarked, the road surface are commonly damaged and aged by the mechanical or heating. This paper presents an alternative technology for removing the stripes, which promises not only to speed up but also improve the safety of the process. After a review of current methods, the results of the designing and testing a semi-automated operation that employs CO_2 will be discussed. Finally, the data collected during field testing the prototype is used to assess its economic viability based on a comparative cost analysis.

Keywords: *CO_2 blaster, road stripe removal, construction automation, economic analysis*

1. Introduction

Automation systems and robots in construction have been utilized within the construction industry to improve of safety, productivity, quality, less noise and efficiency (Kim *et al.*, 2001). In addition, as buildings and civil structures today become more advanced, complicated and qualified, securing technically capable and skilled manpower to meet these needs is important for competitiveness. When considering these situations, the deterioration of construction productivity, sub-standard quality from a recent lack of skilled technicians and declining profitability from an increase in construction accident victims and labor costs, these are definitely problems that need to be solved in the domestic construction industry (Kim *et al.*, 2003).

One maintenance procedure, road stripe removal, has been under consistent pressure to change due to an increase of traffic and a need to repair deteriorated paint. However, there are dangerous elements in the wok, which directly exposes workers, and differences of productivity and quality are generated work process based on repeated manual labor (Kim *et al.*, 2006). In order to solve these problems, the process must change from conventional road stripe removal work, based on manual labor, to a new automated method.

Therefore, this paper presents a new process to substitute traditional methods as a procedure to develop new automation equipment to remove road stripes. In addition, this paper presents elements of the automation system to be applied with the new technology according to work process analysis using existing road stripe removal equipment and perform an experiment in real conditions introducing an Infra Red (IR) sensor. Finally, this paper will perform an experiment on the factors influencing work efficiency upon the cost of a blaster based on a field experiment and automation system elements through sensitivity analysis compared to traditional method operating costs.

2. Current Technology

2.1 Traditional Methods

There are a number of methods available to remove road stripe marking. The methods include grit blasting, shot blasting, soda blasting, grinder with torch, and water jet equipment. The currently applied methods to remove road stripe in Korea are mainly those using grinder with torch. It is the most effective methods, and the only torch used to remove residual marking. In addition, water jet system introduced in improvement of road stripe removal work recently.

Team works the grinder with torch equipment. A team to remove road stripe consists of 5~6 workman, maximum 8 persons to perform task after restricting traffic. In addition, water jet method using super highly pressurized water developed recently

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Table 1. Removal Work Process Analysis

Major Process	Tasks		Impact Value	
			S*	P**
Work Preparation	Arrival at the site, inspection and trial running of machine, work scope order		L	L
	Arrangement of Safety Facilities	To arrange safety facilities around the road stripe to be removed for smooth passage of vehicles and protection of workers	H	L
Road Stripe Removal Cycle	Road Stripe Removal	To remove road stripe using grinder	H	M
	Cleaning Around Removed Road Stripes	To collect removed paint and damaged asphalt residue	H	M
	Residual Cleaning Using Torch	To remove small residual using torch	H	M
	Movement	To move to the next working area	L	L
Work Finishing	Site Arrangement	After road stripe removal, and load various wastes, safety facilities and equipment	L	L

* S : Aspect of Safety ** P : Aspect of Productivity *** L : Lower / M : Medium / H : High
**** Major process and tasks are quoted and modified from work process analysis of Han *et al.* (2004)

is sometimes applied (Han *et al.*, 2004). The water jet method automates many parts of the works so as to require less workers than the existing methods, and it is utilized as safe and eco-friendly equipment comparing to the grinder with torch method.

The existing methods to remove road markings consist of repeated procedures such as the arrangement of safety facilities, the removal of road markings using a grinder, the cleaning of the road surface, heating by flame using propane gas, and floor finishing. As workers in different places follow preceding workers and perform tasks concurrently, the work site becomes complicated.

In addition, the grinder needs to rest for an average of 40-80 minutes per day to prevent overheating and replace bearings. The grinder requires a bearing replacement time of 30-40 minutes and averages one bearing failure per day (Han *et al.*, 2006). The equipment rest time and part replacement time lead to work delays, and equipment failures may stop work. In summer, hot weather may melt asphalt so that road markings may not be fully cleaned, and result in an overload on the equipment. Because vehicles are passing through the lane next to the road stripes, workers are directly exposed to danger, and the dust. In addition, noise generated is harmful to worker health and results in complaints from the nearby residents.

Since using a torch also exposes the workers to traffic, it leads to safety issues and may obstruct the flow of vehicles. Moreover, during the heating of road markings and stripe removal with a brush, harmful elements such as carbon monoxide, hydrogen cyanide, and hydrogen chloride are generated, and the use of propane gas could cause a considerable accident.

An advanced method of using high pressure water jet equipment requires fewer workers than existing methods and uses only water, so it solves the problem of dust generated and minimizes elements harmful to the workers' health. It also increases safety by minimizing dangerous exposure of the workers through automation. However, there are some disadvantages. The equipment is not widely available, and requires a large-capacity water tank. It is also slow moving. In addition, residual water from the removal process wets the road surface, influencing the movement of vehicles, and can result in icy conditions in winter (Koo *et al.*, 2009).

2.2 Work Process Analysis

Based on descriptions of current methods, the target of removal work process for evaluation selects the methods of grinder and torch. It can be used on most asphalt surfaces and for all pavement-marking materials.

To investigate environmental considerations in the development of prototypes, it analyzed work processes through a survey of literature and interviews. Generally, road stripe removal can be divided into three processes including work preparation, the road stripe removal cycle, and finishing work. Major portions of the process include risks such as explosive danger, harmful dust generation, and health issues due to noise and gas. It suggests improvements can be made with the development of eco-friendly materials and prototypes as shown in Table 1, which analyzes the automatic process in terms of safety and productivity for each task.

Four of the sub-processes, including road stripe removal, cleaning around removed road stripe, residual cleaning using torch, could be improved.

First, the grinding method result in asphalt damage and reduces ride-quality for drivers. The introduction of blasting equipment using eco-friendly materials would improve this.

Second, since both dust and residue from the damaged asphalt are generated during road stripe removal work, the introduction of dust collecting and inhalation equipment is required.

Third, the finishing work of using a torch may result in environmental pollution. Dry ice can be substituted for cleaning equipment used to remove road stripes markings.

Fourth, as the equipment moves to the next working area along the road stripes, there exists the possibility of introducing a visual sensor (Kwon *et al.*, 2004).

It determined that road stripe removal, cleaning around the removed road stripes, and residual cleaning using a torch could be improved with the use of dry ice and the introduction of blaster equipment. In addition, the development of a prototype system for automation and a mechatronic system will reduce the number of sub-processes, and result in a reduction of labor and operation cost.

2.3 Comparatives of Test Analysis

The Department of Transportation (DOT) of New York performed tests using a grinder, a water blaster, a combination of a grinder and water blaster, and a high-pressure water blaster using sand. It concluded that sand blasting is the most effective method to remove all types of paints. In addition, it was found that the hydro and water blaster had an effect similar to the sand blaster, but these methods were largely influenced by the pattern of equipment and thickness of paint. It was also found that the grinder was able to quickly remove thin paint but resulted in residue and damage on the road surface. Oregon the Department of Transportation (ODOT) also performed a field test on road stripes on an asphalt pavement surface using the four types of equipment shown in the table below. The test results are shown in Table 2 (Haas, 2001).

ODOT made the following conclusions:

1) Soda blasting is slow but most cleanly removes road markings.
2) Scarifying with a spike and grinder removes road markings faster than other equipment, but damages the pavement.
3) The bobcat planer with a sharp blade is configured similarly to the scarifier with a spike and grinder, and can result in damage to the asphalt.

In performing similar tests in other DOT, the skills required to operate work are to remove requirement for each worker, depending on the rating, this could result in differences mentioned in Table 2.

Table 2. Evaluation of Removal Results

Tests	Removal Rate (m/min)		First Rate (%)		Removal Degree*	
	0.375 mm	0.75 mm	0.375 mm	0.75 mm	0.375 mm	0.75 mm
Soda blaster	0.26	0.10	100	100	1	1
Scarifier	3.11	4.58	95	95	2	3
Grinder	7.20	4.91	99	50	3	2
Bobcat Planer	13.42	4.45	75	100	3	4

*Removal degree: graduated ranges (1~5)

Many research organizations including DOT say that not only road strip removal work efficiency effects on the work method itself, but also it does effect on the experience and skill of labors. As a result, if road strip removal work only depends on human labor, it is hard to maintain steady workability. To solve this problem, induce of automation is required (Moon, 2009).

3. CO_2 Blaster and Fabrication of Prototype

3.1 Principle of CO_2 Blaster

Dry ice is created through a process to vaporize liquid carbon dioxide produced from pressurized gas with sudden expansion erupted from nozzle. It has also a property of sublimate from solid to gas at -78.5°C among atmosphere, absorb evaporation heat from neighborhood to fast reduce temperature, and leave no residue so as to be clean, and it is used as cooling material since it has large amount of evaporation heat per unit weight and does not wet different from ice.

In addition, when dry ice sublimates, pure gas is generated, this is carbon dioxide that occupies 0.03% of air. Since road stripe marking removal work is not progressed within closed space, there is no influence on the human body. Dry ice returns into the air and it is generated from natural carbon dioxide rather than producing new one (Park, 2001).

CO_2 blaster is the equipment that uses these principals of dry ice, so it is able to use in the appreciate works by spraying dry-ice pellet. CO_2 blaster has been widely used equipment to clean mold, fan, printing equipment, and etc. in advanced countries. As shown in Fig. 1, when looking into the mechanism of blasting and cleaning process to remove corrosion materials on the surface using dry ice pellets can be explained by blasting dry ice particles to impact the surface of object to be washed and cleaned.

In addition, from the physical aspect, when blasting dry ice pellets onto the surface of object, collided dry ice pellets expand more than 800 times and sublimate at the same time of collision due to combined impact energy distribution between the object surfaces and rapid thermal transfer (Park, 2001). During the course, sublimated dry ice promptly evaporates with no secondary waste except for removed corrosion so that it is easy to

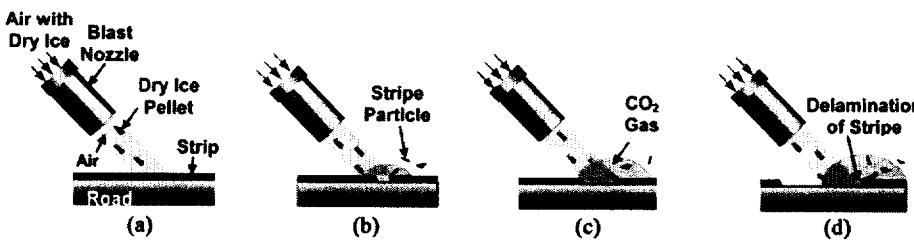

Fig. 1. Principle of CO_2 Blaster: (a) Pellets Shot at Stripe, (b) Pellets Fracking Paint, (c) Pellets Explode into Gas, (d) Thermal Shock Separates Stripe

handle with the second treatment of the residues (Moon, 2009).

3.2 Overview System

The current specifications of the Korea Highway Corporation is to minimize damage to the pavement surface during removal of road stripes, and cleaning of the work section after removal work must be performed. These regulations should be used as criteria when reviewing the feasibility of automated equipment during its development. Therefore, they should be considered specifications for the development of a prototype. The specification of the Ministry of Land, Transport and Maritime Affairs state road marking removal procedures as follows (Ministry of Land, Transport and Maritime Affairs, 2009):

1) Removal methods of road markings should be performed in accordance with design documents, and never apply black paint to remove existing road markings.
2) Removal of road markings should be performed in a manner, which minimizes damage to the pavement surface.
3) Any damage to the pavement surface generated by the removal of road markings should be immediately repaired at the expense of the contractor, and cleaning of the construction section after removing road markings should be performed by the contractor

Based on the reviewing specifications, there are five suggested prototypical parts: a blaster nozzle with holder, a residual filter, a containment box with sensor, wheels for mobility, a transmission system which includes a positioning table with a ball screw.

The width of the prototype was determined by the widths of road lines and roads. The front part was designed to not lean forward; it considered other structures such as a cantilever. For the base plate, lightweight aluminum was selected and formed into a plate 1,200 mm in length, 140 mm in height, and 15 mm in thickness. Casters with diameters of 170 mm were used. Fixed casters were used at the front and free-rolling casters were used at the rear because of the height of the base plate from the road surface. Air-filled tires were used on the casters for improved mobility on unpaved roads and shock absorption (Moon, 2009).

Fig. 2 shows the concept design and prototype fabrication, and Table 3 presents the specification of prototype.

Table 3. Specification of Prototype

Total Load(Nozzle Holder)		20(kg)
Screw	Diameter	20(mm)
	Stroke	800(mm)
	Pitch	20(mm/rev)
Speed of Table		Max. 0.25(m/s)
Motor	Size	85*85*70(mm)
	Rpm	Max. 750(rpm)
	Watt	50(w)
Control box size		30*25*25(cm)

3.3 CO_2 Blast Field Testing

Purpose of field test, which use the CO2 blaster, is analysis of economical effect to find out suitable (most effective) work angle and work place between strip surface and end of nozzle through the field testing.

The CO_2 blaster was applied on old road stripes and overlapped road stripes three times each. The condition was maintained the same: 6 to 10 Bar of pressure for 15 cm of road stripe. The distance to subjects was set to 5 cm or 10 cm and the injection angle was altered to find the best condition. Also, both round nozzles and wide nozzles were tested to determine which is better to use. The amount of pellets varied by the type of subject and surrounding environments, but the average amount consumed was 1 kg/min. To determine the use of fuel, the amount of fuel left after the test was measured. The results of field test indicate the appropriate influence factors for essential road stripe working. Table 4 presents test conditions to find out the best factors throughout the experiments.

3.4 Testing Results

The results present the working data of CO_2 blaster through the field test. From the test results, it found that when wide nozzle

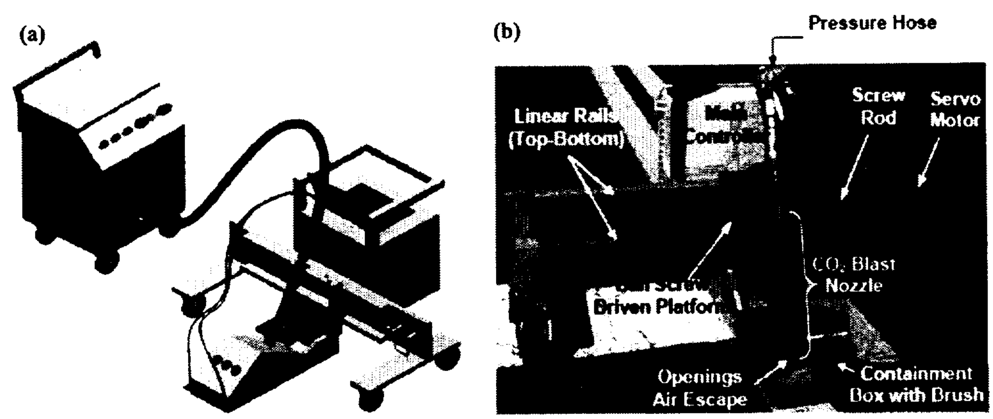

Fig. 2. Design of Automated Road Stripe Removal Prototype: (a) Conceptual Design Model, (b) Prototype Fabrication

Table 4. Test Condition

Test	Fixed value	Variable
Selection of nozzle type	Pressure : 8 bar Angle : 60 degree Distance : 10 cm	Nozzle type : - round nozzle - wide nozzle
Selection of angle	Nozzle type : wide nozzle Pressure : 8 bar Distance : 10 cm	Angle : - 30 / 60 / 90°
Selection of distance	Nozzle type : wide nozzle Pressure : 8 bar Angle : 60 degree	Distance : - 5 / 10 cm
Selection of pressure	Nozzle type : wide nozzle Angle : 60 degree Distance : 5 cm	Pressure : - 6 / 8 / 10 bar

was used, and the wide nozzle took less time than round nozzle (Fig. 3).

It was analyzed that the wide nozzle sprays to wider areas in the same amount of pellet sprayed in same times under same pressure. In addition, Fig. 4 shows on appropriate injection angle, which is 60 degree. When injection angle is 90 degree, the pellet is acted on small surface. In addition, the pellet is sprayed on large surface when injection angle is 30 degree. Therefore, the pellet should be sprayed more often because the ratio of work concentration is weak.

Also, it was analyzed that most optimal the distance between lines and blaster nozzle is 5 cm (Fig. 5). It was not effected on below 5 cm because of characteristics of wide nozzle. The pellet is sprayed on the wide area like injection angle above 5cm, and ratio of work concentration is low.

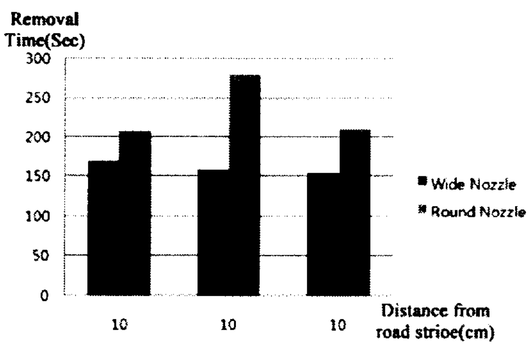

Fig. 3. Compare of Nozzle Types

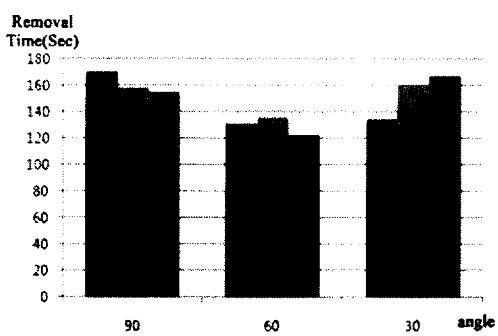

Fig. 4. Compare of Injection Angles

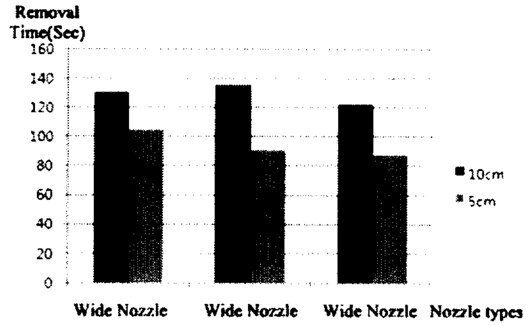

Fig. 5. Compare of Distance

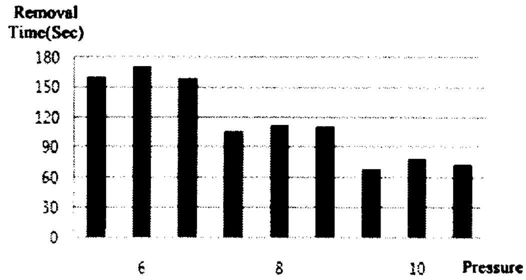

Fig. 6. Compare of Pressure

Injection pressure is faster when injection pressure is 10 bar. Moreover, times of work were decreasing like showing in the Fig. 6 when the pressure was increasing. Therefore, if the pressure is over this pressure, this result seems to correspond to the responses given by CO_2 blaster operators that higher pressure speeds up the removal process.

4. Cost Evaluation of New Technology

4.1 Cost Factors

From the results of field test, the gap between the road stripe to be removed and end of nozzle to spray dry ice pellet and an appropriate nozzle to increase the productivity of the removal of the road stripe could be determined. It is also determined that blaster pressure is the major factor related to the productivity to remove the road stripes. In addition, it is determined that a method to increase productivity is related to the cost of dry ice pellets and oil and the labor to be engaged in the work processes to remove the road stripe has influence on the cost of work. These factors correlate with each other as seen below in Fig. 7.

First, it is expected that development of automated road stripe removal equipment adopting a dry ice blaster will bring a reduction of labor costs. The number of workers engaged in the conventional road stripe removal work as mentioned above has been surveyed as 8 people, but it will be reduced to 3 people by using the dry ice blaster and automatic system.

Second, from an interview with a specialist, it is considered

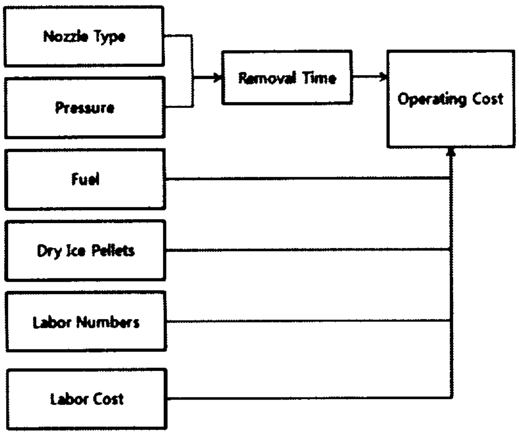

Fig. 7. Operating Cost Model

that the pellet cost for the dry ice blaster equipment depends on the amount of work and special storage space that is required for the work.

Third, the fuel cost depends on time period to use the blaster and expense of the work will vary depending upon changes in oil price.

As shown in Fig. 8 and result of tests, it is expected that the type of nozzle and pressure of the blaster directly affect the removal time, which in turn affects on the expense of the work. However, it is determined that the expense of the work will be influenced by the amount of dry ice pellets consumed, oil cost, number of workers and labor cost but it will be primarily related to the removal time.

4.2 Sensitivity Analysis for Operating Cost

As shown in Table 5, the relation between road stripe removal time and operating cost according to influence factors has been determined by identifying variables through prediction modeling. In addition, sensitivity analysis on cost has been performed with the variables and assumption.

It is known as an analysis required supporting effective decision making. This study intends to predict the direct relation of the expense of the work upon the assumed variables using the

Table 5. Assumption of Variables

Variables	Settings	Base of Setting
Fuel Price*	Yearly 6%	Applied with arithmetical mean of increase and decrease rates for 5 years
Dry Ice Pellets	450~900 (Won, Kg/min)	Interview specialists from dry ice blaster companies
Labor Cost**	- Special worker: 3% - Normal worker: 2.8%	Applied with arithmetical mean of unit labor costs for recent 3 years
Pressure	Until 16bar	The results of field test

* This data are quoted from Annual Energy Statics in Korea (2007)
** Construction Association of Korea (2008)

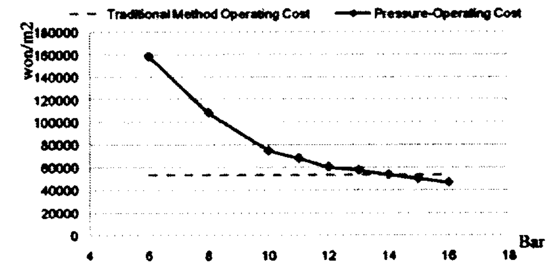

Fig. 8. Effect of Pressure

sensitivity analysis based on experiment results to increase work efficiency of dry ice blaster equipment to improve existing equipment on road stripe removal work.

According to literature review, traditional method operating cost are a large percentage of the overall operating cost, which averaged 53,713 (Won/m^2)[1]. Therefore, it is important to reduce the number of laborers for development of full scale equipment.

The results of field tests show that productivity, consumed fuel and dry ice pellet change upon change of blaster pressure. Fig. 8 shows that the pressure has a relation with removal time, which in turn has close relation with operating cost. Therefore, it would be possible to save operating costs according to performance of the blaster. In addition, if the pressure is over 14bar, it will reduce operating costs compare to traditional methods.

Second, Fig. 9 shows the operating cost change of dry ice pellets. The sensitivity analysis results presents that the cost of

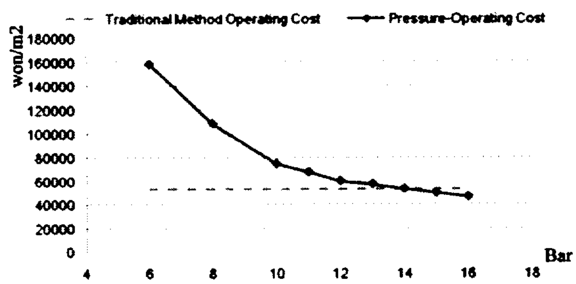

Fig. 9. Effect of Dry Ice Pellets Cost

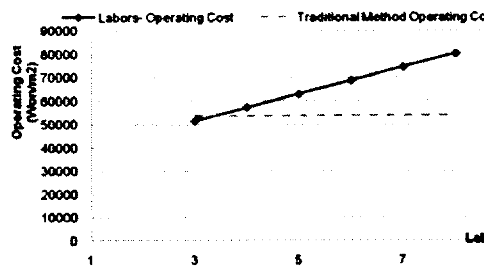

Fig. 10. Effect of Labor Cost

[1]This cost is quoted from work process analysis of Koo *et al.* (2009)

dry ice pellets makes big difference on operating cost. In addition, if dry ice pellets are under 600 Won, it will reduce operating cost compared with traditional methods.

Third, Fig. 10 shows operating cost of labor shown in minutes and displayed against the change of operating cost by assuming an annual increase of 3% for special labor and an annual increase of 2.8% for normal labor.

5. Conclusions

This study suggests the line removal methods using CO_2 blaster as a plan for improving existing line removal works. To accomplish the research goals, this study derives problems by analyzing existing works, researches characteristics of dry ice, suggests the prototype of automation equipment, and executes the field tests.

The purposes of field tests are to find out the best work condition of CO_2 blaster equipment and works on the economical validity for inducing equipments to the construction sites. The following results are come out from the study throughout field tests and sensitivity analysis of operation costs.

1) Wide nozzle type requires less working time than round nozzle type.
2) When executing works, the optimal injection angle of nozzle is 60 degree, and the optimal distance between line and nozzle is 5 cm.
3) If increasing injection pressure of CO_2 blaster, work time and operation cost can be saved.
4) If purchasing mass quantity of dry-ice pellets, work cost is decreasing, and when cost is set as below 600 won, it has more advantages than the traditional methods.
5) Labor costs required in the work can be saved than the traditional methods when maintaining 3 or 3 labors.

It was hard to prove the actual work affections by using the prototype equipment. However, if we consider that specification of CO_2 blaster used in the tests is pretty similar to the blaster equipment used in the final equipment, the research results are reasonable.

For the future study, re-examinations of optimal work condition and economic efficiency throughout development of the actual equipment are required.

Acknowledgements

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