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Development of the Performance Analysis Model Based on Research and Development Phases for Automated Construction Equipment

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Abstract: The automated construction machines have been recently developed to help solve the construction industry problems that significantly affect labour, productivity, quality, and profit. Despite the importance of performance analysis to commercialize the automated construction machines, previous studies have mainly concentrated on developing hardware and software of automated construction machines. This research now focuses on two objectives: (1) to propose an analysis model which can measure productivity, quality, and safety improvement rate of automated construction machines based on research and development (R&D); and (2) to develop a performance analysis system which will aid the evaluator in analysing the performance of automated construction machines. Finally, it is anticipated that the effective use of the performance analysis model and computerized system will ably develop the high-performance, automated construction machines and establish the marketing strategy to increase not only the commercial value but also the upkeep and development of construction machines.

Keywords: Automation, performance analysis, safety, quality

I. INTRODUCTION

A. Background and Purpose

Since 2000, South Korea's construction, civil engineering, and mechatronics experts have led the development of automated construction equipment through the sponsorship of the Ministry of Construction and Transportation. This development aims to solve problems in the local construction industry and to secure the industry's technological competitiveness. The developed automated construction equipment (ACE) has been tested and utilized at construction sites. However, the ACE led to few examples of actual commercialization despite the cost, time, and effort invested in the R&D of the equipment. The assumed reasons are as follows: (a) effective analysis of needs and potential economic feasibility, while taking marketability into consideration, failed to occur at the feasibility analysis phase of ACE; (b) continuous performance analysis did not take place at the ACE production phase, leading to the failure of developing high-performance ACE capable of satisfying what is required at construction sites; and (c) performance analysis linked to marketing strategy did not occur, thus hampering the successful commercialization and dissemination of the completed ACE.

The literature review reveals that there had been previous studies that addressed the efficiency of automated construction, based on performance analysis and comparison with other conventional equipment. However, studies revealed that the focus was only on measuring the degree of productivity and quality improvement and thus failed to perform the required systematic performance analysis in the process of ACE R&D. Moreover, the studies were found to describe the rate of safety and quality improvement (one of the principal reasons for developing ACE) from a qualitative standpoint only. As a result, a comprehensive value analysis of ACE development was not performed, which is a problem pointed out in the development of ACE.

This study was conducted to propose a comprehensive ACE performance analysis model by dividing the ACE R&D phases into feasibility analysis, ACE manufacturing, and commercialization/marketing, and by suggesting a performance analysis procedure and method to ensure an efficient ACE performance analysis required at each phase. In addition, the study aimed to help ACE-developing parties, who have no expert knowledge in performance analysis, to carry out the procedure with ease by developing a computerized system based on the proposed performance analysis model. This second purpose considers the fact that performance analysis requires a considerable amount of time, effort, and cost for ensuring expert knowledge in the field and for testing and evaluating the model. The use of the proposed performance analysis model and computerized system is expected to help analyse the feasibility of ACE development and invent its high-quality performance that can satisfy the requirements of construction sites. The said model and system are also expected to help

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establish an effective marketing strategy for the developed ACE that is linked to performance analysis, and to contribute to the commercialization and dissemination of the equipment.

B. Scope and Method

The literature review examines the current state of the ACE development and performance analysis. The importance of conducting a performance analysis specific to each R&D phase was later addressed to help ensure the efficient development of ACE and to raise the possibility of commercializing the equipment.

Similarly, a quantification measurement for the analysis of performance components was proposed. The productivity, safety, and the degree of quality improvement expected from the development, introduction, and use of the ACE were comprehensively measured and evaluated. Moreover, a performance analysis model linked to the economic feasibility analysis required at each of the ACE development phases was invented in the use of quantification measurement.

A performance analysis system in line with the ACE R&D phases was likewise established to allow the investors, researchers, private enterprises involved in the development of ACE, and end users to make the necessary decisions at each phase of ACE R&D more easily and systematically.

The efficacy of the proposed ACE performance analysis model was tested by applying the model to the locally developed automated pavement crack sealer (Ministry of Construction and Transportation, 2004).

II. CURRENT STATE OF ACE DEVELOPMENT AND PERFORMANCE ANALYSIS

A. Current State of ACE Development

Since the late 1980s, the Korea Institute of Construction Technology (KICT) has conducted research on the need for automated construction and on the selection of projects to which automated construction will be applied. The institute has also conducted studies on the semi-automation of vibrating rollers and tower cranes. More recently, a host of ACE have been studied and developed, including an automatic plastering machine for concrete, an automated bridge substructure inspection data collection system (an automated bridge maintenance equipment), an automated Hume pipe laying machine, a robotic pavement crack-sealing machine (an automated road maintenance machine), and an automated PHC pile head cutting and crushing machine(Kim, Young-Suk, 2006).

Presently, the development of ACE in the Korean construction industry may still lag behind the U.S. and Japan in terms of the amount of investment made in R&D or the number of ACE developed and/or commercialized. Nevertheless, the local industry has become increasingly keen on the need to study and develop ACE to improve the safety, productivity, profitability, and quality of local construction. In fact, a 2002 study (Kim, Jae-young) reported that efforts were being made to increase the R&D budget equivalent to 0.5% of the construction and transportation ministry budget (KRW 75.3 billion) in 2004 to 3% of the ministry budget (KRW 510 billion) by 2007. (The percentage and corresponding figure for 2005, 2006, and 2007 are 1% [KRW 151.9 billion], 2% [KRW 320 billion], and 3% [KRW 510 billion], respectively.)

The development of ACE technology, where the cutting-edge convergence technology is essential, does require an enormous amount of budget as well as collaboration among experts (i.e., from construction, architecture, civil engineering, mechanical engineering, electrical engineering, and electronic engineering). Given this scenario, the latest increase in the R&D budget of the Ministry of Construction and Transportation is expected to lay the groundwork for long-term synergistic effects in the construction industry. In addition, the Advanced Construction Technology Convergence (a new R&D project launched by the ministry in 2005) was found to be under way. The project combines the leading construction technologies with IT, NT, and other technologies to create a comprehensive next generation construction technology. Also, it concerns technology development in six areas, including state-of-the-art material and construction robots (www.kictep.re.kr). Investments in the R&D of ACE are expected to grow and reflect the steadily increasing interest in automated construction. This technical approach aims to solve the recent shortage of experienced workers at local and overseas construction sites and make the desperately needed transition for the local construction industry from the so-called 3D (i.e., “difficult, dangerous, and dirty”) industry to a state-of-the-art industry; improve its image accordingly; and secure its global competitiveness in the future (Kim, 2006).

B. Current State and Problems of ACE Performance Analysis

Table 1 summarizes the present researchers’ examination and analysis of previous studies on ACE development and performance analysis.

Problems with the previous ACE performance analysis are summarized below.

1) Lack of systematic performance analysis methods

The literature review has revealed that there were no systematic methods for analysing ACE performance established for ACE, either underdeveloped or already developed. Therefore, investors, researchers, and end users who lead the ACE development are faced with considerable difficulties in carrying out the ACE performance analysis because they lack not only the expertise but also the source information and systematic analysis methods.

TABLE I
DETAILS AND LIMITATIONS OF PREVIOUS STUDIES ON ACE PERFORMANCE ANALYSIS

Researcher	Title	Key Point	Limitation
Warszawski and Rosenfeld (1997)	Economic Analysis of Robots Employment in Building	• Conducted an economic feasibility analysis on four types of robots used inside the building	• The economic feasibility analysis model was intended only for the robots operated indoors. • The feasibility analysis was limited to the break-even point analysis. • No alternative was proposed to measure the rate of safety and quality improvement.
Kim et al. (1999)	Implementing an Automated Road Maintenance Machine (ARMM)	• Developed an automated road maintenance machine (ARMM) and conducted performance evaluation against the local environment • Developed a productivity measuring model for the ARMM.	• No linkage between productivity improvement and economic benefits was explored.
Rosenfeld and Shapira (1998)	Automation of Existing Tower Cranes: Economic and Technological Feasibility	• Installed a motion controller in the conventional tower crane model to achieve semi-automation. • Conducted technical and economic feasibility analyses • Performed analyses on benefit-cost, NPW, ROR, and break-even point.	• The adopted economic feasibility analysis processes are too complicated • The manual calculation technique used in the feasibility analysis requires a considerable amount of time and effort.
Navon (1995)	Conceptual Design of a Flooring Robot: Development Methodology and Results	• Proposed a design concept for developing a horizontal surface, autonomous multipurpose interior robot • A computerized graphic simulation was carried out based on the proposed design. • The degree of productivity improvement was estimated.	• Only the degree of productivity improvement was estimated in comparison with the conventional flooring method. • No analysis was performed on the foreseeable economic feasibility to be generated from developing the automated flooring machine.
Ham et al. (2005)	Development of Road Stripe-Removing Equipment Using High-Pressure Water Jet	• Developed a semi-automatic road stripe-removing equipment. • Measured the productivity of the developed automatic equipment via field testing.	• The comparison only led to suggesting improvements in productivity associated with the semi-automatic equipment. • Only the qualitative description (no quantitative description) was given of the safety and quality improvement.
Han et al. (2004)	Development of the Prototype for an Automated Stewart Platform Based Hume Concrete Pipe Laying Machine	• Developed a prototype for remotely controlled automated Hume pipe-laying equipment. • Measured productivity and produced data via various on- field tests. • Presented the degree of productivity improvement in quantifiable data.	• The researchers failed to establish a connection between productivity improvement and economic benefits. • No method for measuring the degree of safety and quality improvement was proposed.

2) Lack of performance analysis methodology specific to each R&D phase

Performance analysis conducted at the ACE development feasibility analysis phase bears significance because failure to accurately conduct the analysis will lead to the ACE development with either very little or no field applicability, commercialization possibility, or profitability. The significance of ACE performance analysis carries over into the manufacturing phase if the goal is to develop high-performance ACE capable of reflecting what is needed at the sites, as well as into the commercialization/marketing phase. Without an established business strategy (i.e., in line with the marketing strategy), the usability of ACE will be compromised, leading to an enormous waste of project budget. Therefore, it is imperative to develop a performance analysis methodology that is specific to each of the ACE R&D phases to perform a relevant analysis.

3) Lack of measures for quantifying safety and quality improvement

Previous analyses of ACE performance only offered the qualitative description of increases in the expected construction safety and quality from introducing ACE.

Failure to link the assumed improvement in these areas to economic benefits led to an inadequate assessment of economic value, supposedly enjoyed by end users who might introduce and use ACE. In fact, the inadequate assessment is assumed to bring about the devaluation of ACE with an otherwise outstanding performance capability and to lower the equipment's commercialization possibility. It is therefore necessary to develop a comprehensive performance analysis that allows benefits to come from increased productivity which can be considered from an economic point of view. The improvement in construction safety and quality can be quantified and offered as effective source materials to individuals involved in ACE development.

4) Lack of performance analysis models linked to marketing strategy

In order for the ACE to be marketable among prospective customers, it is essential to establish a marketing strategy that is in line with the proposed performance analysis model and that analyses the ACE economic value for various types of end users. However, there is currently no such model available. As a result, the likelihood of commercializing and using high-performance ACE in construction sites may have decreased.

5) Lack of ACE performance analysis systems

According to the review, previous analyses of ACE performance were conducted manually by experts who require a considerable amount of time, effort, and cost. Moreover, conducting performance analysis under a single set of conditions or assumptions could lead to inaccurate results, as ACE varies in shape and features depending on the work type, process, and operation. Therefore, it is imperative to develop a performance analysis system that allows more flexibility for the researchers/developers, and end users of ACE in that they can change the parameters and assumptions to best reflect their situations while conducting the analysis. With such a system in place, the researchers/developers and end users will be able to carry out the analysis promptly and accurately.

C. Importance of Performance Analysis in Line with ACE R&D Phases

As mentioned earlier, R&D should be carried out on ACE where the development feasibility has been ensured through analysis. As regards the ACE manufacturing phase, the performance level analyses required at each construction site should be conducted. Afterwards, ACE with substandard performance should be modified and their defects be compensated to ensure high performance. Moreover, upon the completion of development, the performance of ACE should be compared with that of the conventional methods. A performance analysis should also be implemented in relation to the economic value to be enjoyed by the constructors provided they adopted ACE. These procedures would help commercialize the developed ACE and help spread or disseminate them with success.

In the development feasibility analysis phase, the researchers/developers and investors of ACE get to decide whether to proceed with R&D or investment on ACE, based on the results of potential performance analysis (see Figure 1). In the manufacturing phase and based on the field testing results, the researchers/developers will conduct a performance analysis on the ACE under development to ensure that the ACE will have outstanding performance capabilities.

Lastly, in the commercialization/marketing phase, the private enterprises will carry out ACE performance analysis targeting end users to establish effective marketing strategy after having completed the technology transfer from the researchers/developers. In sum, by carefully analysing the performance of the developed ACE at each of the R&D phases (i.e., development feasibility analysis, manufacturing, and commercialization/marketing), the interested parties could prevent or minimize the wastage of R&D funds and efforts as a result of inventing ACE with low development feasibility. Such precaution will likely play a crucial role in improving the performance of ACE under development and in ensuring its successful commercialization.

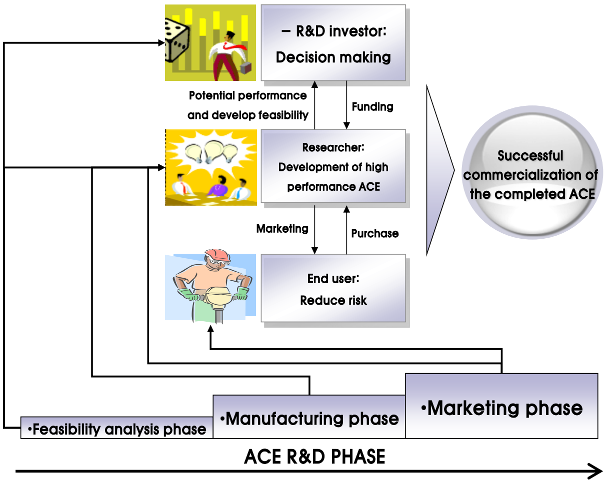

FIGURE I
SIGNIFICANCE OF ACE PERFORMANCE ANALYSIS SPECIFIC TO 'R&D PHASE.

III. DEVELOPMENT OF PERFORMANCE ANALYSIS MODEL SPECIFIC TO EACH PHASE OF ACE R&D

A. Selecting the Target of ACE Performance Analysis

1) Target of performance analysis at the development feasibility analysis phase

At this phase, the interested parties can figure out the approximate number of workers and equipment/machines to be deployed. This can be done by defining the function of the ACE to be developed and by using the conceptual and detailed design information. At this point, however, they cannot measure the degree of safety and quality improvement in quantitative terms or incorporate the quantitative data into the economic feasibility analysis because the lab and field tests on the prototype have yet to be conducted. Therefore, in the feasibility analysis phase, the interested parties may incorporate ACE productivity data into the conventional methodology, calculate approximate costs of labour and equipment to be invested, and carry out an economic feasibility analysis based on the estimates while taking into account the annual benefits and expenses to be accrued. Afterwards, the interested parties may utilize the results of the economic feasibility analysis (e.g., benefit-to-cost ratio, net present worth, rate-of-return, and break-even-point analyses) to decide whether to carry on with ACE development. In addition, the interested parties may conduct a sensitivity analysis, as the development feasibility analysis phase also requires the establishment of various assumptions and parameters for the purpose of economic feasibility analysis. The sensitivity analysis will help ensure the effective performance analysis on ACE development.

2) Target of performance analysis at the manufacturing and commercialization/marketing phases

At these phases, the productivity and safety of ACE and the degree of quality improvement can be analysed through the results of field testing conducted on the prototype. Given that, analysing benefits generated from the increased productivity and the resulting reduction in work period and labour and equipment costs to be invested is also possible at these phases. Meanwhile, the quantified rate of safety and quality improvement may be incorporated into the economic feasibility analysis as deemed necessary by each party involved. The users may otherwise choose to calculate the decreased rate of accidents and rate of quality improvement in comparison with the conventional methods and use the data to analyse the presumed effects of ACE development. Note that the performance analyses at the manufacturing as well as the commercialization/marketing phases have different parameters but have the same target for analysis. Therefore, in this study, the performance analysis of ACE was divided into the manufacturing phase and the commercialization/marketing phase. The interested parties may look into the economic feasibility analysis data derived from the manufacturing and commercialization/marketing phases. These phases may be used to ensure the development of high-performance ACE and the effective commercialization of the equipment once they are completed (see Figure 2).

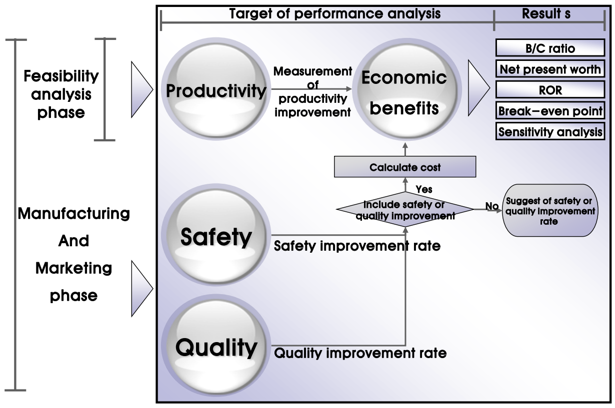

FIGURE II
SIGNIFICANCE OF ACE PERFORMANCE ANALYSIS SPECIFIC TO 'R&D PHASE.

B. Quantification Measures for Performance Analysis Components

1) Quantification measures for economic benefits to be generated from higher productivity

The development of high-performance ACE promises higher productivity compared with the conventional method of construction. The use of automated equipment will likely reduce the time spent in executing the same amount of work. Verification is required from the economic benefits coming from such increased productivity. First, the number of days worked in each year (NDWY) must be calculated for the conventional method of construction and for automated construction. As regards the NDWY with the conventional method, one may take into account the statistics for average yearly work days compiled by professional constructors taking on the work. The amount of construction work carried out each year (AWCY) with the conventional method is obtained by multiplying the daily productivity (conventional method) by the NDWY (conventional method). On the other hand, the NDWY, which has an automated construction required to execute the same amount of construction work as the conventional method, can be obtained by dividing the AWCY (conventional method) by daily productivity (automated construction).

In the case where automated construction did bring about the expected improvement in performance, a decrease in the number of equipment and workers needed to do the same amount of work would normally happen with the use of ACE. A decrease in the NDWY as well as the resulting drop in the number of equipment and workers needed each year is likewise anticipated. Therefore, using ACE would save on annual costs of equipment and labour. Note that reducing the amount of wasted materials is one of the goals for developing ACE; however, the amount of waste varies with the work method and proficiency of each worker. Thus, measuring the amount of waste and converting it into costs was carefully determined not to compromise the reliability of the results of economic feasibility analysis. In this study, therefore, the impact of material costs was left out while conducting the economic feasibility analysis.

With the conventional method of construction, the annual costs of equipment and labour can be obtained by multiplying the NDWY by the sum of daily cost of equipment and daily cost of labour. By the same principle, the annual costs of equipment and labour with automated construction can be obtained by multiplying the NDWY (automated construction) by the sum of daily cost of equipment and daily cost of labour (automated construction). The difference between the sum of annual costs of equipment and labour using conventional method and the sum of annual costs of equipment and labour using automated construction accounts for the annual benefits accrued from introducing ACE. Table 2 summarizes the procedure for obtaining the accrued annual benefits.

TABLE II
ANNUAL CONSTRUCTION COSTS OF CONVENTIONAL METHOD VS. AUTOMATED CONSTRUCTION

Conventional Method (X number of days worked yearly)			Automated Construction (Y number of days worked yearly)		
Category	Construction cost to be invested each day (in Korean Won)	Construction cost to be invested each year (in Korean Won)	Category	Construction cost to be invested each day (in Korean Won)	Construction cost to be invested each year (in Korean Won)
Equipment cost	A	A × X	Equipment cost	B	B × Y
Labor cost	C	C × X	Labor cost	D	D × Y
Total	A + C	(A + C) × X	Total	B + D	(B + D) × Y
Annual benefits to be accrued from ACE introduction = (A + C) × X - (B + D) × Y					

2) Quantification measures for safety improvement

The question behind measuring the safety improvement was determined considering a comparison between the conventional method and the proposed automated construction. How long have the workers been exposed to risks and how detrimental are the risks? In other words, by measuring and analysing, three things were considered: (a) if there were workers involved in a particular high-risk task; (b) what kinds of risks were included in that task; and (c) how long and in what hours that the workers, if any, were exposed to the risks. Through these considerations, the extent of risks involved in the conventional method and in automated construction can be measured. Table 3 summarizes the process in which the decreased rate of accidents owing to the use of ACE is quantified. Table 5 summarizes the formulas used to calculate the decreased rate of accidents due to the introduction of ACE, as compared with the conventional method.

TABLE III
QUALIFICATION MEASURES FOR SAFETY IMPROVEMENT

Quantification Procedure	Details
1. Divide the work into units according to the work process	● Divided conventional construction and automated construction each into units according to the work process to measure and assess safety improvement in quantitative terms.
2. Identify risk factors in each unit	● Identified all possible risk factors included in each unit work to quantify safety improvement resulting from the development and introduction of ACE.
3. Assess risk factors associated with conventional and automated construction	● The performance evaluator should indicate in either "Yes (1)" or "No (0)" the possibility of having risk factors in carrying out construction
4. Estimate the importance of risk factors included in each unit work by using the AHP	● The risk factors identified in each unit work have different impacts on accidents ● In this study, possible risk factors in each unit work were subjected to pair-wise comparison using the analytical hierarchy process (AHP). The importance (weight) of the influences those factors have on accidents was estimated.
5. Measure the time spent in executing the tasks included in each work unit	● Measured the time spent in executing each task included in work units according to either the conventional or automated construction method to quantify the expected safety improvement from introducing ACE.
6. Estimate the possibility of having accidents while executing each work unit (consider risk factors, importance [weight] and work time)	● Incorporated the influences of each risk factor on accident occurrence by multiplying the importance (weight) of risk factors by the presence-absence status of the risk factors within each work unit, according to the conventional or automated construction method (the "Multiplication Results"). ● Identified the possibility of accidents for each work unit which takes into account factors such as risk, weight of risk, and duration of exposure to risks by multiplying the Multiplication Results by the work time measured according to the conventional or automated method.
7. Compare the risk ratio of each work unit measured for conventional and automated construction	● Calculated the risk ratio of the accident occurrence possibility for each work unit by dividing it using ACE by the possibility of accident occurrence for each work unit using the conventional construction methods.
8. Estimate the weighted value between work units using the AHP	● The degree of risks that may occur in each work unit using ACE varies with work unit, thus the degree of risks may affect the risk ratio of automated construction compared to the conventional construction method. ● The degree of risks included in each work unit was subjected to pair-wise comparison using the AHP to calculate the weight of each work unit.
9. Calculate the risk ratio for each work unit (ACE) considering the weighted value	● Computed the risk ratio for each work unit which takes the weighted value into account by multiplying the risk ratio for each work unit using ACE by the weighted value obtained via the AHP.
10. Calculate the total risk ratio and the decreased rate of accidents (ACE)	● The total risk ratio for automated construction corresponds with the sum of risk ratio for each work unit using ACE which took the weighted value into account. ● The decreased rate of accidents expected from introducing automated construction corresponds with the value obtained by deducting the total risk ratio (ACE) from 100% (risk ratio for conventional method).

3) Quantification measures for quality improvement

The economic benefits expected to come from quality improvement that is assumed to result from introducing ACE can be measured by quantifying the effects of developing ACE. The literature review, however, revealed that measuring improvement in quality in the wake of ACE development had been carried out mostly in qualitative terms, similar with measuring improvement in safety. Therefore, in this study, a quantifying method was proposed so that users can enjoy economic benefits, which are expected to come from higher construction quality associated with developing and introducing ACE. The proposed method for quantifying quality improvement was designed such that it allows the performance evaluator to measure and evaluate the degree of improvement based on the results of on-site field testing of automated prototypes compared with the conventional method of construction. Table 4 summarizes the process in which the rate of quality improvement generated by using ACE can be quantified. Table 6 shows the measurement for quantifying improvement in quality, comparing ACE introduction with conventional construction.

TABLE IV
QUANTIFICATION MEASURES FOR QUALITY IMPROVEMENT

Quantification Procedure	Details
1. Divide the work process into units	● Divided the conventional method of construction and automated construction into units according to the work process.
2. Identify quality-affecting factors	● Identified all possible quality-affecting factors in each work unit.
3. Evaluate quality (conventional method vs. automated construction)	● The performance evaluator should rate the quality of construction executed either through conventional method or automated construction on a 5-point scale: (1) Extremely poor, (2) Poor, (3) Average, (4) Good, and (5) Excellent, according to the identified quality-affecting factors and based on the results of construction.
4. Compute the rate of quality improvement for each work unit	● By comparing and evaluating the conventional method and automated construction according to quality-affecting factors (or obtaining the sum of rating scores), the rate of quality improvement can be computed for a particular work unit and can be compared (conventional vs. automated). ● This is done by dividing the quality-affecting factor evaluation score for each work unit using ACE by the quality-affecting factor evaluation score using conventional construction.
5. Estimate the weighted value among work units using the AHP	● The quality of each unit that makes up the automated construction work varies in terms of its contribution to the whole quality of the construction. Therefore, the weighted value among work units must be calculated and considered. ● In this study, the degree of quality contribution by each work unit was subjected to pair-wise comparison using the AHP. Also, the weighted value of each work unit was estimated.
6. Calculate the quality improvement rate for unit work (consider weighted value)	● The quality improvement rate for work unit, which took the weighted value into account, is obtained by multiplying the quality improvement rate by the weighted value for each work unit.
7. Compute and compare the quality improvement rate (conventional method vs. automated construction)	● The sum of quality improvement rate for each work unit using ACE corresponds with the quality improvement rate for the construction using ACE, as opposed to the quality improvement rate for the construction using conventional method.

C. Development of Performance Analysis Model

1) Factors to be considered for performance analysis

The main issues with the ACE development feasibility analysis phase include assessing potential economic value to be obtained by investors (such as public agencies or the government and constructors in need of automated machines, via the development of ACE) and making decisions about whether to proceed with the development. As regards the researchers/developers of ACE, the main issue is to define and verify the basic functions of ACE so that the equipment can serve as automated machines with field applicability and commercialization possibility.

At the manufacturing and commercialization/marketing phases, the conceptual and detailed design of ACE, which were proposed at the development feasibility analysis phase, were used as the basic materials upon which the pilot type and prototype of the equipment are manufactured. Laboratory and field tests were conducted on the fabricated machines, and the results were used to measure with reasonable accuracy the production costs, the number of workers to be deployed, the number and type of equipment to be mobilized, the number of work hours, and the degree of safety and quality improvement. Due to the extent of tests performed, the results of economic feasibility analysis conducted at the manufacturing and commercialization/marketing phases will have a higher reliability than the results of economic feasibility analysis conducted at the development feasibility analysis phase.

To carry out a performance analysis of ACE to be developed at the feasibility analysis, manufacturing, and commercialization/marketing phases, assumptions and parameters must first be established, as shown in Table 7.

2) Development of economic feasibility analysis model

a. Benefit/cost ratio

The economic benefits achieved from introducing ACE at the development feasibility analysis phase include (a) saving on annual labour cost resulting from the reduction in the number of days worked each year (NDWY), brought by the reduction in the number of workers deployed and by the improvement in productivity; and (b) saving on annual equipment cost resulting from the reduction in the number of equipment mobilized. Additional costs to be accrued from introducing ACE and carrying out the construction with them include the inevitable cost of manufacturing and annual maintenance once the machines are operated. Since the development feasibility analysis phase covers up to the completion of the conceptual and detailed design of the developed machines, the performance evaluator has no way of knowing, at this point, the manufacturing and annual maintenance costs of the equipment that is under development. Thus, the lack of information makes it necessary for the evaluator to estimate the manufacturing cost within the project budget and to estimate and propose the annual maintenance cost by taking into account the amount spent in maintaining similar construction equipment.

TABLE V

A METHOD FOR ESTIMATING ACCIDENT RATE IN WORK USING ACE

Work	Risk Factors	Conventi-onal Method	Automated Construction	Weight of Risk Factors within Unit Work	Duration of Work (seconds/work)		Possibility of Accident Occurrence (considering risk factors, weight, and work time)		Risk Ratio of Each Unit Work Using ACE (compared to conventional method)	Weighted Value between Unit Works	Risk Ratio of Each Unit Work Using ACE (considering weighted value)
					Conven-tional	Automated	Conven-tional	Automated			
Unit work (UW) 1	Risk factor 1	A	B	C	D	E	$A\times C\times D$	$B\times C\times E$	$(G/F)\times 100$ (%)	H	$(G/F)\times H\times 100$ (%)
	Risk factor n										
	Sum						F	G			
Unit work (UW) n	Risk factor 1										
	Risk factor n										
	Sum										
Rate of accidents due to the use of ACE											$\sum((G/F)\times H\times 100$ (%))

TABLE VI

A METHOD FOR QUANTIFYING QUALITY IMPROVEMENT FROM USING ACE

Unit Work (UW)	Quality-affecting factors	Conventional method					Automated method					Quality improvement rate for unit work	Weighted value	Quality improvement rate (considering weighted value)
		1	2	3	4	5	1	2	3	4	5			
UW 1	Quality-affecting factors 1 - n											$(B/A)\times 100$(%)	C	$(B/A)\times C\times 100$(%)
	The number	a	b	c	d	e	f	g	h	i	j			
	Sum	1×a	2×b	3× c	4×d	5× e	1× f	2×g	3×h	4× i	5 × j			
	Total	A					B							
UW n	Quality-affecting factors 1 - n													
	The number													
	Sum													
	Total													
Rate of quality improvement due to the use of ACE													1	$\sum([B/A]\times C\times 100$ [%])

※ Note: 1 = Extremely poor; 2 = Poor; 3 = Average; 4 = Good; 5 = Excellent

TABLE VII

ASSUMPTIONS AND PARAMETERS FOR ECONOMIC FEASIBILITY ANALYSIS ON ACE

Assumptions and Parameters	Details
Productivity from conventional method	● The rate of time required for executing a particular amount of work ● The rate is computed via interviews with professional constructors and based on on-site work (actual measurement).
Productivity from automated construction	● At the feasibility analysis phase, the data on conventional productivity are used to predict the productivity of ACE. ● At the manufacturing and commercialization/marketing phases, the productivity of ACE is estimated via a number of lab and field tests.
The number of days worked each year (NDWY) using conventional method	● The annual amount of construction work is calculated by multiplying the NDWY by the conventional productivity. ● The NDWY using ACE is calculated by using the productivity (value) of ACE.
Costs of manufacturing ACE	● At the feasibility analysis phase, the estimated cost of manufacturing ACE is established within a range that gives competitive compared to the conventional construction method. ● At the manufacturing and commercialization/marketing phases, the cost of producing prototypes and commercialization models should be established.
Service life of ACE	● Normally, the service life of construction equipment/machines at the time of planning construction equipment development is about 10 years. The residual value of the equipment older than 10 years is estimated at 5% of the purchase price.
Costs of annual maintenance	● Suit the cost estimation to the R&D implementer's circumstances, by either indicating each yearly cost throughout the service life of ACE or applying a set rate used for similar equipment.
Interest	● At the development feasibility analysis phase, the development of ACE is a new program that poses higher risks to investors. Thus, MARR should be set at 25% to 30% ● At the manufacturing and commercialization/marketing phases, either MARR rate in the development feasibility analysis or the loan interest can be used to continuously check the reliability and validity of made on ACE development.

In this study, two methods for establishing the maintenance cost were proposed. The interested parties may choose either (a) the method in which the performance evaluator directly establishes the maintenance cost expected to be spent every year throughout the equipment's service life; or (b) the method in which the evaluator assumes that a certain percentage of the manufacturing cost will be spent on maintenance over a period of time.[1]

There are four economic benefits achieved from introducing ACE at either the manufacturing phase or the commercialization/marketing phase: (a) saving on annual labour cost due to the decrease in labour deployed; (b) saving on annual equipment cost owing to the reduction in equipment mobilized; (c) reduction in the amount of estimated annual accident costs resulting from a decrease in accident occurrences; and (d) reduction in the amount of annual rework cost due to the improved quality. On the other hand, the manufacturing cost and annual maintenance cost have become additional costs which result from introducing ACE. At the ACE manufacturing phase, the production cost can be estimated with reasonable accuracy by taking into account the prices of components that make up the prototype. At the commercialization/marketing phase, the production cost can be estimated based on commercialization models. However, calculating the exact amount of maintenance cost required throughout the service life of the equipment is impossible at this point, just as it was impossible during the development feasibility analysis phase. Therefore, a rough amount should be computed.

Note that while conducting the development feasibility analysis for ACE, the performance evaluator must stop the development if the benefit-cost ratio is found to be less than 1, provided the assumptions and parameters set for the feasibility analysis are at their optimal state.

b. Net present worth

At the ACE development feasibility analysis phase, the net present worth of developing ACE can be obtained by subtracting the present value of the amount spent on ACE manufacturing and annual maintenance from the present value of the benefits, accrued from a reduction in required labour and equipment. At the manufacturing and commercialization/marketing phases, the net present worth can be achieved by deducting the present value of the amount spent on ACE manufacturing and annual maintenance from the present value of the benefits accrued from decreased labour and equipment uses, the benefits accrued from a reduction in accidents, and the benefits accrued from decreased rework expenses as a result of improved quality.

c. Annual profit

The annual profit to be generated from using ACE throughout their service life ("n" years) can be calculated by subtracting the total annual construction cost, using automated construction, from the total annual construction cost, using the conventional construction method.

d. Rate of return

At the development feasibility analysis phase, the rate of return refers to interest(i) that makes "0" the difference between the present value of the benefits resulting from decreased labour and equipment costs and the present value of the costs arising from ACE development and annual maintenance. On the other hand, the rate of return at the manufacturing and commercialization/marketing phases corresponds with the interest that makes "0" the difference between the present value of the benefits (generated from decreased labour and equipment costs, reduced rates of accidents, and smaller rework costs due to improved quality) and the present value of the ACE manufacturing and annual maintenance costs. At whichever phase, the rate of return must be greater than the MARR expected by the constructor.

e. Break-even point

The break-even point analysis focuses on just how quickly the professional constructor adopting ACE can collect the purchase money and start creating profits provided the developed machine has performance capabilities at par with what is expected by the researchers/developers and investors. Results of the analysis can be used as basic data with which the interested parties can determine the validity of developing ACE.

f. Sensitivity analysis

At the development feasibility analysis phase, the only available information on the equipment under development is its conceptual and detailed design. At this point, there is no way of accurately figuring out the amount of manufacturing cost and annual maintenance cost, the decrease in the number of workers required, or the drop in the number of equipment mobilized. The results (values) of economic feasibility analysis conducted at the development feasibility analysis phase are affected significantly by the set assumptions and parameters. Therefore, a sensitivity analysis incorporating changes in the assumptions and parameters must be conducted at this phase.

Sensitivity analysis can also be carried out at the manufacturing and commercialization/marketing phases, on the set assumptions and parameters including the expected service life of ACE, the annual maintenance cost, and the MARR. The analysis conducted at this phase can effectively assist in the performance evaluator's decision making on ACE development, commercialization, and marketing.

Table 8 summarizes the reviewable economic feasibility analysis indexes at different phases.

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[1] Maintenance Costs of Similar Construction Equipment at the Planning, Development, and Feasibility Analysis Phases (Hyeon, Sang-heum, 2005); 5% of the manufacturing cost during 1 - n/2 years, and 10% of the manufacturing cost during n/2 - n years

TABLE VIII
ECONOMIC FEASIBILITY ANALYSIS INDEXES

Economic Feasibility Analysis Indexes	Formula	Remarks
PW of benefit	• Development feasibility analysis phase: Ⓐ (Benefits from the reduced costs of mobilized labor and equipment) × (P/A, i_m, n) • Manufacturing and commercialization/marketing phases: Ⓐ (Annual benefits accrued from the reduced costs of mobilized labor and equipment and the improved quality of safety and quality) × (P/A, i_{fw}, n)	• MARR = i_m • Analysis period = n • (P/A, i_m, n) = $[\{(1+ i_m)^n-1\}\div\{i_m\times(1+ i_m)^n\}]$: present value efficient, $i_{fw:}$ • Manufacturing phase: MARR = i_m, current interest rate considering inflations = i_f, •Commercialization/marketing phase: weighted average cost of capital[2] = WACC, current interest rate adjusting inflations into weighted average cost of capital = i_w,, service life of ACE = n
PW of cost	• Development feasibility analysis phase: Ⓑ (Manufacturing cost + annual maintenance cost) × (P/A, i_m, n) • Manufacturing and commercialization/marketing phases: Ⓑ (Manufacturing cost + annual maintenance cost) × (P/A, i_{fw}, n)	
① Benefit-cost ratio	Ⓐ/Ⓑ	B/C Ratio ≧ 1 (prerequisite for proceeding with development/investment)
② Net present worth	Ⓐ-Ⓑ	
③ Annual profit	Total annual construction cost (conventional method) - total annual construction cost (automated construction)	
④ Rate of return	Ⓐ-Ⓑ = 0	The i value that makes Ⓐ-Ⓑ "0"
⑤ Break-even point	Ⓑ = Ⓐ	The n value that satisfies the equation Ⓑ = Ⓐ
⑥ Sensitivity analysis	Changes in economic feasibility analysis indexes reflecting changes in assumptions and parameters	

Figure 3 illustrates the proposed ACE performance analysis model for this study. At the development feasibility analysis phase, savings on labour and equipment costs resulting from ACE development were used as benefit factors. At the manufacturing and commercialization/marketing phases, the reduction in rework costs due to decreased accident costs and improved quality was added to the benefit factors. On the other hand, the equipment manufacturing and annual maintenance costs were considered as cost factors in all phases. The performance analysis on ACE was conducted based on the cash flow chart, as shown in Figure 3.

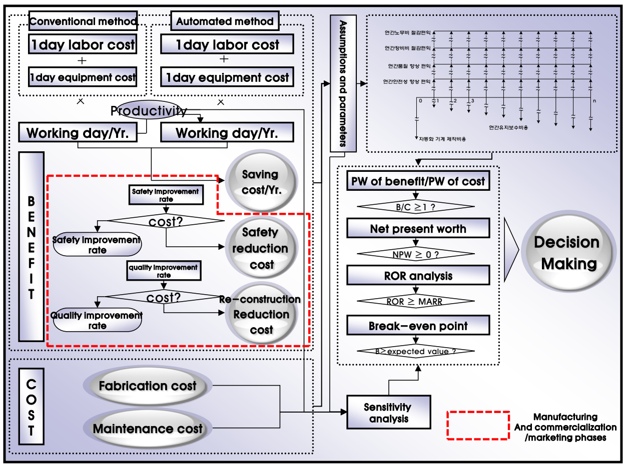

FIGURE III
ACE PERFORMANCE ANALYSIS MODEL.

IV. Establishment and Implementation of the ACE Performance Analysis System

A. Users of the Performance Analysis System

Users of the ACE performance analysis system include researchers/developers and investors of ACE, private enterprises receiving technology transfer, and professional constructors wanting to purchase and use ACE. At the development feasibility analysis phase, the researchers/developers will use the performance analysis system to examine the performance capability of ACE that is under review for development. When presented with the results of the examination, the investors will then review the validity of the established assumptions and parameters and analyse the results of economic feasibility analysis. Based on these data, the investors will determine whether to make an investment.

At the manufacturing phase, the researchers/developers of ACE are the principal users of the performance analysis system. By utilizing the system proposed for each key phase of ACE manufacturing, the researchers/developers should conduct continuous performance analysis to see if the underdeveloped or developed ACE can satisfy the sites' demands or satisfy the level of expectations harboured by the professional constructors, respectively.

At the commercialization/marketing phase, the researchers/developers may use the performance analysis system to quantitatively analyse the performance of the completed ACE. In addition, they may consider the potential marketability of the ACE to predict the sales potential of the equipment. They may even propose a model for profits generated by technology transfers for private enterprises. The proposed system can be utilized by private enterprises in determining whether to proceed with the manufacturing of ACE. It can also be used to

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[2] Weighted average cost of capital (WACC) is the weighted average against the loan interest rate imposed by financial institutions and the earnings from equity capital.
• WACC = (Borrowed capital costs × proportion ratio of borrowed capital) + (Equity capital costs × proportion ratio of equity capital)
□ Proportion ratio of borrowed capital = borrowed capital/(borrowed capital + equity capital)
□ Proportion ratio of equity capital = equity capital/(borrowed capital + equity capital)

establish a marketing strategy for professional constructors—the prospective customer. Professional constructors are thought to benefit from the performance analysis system when deciding to purchase ACE, by using the results (values) derived from the system.

B. Designing and Implementing the System User Interface

In this study, a performance analysis system was designed, taking into account the user interface, to enable the system user to carry out the performance analysis with ease, along with the ACE R&D phases. The parties leading the development of ACE may put the assumption and parameter data into the proposed performance analysis system in the sequence presented in the system to obtain various data relevant to the economic feasibility analysis.

1) Composition of the performance analysis system to ensure development feasibility analysis

The performance analysis system designed to carry out the economic feasibility analysis in the development feasibility analysis phase consists of five steps (see Figure 4):

Step 1. Basic assumptions and parameters are established to analyse potential performance capabilities of ACE.
Step 2. A user interface was designed to allow the analysis of labour cost using either conventional or automated construction.
Step 3. The user may estimate the cost of mobilized equipment for either the conventional or automated method.
Step 4. The annual cost of construction is compared (conventional vs. automated) and analysed.
Step 5. The performance analysis system allows the user to obtain the results of various economic feasibility analyses, based on the data entered into the system through Steps 1 to 4.

2) Composition of the performance analysis system at the manufacturing and commercialization/marketing phases

The performance analysis system devised in this study can be used at the manufacturing and commercialization/marketing phases of ACE R&D. The system is designed to operate in the following order:

(a) Enter the productivity information of ACE;
(b) Enter the unit work (task);
(c) Enter the safety-related parameters for safety improvement rate analysis;
(d) Enter the quality-related parameters for quality improvement rate analysis;
(e) Establish the assumptions and parameters for economic feasibility analysis;
(f) Analyse the daily labour cost for the conventional and automated methods, respectively;
(g) Analyse the daily equipment cost for the conventional and automated methods, respectively;
(h) Analyse the annual cost of construction for the conventional and automated methods, respectively; and
(i) Conduct an economic feasibility analysis based on the entered data (see Figure 5).

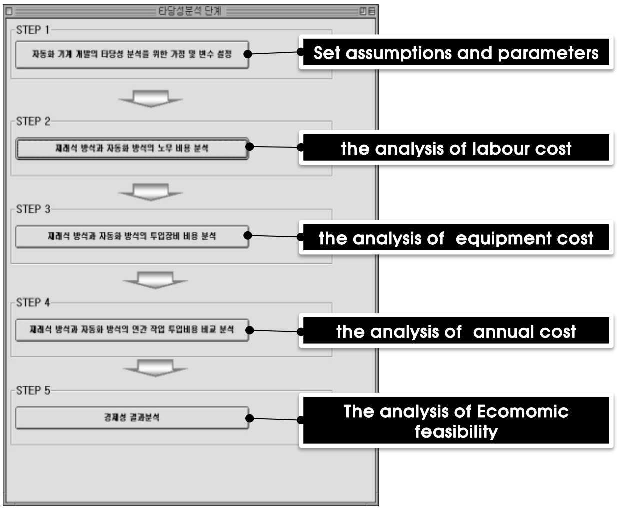


FIGURE IV
COMPOSITION OF THE PERFORMANCE ANALYSIS SYSTEM AT THE DEVELOPMENT FEASIBILITY ANALYSIS PHASE.

FIGURE V.
DESIGN OF THE PERFORMANCE ANALYSIS SYSTEM IN THE MANUFACTURING AND COMMERCIALIZATION/MARKETING PHASES.

C. Implementation of the Performance Analysis System

In this study, the performance analysis model was applied to the previously researched and developed robotic crack-sealing machine for automated pavement maintenance (Ministry of Construction and Transportation, 2004) as the target of the analysis. The efficacy of the model proposed to analyse the performance of ACE was tested.

1) Analysis of the safety improvement rate

While using the proposed ACE performance analysis system, the rate of safety improvement expected from using the automated pavement crack-sealing machine was measured and evaluated. To quantify the said rate, the present researchers of this study divided the work unit into smaller tasks (i.e., crack cutting, air blowing, sealant injection, squeezing, and curing according to the crack sealing process). Next, the researchers measured via site surveys, the time in seconds per meter as required to execute each of the said tasks using either the conventional or automated method and then entered the data into the system. Under both the conventional and automated methods, crack cutting and curing are carried out in the same manner. Thus, the time required for these tasks was the same regardless of the method used: 60 secs/min for crack cutting and 5 secs/min for curing.

Air blowing, sealant injecting, and squeezing are normally executed as separate tasks with the conventional method. However, they are performed simultaneously via a multipurpose manipulation device when using the automated crack sealing method. In this study, approximately 20 secs/ min was spent in doing all of the air blowing, sealant injecting, and squeezing. The researchers entered 10 secs/min for air blowing and another 10 secs/min for sealant injecting and squeezing. As regards the same tasks done in the conventional method, air blowing was measured to take 20 secs/min, and sealant injecting and squeezing 20 secs/min.

Brainstorming was used in this study to identify possible risk factors within each task and quantify the degree of safety improvement expected from introducing the robotic crack-sealing machine. The brainstorming led to the identification of risk factors first related to crack cutting: (a) injuries caused by the blade of grinder; (b) injuries from flying asphalt debris; and (c) car accidents from the traffic in the work area.

The risk factors for air blowing were identified as follows: (a) burns caused by using the heat transfer system; (b) injuries from flying asphalt debris; and (c) accidents from the traffic in the work area. The risk factors possibly associated with sealant injecting and squeezing included (a) burns from using the high-temperature sealant and (b) motor accidents from the traffic in the work area. As for the risk factors identified in curing, there was the risk of having accidents due to the traffic in the work area.

In using a total of nine risk factors identified from brainstorming, possible risks inherent in the conventional and automated crack sealing methods were evaluated, as shown in Figure 6. In addition, the importance (weight) of the risk factors in each task was rated using the AHP, as shown in Tables 9, 10, and 11, taking into account the influences of the risk factors of each task on the severity of accidents.

TABLE IX
WEIGHT OF RISK FACTORS FOUND IN CRACK CUTTING

Risk Factors	Grinder Blade	Asphalt Debris	Area Traffic	Total	Weighted Value
Grinder blade	1	1/2	1/3	0.5	0.16
Asphalt debris	2	1	1/2	0.9	0.3
Traffic in the area	3	2	1	1.6	0.54
Total	6	3.5	1.83	3	1

TABLE X
WEIGHT OF RISK FACTORS FOUND IN AIR BLOWING

Risk Factors	Heat Transfer System	Asphalt Debris	Traffic in the Area	Total	Weighted Value
Heat transfer system	1	1/2	1/4	0.4	0.14
Asphalt debris	2	1	1/3	0.7	0.24
Traffic in the area	4	3	1	1.9	0.62
Total	7	4.5	1.58	3	1

TABLE XI
WEIGHT OF RISK FACTORS FOUND IN SEALANT INJECTING AND SQUEEZING

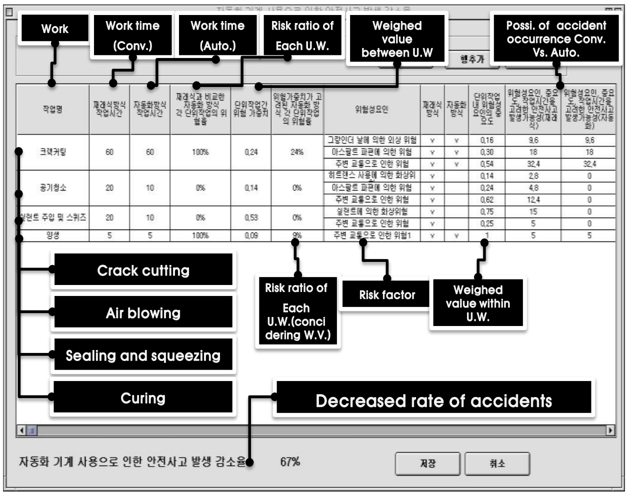
Risk Factors	Burns by Sealant	Traffic in the Area	Total	Weighted Value
Burns by sealant	1	3	1.5	0.75
Traffic in the area	1/3	1	0.5	0.25
Total	1.33	4	2	1

To compare the data between conventional and automated methods, the risk rate of each task using automated crack-sealing machines was computed. Data were compared with the conventional method using the likelihood of accidents during each task. Either conventional or automated crack sealing was adopted, taking into account the risk factors, weight value, and duration of work. The risk rates were 100% for crack cutting, 0% for air blowing, 0% for sealant injecting and squeezing, and 100% for curing (see Figure 6). Afterwards, the degree of risk in each task was subjected to pair-wise comparison using the AHP. The results were applied to compute the weighted value of each task: 0.24 for crack cutting, 0.14 for air blowing, 0.53 for sealant injecting and squeezing, and 0.09 for curing (see Table 12).

TABLE XII
WEIGHTED VALUE OF EACH TASK INCLUDED IN CRACK SEALING

Task	Crack Cutting	Air Blowing	Sealant Injecting and Squeezing	Curing	Total	Weighted Value
Crack cutting	1	2	1/3	3	1	0.24
Air blowing	1/2	1	1/4	2	0.6	0.14
Sealant injecting and squeezing	3	4	1	4	2.1	0.53
Curing	1/3	1/2	1/4	1	0.4	0.09
Total	4.83	7.5	1.83	10	4	1

In using the weighted value among tasks, the risk rate of each task due to the introduction of the automated crack sealer was calculated. As a result, the risk rate for crack cutting, air blowing, sealant injecting and squeezing, and curing was found to be 24%, 0%, 0%, and 9%, respectively, or 33% in total. Based on these numbers, the decreased rate of accidents associated with ACE introduction was found to be 67%.



자동화 기계 사용으로 인한 안전사고 발생 감소율

작업명	재래식방식 작업시간	자동화방식 작업시간	재래식과 비교한 자동화 방식 각 단위작업의 위험률	단위작업간 위험 가중치	위험가중치가 고려된 자동화 방식 각 단위작업의 위험률	위험성요인	재래식 방식	자동화 방식	단위작업 내 위험성 요인의 중요도	위험성요인, 중요도, 작업시간을 고려한 안전사고 발생가능성(재래식)	위험성요인, 중요도, 작업시간을 고려한 안전사고 발생가능성(자동화)
크랙커팅	60	60	100%	0,24	24%	그라인더 날에 의한 외상 위험	v	v	0,16	9,6	9,6
						아스팔트 파편에 의한 위험	v	v	0,30	18	18
						주변 교통으로 인한 위험	v	v	0,54	32,4	32,4
공기청소	20	10	0%	0,14	0%	히트랜스 사용에 의한 화상위	v		0,14	2,8	0
						아스팔트 파편에 의한 위험	v		0,24	4,8	0
						주변 교통으로 인한 위험	v		0,62	12,4	0
실런트 주입 및 스퀴즈	20	10	0%	0,53	0%	실런트에 의한 화상위험	v		0,75	15	0
						주변 교통으로 인한 위험	v		0,25	5	0
양생	5	5	100%	0,09	9%	주변 교통으로 인한 위험1	v	v	1	5	5

자동화 기계 사용으로 인한 안전사고 발생 감소율 67%

FIGURE VI
MEASURING THE DECREASED RATE OF ACCIDENTS
UNDER AUTOMATED CRACK SEALING

2) Analysis of the quality improvement rate

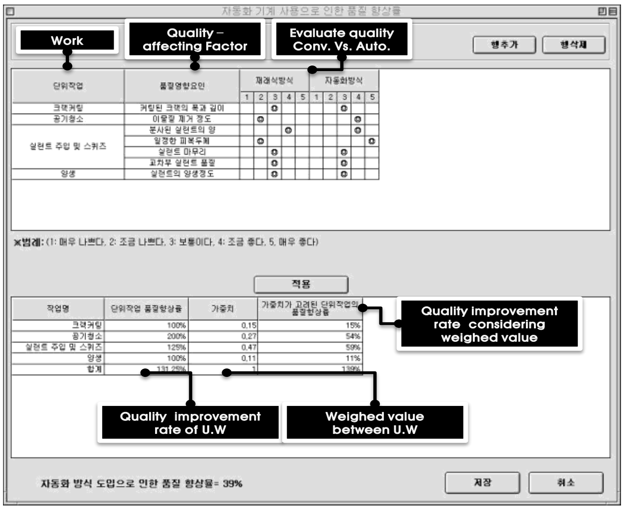
To compute the quality improvement rate associated with using the robotic crack-sealing machine, quality-affecting factors were first identified for each of the tasks included in crack sealing. These were the same tasks used in measuring the safety improvement rate. The factors affecting the quality of crack cutting were found to be the width and depth of the cut cracks. The factor affecting air blowing quality was the status of foreign matter removal. The factors affecting the quality of sealant injecting and squeezing included the amount of sprayed sealant, the consistency in coating thickness, the finish of sealant injecting, and the quality of sealant application at the corners. The curing quality-affecting factor was found to be the sealant's curing state.

Based on the seven factors found to affect the quality of the tasks and by using the results of field tests, the quality of crack sealing conducted in the conventional method and the automated method was rated on a 5-point scale, as illustrated in Figure 7. The data revealed that the rate of quality improvement in each task using the robotic crack sealer machine was 100% (crack cutting), 200% (air blowing), 125% (sealant injecting and squeezing), and 100% (curing). The quality improvement rate calculated for each task using either the conventional or automated method did not take into account the weighted value in quality between tasks. Thus, the AHP method was used to compute the weighted value of each task. The numbers were 0.15 for crack cutting, 0.27 for air blowing, 0.47 for sealant injecting and squeezing, and 0.11 for curing (see Table 13).

TABLE XIII
WEIGHTED VALUE OF QUALITY IN EACH TASK OF CRACK SEALING

Task	Crack Cutting	Air blowing	Sealant Injecting and Squeezing	Curing	Total	Weighted Value
Crack cutting	1	1/2	1/4	2	0.6	0.15
Air blowing	2	1	1/2	3	1.1	0.27
Sealant injecting and squeezing	4	2	1	3	1.9	0.47
Curing	1/2	1/3	1/3	1	0.4	0.11
Total	7.5	3.83	2.08	9	4	1

The quality improvement rate of each task using automated crack-sealing machines, which took into account the weighted value between tasks, was 15% (crack cutting), 54% (air blowing), 59% (sealant injecting and squeezing), and 11% (curing). The numbers suggest an approximately 39% increase in quality compared to the conventional method.



자동화 기계 사용으로 인한 품질 향상률

단위작업	품질영향요인	재래식방식 1	2	3	4	5	자동화방식 1	2	3	4	5
크랙커팅	커팅된 크랙의 폭과 깊이			●					●		
공기청소	이물질 제거 정도		●							●	
실런트 주입 및 스퀴즈	분사된 실런트의 양				●					●	
	일정한 피복두께		●								●
	실런트 마무리			●					●		
	교차부 실런트 품질			●					●		
양생	실런트의 양생정도			●					●		

※범례: (1: 매우 나쁘다, 2: 조금 나쁘다, 3: 보통이다, 4: 조금 좋다, 5. 매우 좋다)

작업명	단위작업 품질향상률	가중치	가중치가 고려된 단위작업의 품질향상률
크랙커팅	100%	0,15	15%
공기청소	200%	0,27	54%
실런트 주입 및 스퀴즈	125%	0,47	59%
양생	100%	0,11	11%
합계	131,25%	1	139%

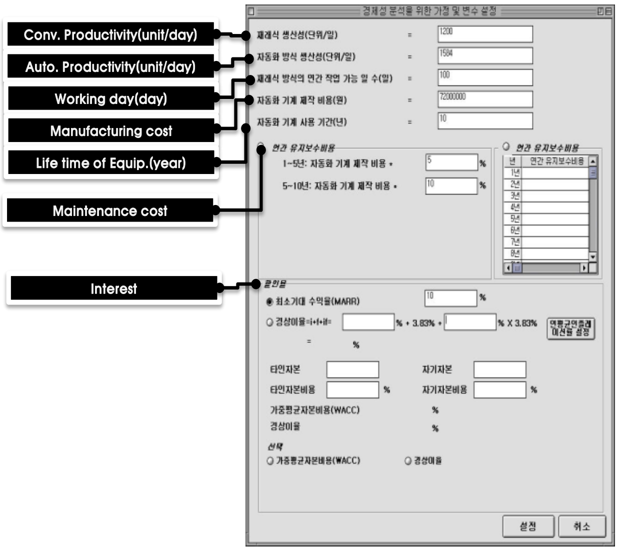
자동화 방식 도입으로 인한 품질 향상률= 39%

FIGURE VII.
MEASURING QUALITY IMPROVEMENT FROM INTRODUCING AUTOMATED
CRACK-SEALING MACHINES

3) Analysis of economic feasibility

a. Establishing basic assumptions and parameters

In this study, the basic assumptions and parameters illustrated in Figure 8 were established prior to conducting economic feasibility analysis using the degree of productivity improvement resulting from introducing robotic pavement crack-sealing machines. The economic feasibility analysis purposefully left out the degree of safety and quality improvement because, at present, there are no available data on the reduced costs of accidents (safety improvement-related parameter) or the reduced costs of rework (quality improvement-related parameter). These parameters will help quantify just how much improvement has been made with automated pavement crack sealing. For the purpose of the analysis, the productivity of conventional crack sealing and automated crack sealing was established at 1,200 meters/day and 1,584 meters/day, respectively, based on the results of site surveys and tests (Ministry of Construction and Transportation, 2004). The cost of manufacturing the prototype of robotic pavement crack-sealing machines was KRW 72,000,000. The service life and annual maintenance cost of the machines were established at the value that is normally applied to planning and developing construction equipment (i.e., 10 years as the service life; 5% of the manufacturing cost during the first year to five years and 10% of the manufacturing cost during the 6th through 10th year as the annual maintenance cost). These numbers were applied as parameters for the analysis. Site surveys revealed that the number of workable days each year for conventional crack sealing is 100. As for the interest, a MARR of 10% was set for the development feasibility analysis on robotic pavement crack-sealing machines, as professional construction entities require (see Figure 8).



재래식 생산성(단위/일) = 1200
자동화 방식 생산성(단위/일) = 1584
재래식 방식의 연간 작업 가능 일 수(일) = 100
자동화 기계 제작 비용(원) = 72000000
자동화 기계 사용 기간(년) = 10

○ 연간 유지보수비용
1~5년: 자동화 기계 제작 비용 * 5 %
5~10년: 자동화 기계 제작 비용 * 10 %

○ 연간 유지보수비용

년	연간 유지보수비용
1년	
2년	
3년	
4년	
5년	
6년	
7년	
8년	

할인율
● 최소기대 수익율(MARR) 10 %
○ 경상이율=i+f+if= % + 3.83% + % X 3.83%
= %
타인자본
자기자본
타인자본비용 %
자기자본비용 %
가중평균자본비용(WACC) %
경상이율 %
선택
○ 가중평균자본비용(WACC) ○ 경상이율

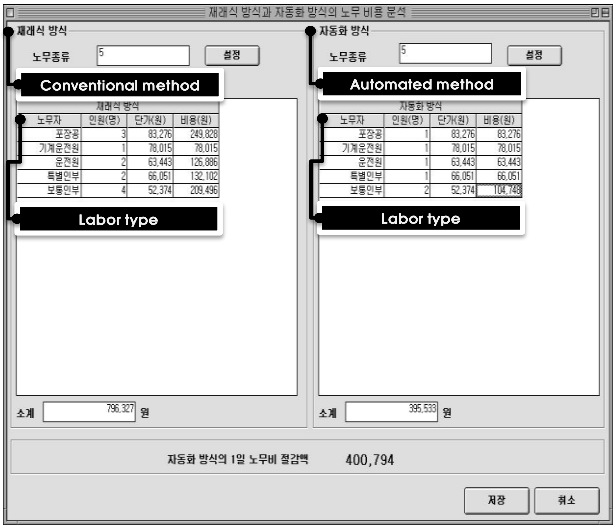
FIGURE VIII
ASSUMPTIONS AND PARAMETERS SET FOR ECONOMIC FEASIBILITY ANALYSIS ON AUTOMATED PAVEMENT CRACK SEALING.

b. Benefits analysis on reduced costs of labour and equipment

Based on the number and assignment of workers deployed for conventional and automated pavement crack sealing and the cost per day, the daily cost of labour was computed for conventional crack sealing and for robotic crack sealing (see Figure 9). Also, the daily labour savings due to the introduction of automated crack sealing were computed, resulting in KRW 400,794. In addition, the number and type of mobilized machines and the daily cost of lease for the two crack-sealing methods were examined and analysed (see Figure 10). In using these data, the daily savings on equipment owing to the introduction of automated crack sealing were computed (i.e., KRW 250,000).

c. Analysis of annual benefit accrued

Based on the results of productivity measurement via field tests, the productivity of conventional pavement crack sealing was found to be 1,200 meters/day, and the number for automated crack sealing 1,584 meters/day. The number of workable days each year was set at 100 during the phase of establishing assumptions and parameters. Suppose a crack-sealing company's annual amount of crack sealing performed via the conventional method is 120,000 meters (= 100 days × 1,200 meters/day). The same amount of work can be done in 76 days (=120,000 meters/day ÷ 1,584 meters/day) if the company chooses the robotic crack-sealing method. Based on the number of days worked each year (NDWY) for the conventional method (100) and for the automated method (76) as well as the daily saving on labour and equipment costs for each method, the annual benefit accrued from introducing the robotic crack-sealing machine was computed to be KRW 90,892,192/year (see Figure 11).



재래식 방식
노무종류 5

노무자	인원(명)	단가(원)	비용(원)
포장공	3	83,276	249,828
기계운전원	1	78,015	78,015
운전원	2	63,443	126,886
특별인부	2	66,051	132,102
보통인부	4	52,374	209,496

소계 796,327 원

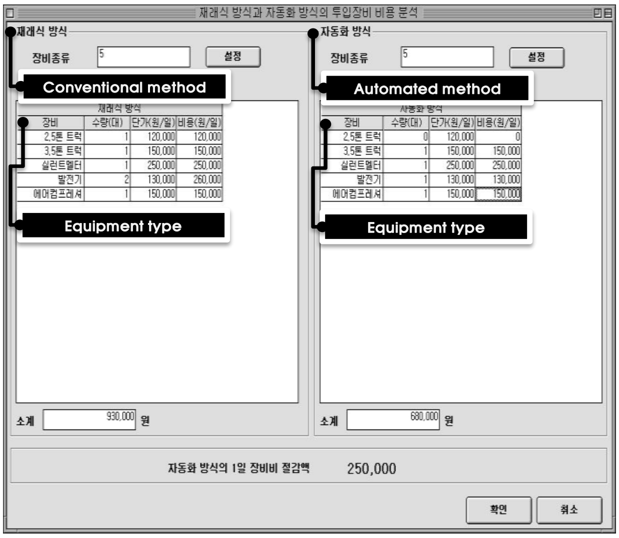
자동화 방식
노무종류 5

노무자	인원(명)	단가(원)	비용(원)
포장공	1	83,276	83,276
기계운전원	1	78,015	78,015
운전원	1	63,443	63,443
특별인부	1	66,051	66,051
보통인부	2	52,374	104,748

소계 395,533 원

자동화 방식의 1일 노무비 절감액 400,794

FIGURE IX
DAILY SAVING ON LABOUR DUE TO THE INTRODUCTION OF AUTOMATED PAVEMENT CRACK SEALING



재래식 방식과 자동화 방식의 투입장비 비용 분석

재래식 방식

장비종류 5

재래식 방식

장비	수량(대)	단가(원/일)	비용(원/일)
2.5톤 트럭	1	120,000	120,000
3.5톤 트럭	1	150,000	150,000
실런트멜터	1	250,000	250,000
발전기	2	130,000	260,000
에어컴프레셔	1	150,000	150,000

소계 930,000 원

자동화 방식

장비종류 5

자동화 방식

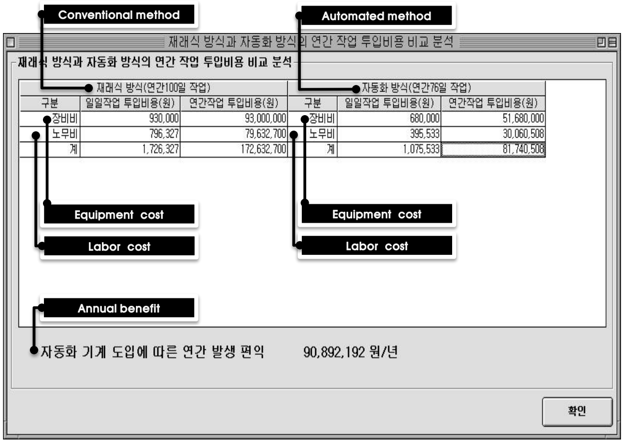
장비	수량(대)	단가(원/일)	비용(원/일)
2.5톤 트럭	0	120,000	0
3.5톤 트럭	1	150,000	150,000
실런트멜터	1	250,000	250,000
발전기	1	130,000	130,000
에어컴프레셔	1	150,000	150,000

소계 680,000 원

자동화 방식의 1일 장비비 절감액 250,000

FIGURE X

DAILY SAVING ON EQUIPMENT DUE TO THE INTRODUCTION AUTOMATED CRACK SEALING



재래식 방식과 자동화 방식의 연간 작업 투입비용 비교 분석

재래식 방식과 자동화 방식의 연간 작업 투입비용 비교 분석

재래식 방식(연간100일 작업)			자동화 방식(연간76일 작업)		
구분	일일작업 투입비용(원)	연간작업 투입비용(원)	구분	일일작업 투입비용(원)	연간작업 투입비용(원)
장비비	930,000	93,000,000	장비비	680,000	51,680,000
노무비	796,327	79,632,700	노무비	395,533	30,060,508
계	1,726,327	172,632,700	계	1,075,533	81,740,508

자동화 기계 도입에 따른 연간 발생 편익 90,892,192 원/년

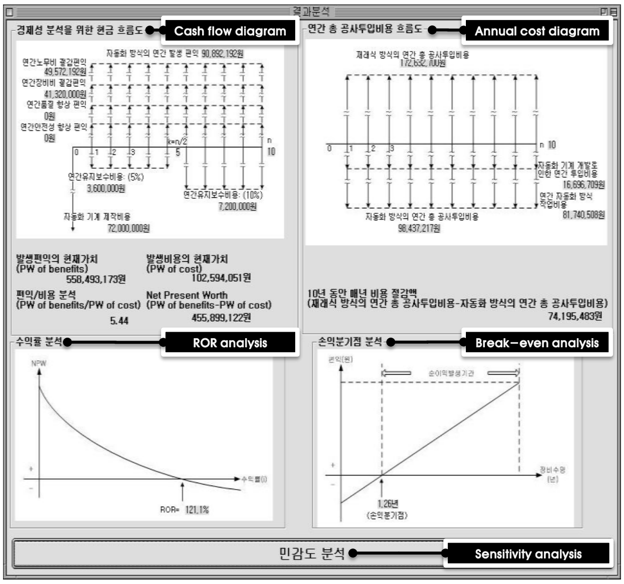
FIGURE XI

ANNUAL BENEFIT ACCRUED FROM INTRODUCING AUTOMATED CRACK SEALING

d. Economic feasibility analysis

In this study, an economic feasibility analysis was conducted using the proposed performance analysis system that took into account (a) the annual benefit accrued as mentioned above, based on the improvement in quality and reduction in costs of mobilized labour and equipment; and (b) the additional costs resulting from developing ACE (manufacturing costs and annual maintenance costs). This process automatically resulted in a cash flow chart which took the annual benefit and cost accrued into consideration (see Figure 12). The present value of the benefit accrued was found to be KRW 558,493,173. The present value of the cost accrued was KRW 102,594,051. Using these figures, the benefit-cost ratio was calculated to be 5.44, which is greater than 1, indicating that the development of the automated machine was efficacious. The difference between the present value of benefit accrued and that of cost accrued was KRW 455,899,122. This means that the parties using the robotic crack-sealing machine can enjoy the benefit amounting to KRW 455,899,122 in present value for the 10 years that they will utilize the machine.

The flow chart on annual total construction cost was analysed. Results showed that the annual cost accrued from labour and equipment that were mobilized for conventional crack sealing and automated crack sealing was KRW 172,632,700 (conventional) and KRW 81,740,508 (automated). Moreover, an additional cost of KRW 16,696,709 was required each year due to the introduction of automated crack-sealing machines (the same amount to be applied over the 10-year period). Therefore, the annual cost saving for the 10-year period was calculated to be KRW 74,195,483. The rate of earnings expected from introducing the robotic crack-sealing machine was computed at 121.1%, which greatly exceeds the MARR of 10%. According to the break-even-point analysis, the invested capital can be collected in about 15 months if the automated crack-sealing machine is introduced (see Figure 12).



발생편익의 현재가치 (PW of benefits) 558,493,173원

발생비용의 현재가치 (PW of cost) 102,594,051원

편익/비용 분석 (PW of benefits/PW of cost) 5.44

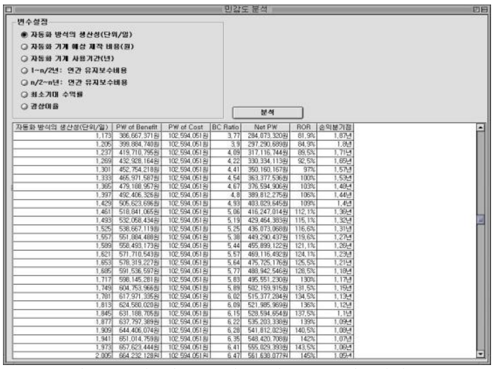
Net Present Worth (PW of benefits-PW of cost) 455,899,122원

10년 동안 매년 비용 절감액 (재래식 방식의 연간 총 공사투입비용-자동화 방식의 연간 총 공사투입비용) 74,195,483원

FIGURE XII

RESULTS OF ECONOMIC FEASIBILITY ANALYSIS ON AUTOMATED PAVEMENT CRACK SEALING

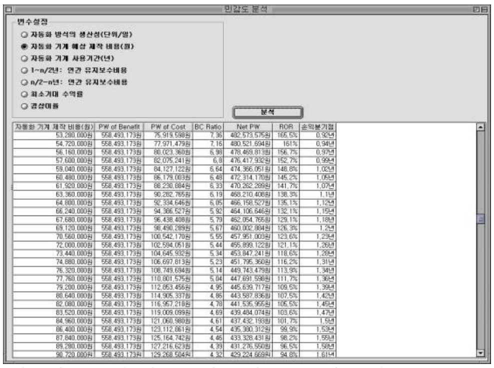
As described above, the parties involved in developing ACE can utilize the performance analysis system proposed in this study. The parties are enabled to use the results of tests conducted at their own sites, use their own productivity data (conventional vs. automated), establish their own assumptions and parameters, and obtain various data on economic feasibility analysis. The proposed system will also enable the parties to conduct sensitivity analysis (see Figure 13) on the changes in the results of economic feasibility analysis influenced by fluctuations in the parameters set for the productivity, manufacturing cost, service life, MARR, and annual maintenance cost of automated pavement crack-sealing machines. These features of the system are intended to assist the interested parties' decision-making for ACE development.



● 자동화 방식의 생산성(단위/일)
○ 자동화 기계 예상 제작 비용(원)
○ 자동화 기계 사용기간(년)
○ 1~n/2년: 연간 유지보수비용
○ n/2~n년: 연간 유지보수비용
○ 최소기대 수익률
○ 경상이율

자동화 방식의 생산성(단위/일)	PW of Benefit	PW of Cost	BC Ratio	Net PW	ROR	손익분기점
1.173	386,667,371원	102,594,051원	3.77	284,073,320원	81.9%	1.87년
1.205	399,884,740원	102,594,051원	3.9	297,290,689원	84.9%	1.8년
1.237	419,710,795원	102,594,051원	4.09	317,116,744원	89.5%	1.71년
1.269	432,928,164원	102,594,051원	4.22	330,334,113원	92.5%	1.65년
1.301	452,754,218원	102,594,051원	4.41	350,160,167원	97%	1.57년
1.333	465,971,587원	102,594,051원	4.54	363,377,536원	100%	1.53년
1.365	479,188,957원	102,594,051원	4.67	376,594,906원	103%	1.48년
1.397	492,406,326원	102,594,051원	4.8	389,812,275원	106%	1.44년
1.429	505,623,696원	102,594,051원	4.93	403,029,645원	109%	1.4년
1.461	518,841,065원	102,594,051원	5.06	416,247,014원	112.1%	1.36년
1.493	532,058,434원	102,594,051원	5.19	429,464,383원	115.1%	1.32년
1.525	538,667,119원	102,594,051원	5.25	436,073,068원	116.6%	1.31년
1.557	551,884,488원	102,594,051원	5.38	449,290,437원	119.6%	1.27년
1.589	558,493,173원	102,594,051원	5.44	455,899,122원	121.1%	1.26년
1.621	571,710,543원	102,594,051원	5.57	469,116,492원	124.1%	1.23년
1.653	578,319,227원	102,594,051원	5.64	475,725,176원	125.5%	1.21년
1.685	591,536,597원	102,594,051원	5.77	488,942,546원	128.5%	1.18년
1.717	598,145,281원	102,594,051원	5.83	495,551,230원	130%	1.17년
1.749	604,753,966원	102,594,051원	5.89	502,159,915원	131.5%	1.15년
1.781	617,971,335원	102,594,051원	6.02	515,377,284원	134.5%	1.13년
1.813	624,580,020원	102,594,051원	6.09	521,985,969원	136%	1.12년
1.845	631,188,705원	102,594,051원	6.15	528,594,654원	137.5%	1.1년
1.877	637,797,389원	102,594,051원	6.22	535,203,338원	139%	1.09년
1.909	644,406,074원	102,594,051원	6.28	541,812,023원	140.5%	1.08년
1.941	651,014,759원	102,594,051원	6.35	548,420,708원	142%	1.07년
1.973	657,623,444원	102,594,051원	6.41	555,029,393원	143.5%	1.06년
2.005	664,232,128원	102,594,051원	6.47	561,638,077원	145%	1.05년

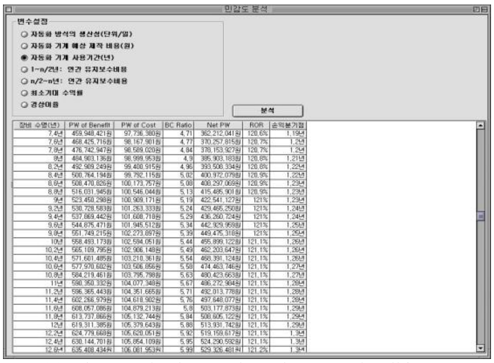
(a) Changes in the crack sealer's productivity



○ 자동화 방식의 생산성(단위/일)
● 자동화 기계 예상 제작 비용(원)
○ 자동화 기계 사용기간(년)
○ 1~n/2년: 연간 유지보수비용
○ n/2~n년: 연간 유지보수비용
○ 최소기대 수익률
○ 경상이율

자동화 기계 제작 비용(원)	PW of Benefit	PW of Cost	BC Ratio	Net PW	ROR	손익분기점
53,280,000원	558,493,173원	75,919,598원	7.36	482,573,575원	165.5%	0.92년
54,720,000원	558,493,173원	77,971,479원	7.16	480,521,694원	161%	0.94년
56,160,000원	558,493,173원	80,023,360원	6.98	478,469,813원	156.7%	0.97년
57,600,000원	558,493,173원	82,075,241원	6.8	476,417,932원	152.7%	0.99년
59,040,000원	558,493,173원	84,127,122원	6.64	474,366,051원	148.8%	1.02년
60,480,000원	558,493,173원	86,179,003원	6.48	472,314,170원	145.2%	1.05년
61,920,000원	558,493,173원	88,230,884원	6.33	470,262,289원	141.7%	1.07년
63,360,000원	558,493,173원	90,282,765원	6.19	468,210,408원	138.3%	1.1년
64,800,000원	558,493,173원	92,334,646원	6.05	466,158,527원	135.1%	1.12년
66,240,000원	558,493,173원	94,386,527원	5.92	464,106,646원	132.1%	1.15년
67,680,000원	558,493,173원	96,438,408원	5.79	462,054,765원	129.1%	1.18년
69,120,000원	558,493,173원	98,490,289원	5.67	460,002,884원	126.3%	1.2년
70,560,000원	558,493,173원	100,542,170원	5.55	457,951,003원	123.6%	1.23년
72,000,000원	558,493,173원	102,594,051원	5.44	455,899,122원	121.1%	1.26년
73,440,000원	558,493,173원	104,645,932원	5.34	453,847,241원	118.6%	1.28년
74,880,000원	558,493,173원	106,697,813원	5.23	451,795,360원	116.2%	1.31년
76,320,000원	558,493,173원	108,749,694원	5.14	449,743,479원	113.9%	1.34년
77,760,000원	558,493,173원	110,801,575원	5.04	447,691,598원	111.7%	1.36년
79,200,000원	558,493,173원	112,853,456원	4.95	445,639,717원	109.5%	1.39년
80,640,000원	558,493,173원	114,905,337원	4.86	443,587,836원	107.5%	1.42년
82,080,000원	558,493,173원	116,957,218원	4.78	441,535,955원	105.5%	1.45년
83,520,000원	558,493,173원	119,009,099원	4.69	439,484,074원	103.6%	1.47년
84,960,000원	558,493,173원	121,060,980원	4.61	437,432,193원	101.7%	1.5년
86,400,000원	558,493,173원	123,112,861원	4.54	435,380,312원	99.9%	1.53년
87,840,000원	558,493,173원	125,164,742원	4.46	433,328,431원	98.2%	1.55년
89,280,000원	558,493,173원	127,216,623원	4.39	431,276,550원	96.5%	1.58년
90,720,000원	558,493,173원	129,268,504원	4.32	429,224,669원	94.8%	1.61년

(b) Changes in the crack sealer manufacturing cost



○ 자동화 방식의 생산성(단위/일)
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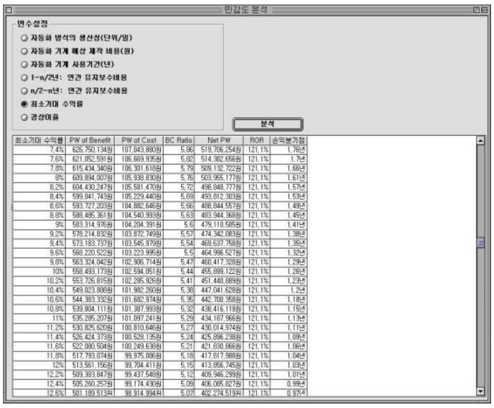
○ n/2~n년: 연간 유지보수비용
○ 최소기대 수익률
○ 경상이율

장비 수명(년)	PW of Benefit	PW of Cost	BC Ratio	Net PW	ROR	손익분기점
7.4년	459,948,421원	97,736,380원	4.71	362,212,041원	120.6%	1.19년
7.6년	468,425,716원	98,167,901원	4.77	370,257,815원	120.7%	1.2년
7.8년	476,742,947원	98,589,020원	4.84	378,153,927원	120.7%	1.2년
8년	484,903,136원	98,999,953원	4.9	385,903,183원	120.8%	1.21년
8.2년	492,909,249원	99,400,915원	4.96	393,508,334원	120.8%	1.22년
8.4년	500,764,194원	99,792,115원	5.02	400,972,079원	120.9%	1.22년
8.6년	508,470,826원	100,173,757원	5.08	408,297,069원	120.9%	1.23년
8.8년	516,031,945원	100,546,044원	5.13	415,485,901원	120.9%	1.23년
9년	523,450,298원	100,909,171원	5.19	422,541,127원	121%	1.23년
9.2년	530,728,583원	101,263,333원	5.24	429,465,250원	121%	1.24년
9.4년	537,869,442원	101,608,718원	5.29	436,260,724원	121%	1.24년
9.6년	544,875,471원	101,945,512원	5.34	442,929,959원	121%	1.25년
9.8년	551,749,215원	102,273,897원	5.39	449,475,318원	121%	1.25년
10년	558,493,173원	102,594,051원	5.44	455,899,122원	121.1%	1.26년
10.2년	565,109,795원	102,906,148원	5.49	462,203,647원	121.1%	1.26년
10.4년	571,601,485원	103,210,361원	5.54	468,391,124원	121.1%	1.26년
10.6년	577,970,602원	103,506,856원	5.58	474,463,746원	121.1%	1.27년
10.8년	584,219,461원	103,795,798원	5.63	480,423,663원	121.1%	1.27년
11년	590,350,332원	104,077,348원	5.67	486,272,984원	121.1%	1.28년
11.2년	596,365,443원	104,351,665원	5.71	492,013,778원	121.1%	1.28년
11.4년	602,266,979원	104,618,902원	5.76	497,648,077원	121.1%	1.28년
11.6년	608,057,086원	104,879,213원	5.8	503,177,873원	121.1%	1.29년
11.8년	613,737,866원	105,132,744원	5.84	508,605,122원	121.1%	1.29년
12년	619,311,385원	105,379,643원	5.88	513,931,742원	121.1%	1.29년
12.2년	624,779,668원	105,620,051원	5.92	519,159,617원	121.1%	1.3년
12.4년	630,144,701원	105,854,109원	5.95	524,290,592원	121.1%	1.3년
12.6년	635,408,434원	106,081,953원	5.99	529,326,481원	121.2%	1.3년

(c) Changes in the crack sealer's service life



○ 자동화 방식의 생산성(단위/일)
○ 자동화 기계 예상 제작 비용(원)
○ 자동화 기계 사용기간(년)
○ 1~n/2년: 연간 유지보수비용
○ n/2~n년: 연간 유지보수비용
● 최소기대 수익률
○ 경상이율

최소기대 수익률	PW of Benefit	PW of Cost	BC Ratio	Net PW	ROR	손익분기점
7.4%	626,750,134원	107,043,880원	5.86	519,706,254원	121.1%	1.76년
7.6%	621,052,591원	106,669,935원	5.82	514,382,656원	121.1%	1.7년
7.8%	615,434,340원	106,301,618원	5.79	509,132,722원	121.1%	1.66년
8%	609,894,007원	105,938,830원	5.76	503,955,177원	121.1%	1.61년
8.2%	604,430,247원	105,581,470원	5.72	498,848,777원	121.1%	1.57년
8.4%	599,041,743원	105,229,440원	5.69	493,812,303원	121.1%	1.53년
8.6%	593,727,203원	104,882,646원	5.66	488,844,557원	121.1%	1.49년
8.8%	588,485,361원	104,540,993원	5.63	483,944,368원	121.1%	1.45년
9%	583,314,976원	104,204,391원	5.6	479,110,585원	121.1%	1.41년
9.2%	578,214,832원	103,872,749원	5.57	474,342,083원	121.1%	1.38년
9.4%	573,183,737원	103,545,979원	5.54	469,637,758원	121.1%	1.35년
9.6%	568,220,522원	103,223,995원	5.5	464,996,527원	121.1%	1.32년
9.8%	563,324,042원	102,906,714원	5.47	460,417,328원	121.1%	1.29년
10%	558,493,173원	102,594,051원	5.44	455,899,122원	121.1%	1.26년
10.2%	553,726,815원	102,285,926원	5.41	451,440,889원	121.1%	1.23년
10.4%	549,023,888원	101,982,260원	5.38	447,041,628원	121.1%	1.2년
10.6%	544,383,332원	101,682,974원	5.35	442,700,358원	121.1%	1.18년
10.8%	539,804,111원	101,387,993원	5.32	438,416,118원	121.1%	1.15년
11%	535,285,207원	101,097,241원	5.29	434,187,966원	121.1%	1.13년
11.2%	530,825,620원	100,810,646원	5.27	430,014,974원	121.1%	1.11년
11.4%	526,424,373원	100,528,135원	5.24	425,896,238원	121.1%	1.09년
11.6%	522,080,504원	100,249,638원	5.21	421,830,866원	121.1%	1.06년
11.8%	517,793,074원	99,975,086원	5.18	417,817,988원	121.1%	1.04년
12%	513,561,156원	99,704,411원	5.15	413,856,745원	121.1%	1.03년
12.2%	509,383,847원	99,437,548원	5.12	409,946,299원	121.1%	1.01년
12.4%	505,260,257원	99,174,430원	5.09	406,085,827원	121.1%	0.99년
12.6%	501,189,513원	98,914,994원	5.07	402,274,519원	121.1%	0.97년

(d) Changes in MARR

FIGURE XII
RESULTS OF SENSITIVITY ANALYSIS ON AUTOMATED PAVEMENT CRACK SEALING

V. CONCLUSION

The following conclusions were drawn from this study:

1) Proposing an efficient way of analysing ACE performance

In this study, the current state of the development and performance analysis of ACE in Korea and elsewhere were examined. Afterwards, the need for and significance of developing an ACE performance analysis model was addressed. In addition, the R&D of ACE was divided into three phases (development feasibility analysis, manufacturing, and commercialization/marketing) to help ensure the efficiency of ACE performance analysis.

2) Establishing a quantification measure for the performance analysis components of ACE

Despite the fact that improving safety and quality is one of the principal goals for developing ACE, previous studies failed to propose methods for quantifying the improvement in terms of the economic benefits. In this study, the degree of improvement in productivity, safety, and quality was quantified and was presented as parameters to be chosen by the parties involved in ACE development while they consider economic benefits. The quantification was intended to help improve the value driven from ACE development and to increase the possibility of commercializing the developed equipment.

3) Proposing a performance analysis model specific to each R&D phase

The researchers of this study proposed a performance analysis model designed to help conduct economic feasibility analysis (e.g., benefit-cost ratio, net present worth, rate of return, break-even point, and sensitivity analysis, among others) with ease. A number of factors were considered: (a) additional costs, that is, ACE manufacturing cost and annual maintenance cost; (b) annual benefit accrued from productivity improvement or from reduction in labour and equipment costs; and (c) benefits accrued from improved safety and quality. The proposed model was intended to assist in the decision–making of interested parties.

4) Establishing an ACE performance analysis system

An ACE performance analysis system was established for this study. The aim was to help the investors, researchers/developers, and end users of ACE and other interested private enterprises to quickly and easily analyse the performance of ACE according to the R&D phases. The established system is believed to assist the performance evaluators of ACE in establishing their own assumptions and parameters that suit their circumstances (according to the ACE R&D phases). Functions include measuring and evaluating the performance of ACE, ensuring the validity of the development, inventing high-performance ACE, and effectively setting up the marketing strategy for the developed ACE.

5) Reviewing the efficacy of the development system through case studies

The present researchers of this study used a robotic pavement crack-sealing machine as the target on which the established ACE performance analysis system was to be tested. Using the target and the system, a comprehensive performance analysis was conducted by examining mainly the productivity, safety, and quality. The results revealed that the performance evaluators could easily produce a number of economic feasibility indexes using the proposed system. They were also able to enter, assisted by the proposed performance analysis process, productivity data on the conventional, and automated crack-sealing methods to evaluate the factors affecting safety and quality as well as to establish and enter assumptions and parameters for economic feasibility analysis.

Based on the results of this study, the parties involved in ACE development are judged to be capable of developing, commercializing, and investing in ACE successfully by utilizing the results of the economic feasibility analysis carried out with the phases of ACE R&D.

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