Analysis of Economic Feasibility for a Window Cleaning Device

Kyoon-Tai Kim and Young-Hun Jun

***Abstract*—In recent years, there has been an increased demand from luxury shops for clean windows in Korea. To satisfy this demand, efforts have been made to develop a window cleaning device. However, as these efforts are at an early stage, the economic feasibility of such a device is not yet clearly understood. This study aims to estimate the economic feasibility of a window cleaning device through an LCC analysis. The LCC analysis was done for the conventional cleaning method and a newly-developed window cleaning device. Based on the study findings, it is expected that such a window cleaning device could reach break-even point in seven years after its introduction.**

***Index Terms*—Construction automation, window cleaning, cleaning robot, maintenance, life cycle cost (LCC).**

I. Introduction

Of the various maintenance activities engaged in during the use of a building structure, cleaning is the one that is performed most frequently. As incomes and quality of life in Korea have improved, Koreans have taken a keener interest in appearance and cleanliness. This trend is also being applied to buildings, as businesses for which image is important, including clinics, fitness centers, beauty shops, etc. want not only their indoor space but also their external windows to be cleaned and spotless. However, cleaning the windows is not easy, if clients who want a particularly clean environment are not on the first floor. The reason why is conventional window cleaning methods are heavily dependent on human labor to clean the entire façade, making it difficult to meet the demands of them [1].

As a plan to satisfy the demand for keeping the environment clean, window cleaning devices that can target specific windows are being developed in Korea. However, as there has been little application cases of such devices in Korea, it is very difficult to estimate the economic feasibility and practicality of such a cleaning machine. However, unless an economic feasibility analysis is performed, it is not easy for the supplier of this device to make business judgment. In other words, if the economic feasibility is confirmed, it will be possible to judge the price of the equipment, the amount of production, and the degree of service provision, etc.

The aim of this study is to estimate the feasibility of such a window cleaning device through a LCC (Life Cycle Cost) analysis. To perform an effective estimation, the process of window cleaning work done manually from the outside of a building was analyzed, and then the limitations are examined. Next, a comparative analysis between the machine cleaning method and the manual cleaning method was conducted. Finally, an LCC analysis model was hypothesized and set to estimate the economic feasibility of the cleaning device.

II. Conventional Window Cleaning

A. Conventional Cleaning Method

The most common window cleaning method is that cleaning is performed by a worker while hanging from a rope [2]. In other words, depending on the rope, the worker hanging on the outer wall of the building cleans windows with water, sponge, wiper, mop and so on and the cleaning process consists of pre-work, main work, and finishing work. This labor-intensive cleaning method is done in the sequence shown in Fig. 1.

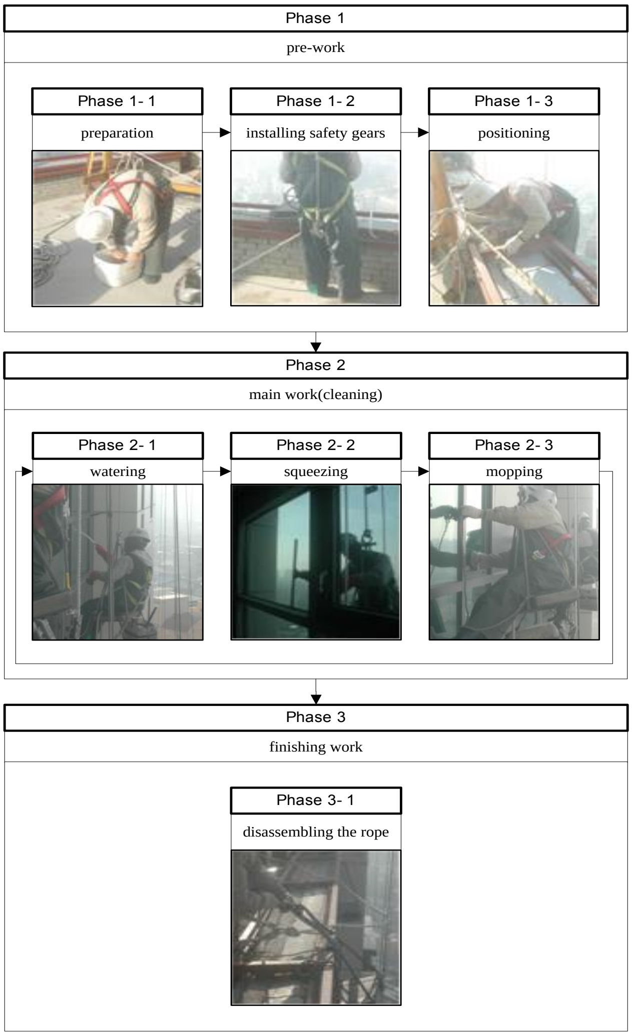

Fig. 1. Conventional window cleaning method.

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More specifically, pre-work is a preparatory work before performing main cleaning work, so it is consist on preparation, installing safety gears, and positioning. It is carried out at the beginning of the day's work, where the ropes are secured and safety gear is prepared. If a building is large and needs to be cleaned for several days, the pre-work on the first day will take a long time, but on the second day, the time required for the work will be relatively short. As a result of the worker interview, 60 minutes of preparation time was required on the first day. From the second day, it took 30 minutes to prepare the work.

The main work is that the worker actually cleans the window, it consists of watering, squeezing and mopping. However, depending on the working environment and situation, specific tasks may be added, or certain tasks may be excluded. This main work is started at a window of the top and when the window cleaning work on one floor is completed, the worker moves to the lower floor. This process repeated until it reaches the bottom. In the course of this work, the worker frequently cleans windows of the side row by performing a watch movement. When the worker arrives at a window of the lowest floor, the worker performs this main work again after he/she takes a rest about 15 minutes. This work process requires the worker to work from the outside of a building, and involves high risk including falling [3]. In the case of this work, the cleaning time differs depending on the skill level of the worker, the angle of the watch movement, the window condition, and so on, but usually it took about 1 minute 30 seconds per window. In addition, when a row of windows was cleaned and the worker came down to the ground, he took a rest for about 20 minutes and started roping for the next job.

The finishing work is performed after the completion of the daily cleaning work or the entire building cleaning work. It is includes rooftop cleanup, cleaning tools cleaning, rope untying, and rope recovery, and it took about 30 minutes to complete the work.. These works are also performed by the workers themselves, which is a high-risk task. For example, in the process of recovering the rope hanging on the outer wall of the building, the worker may lose his/her balance and fall down, resulting in an accident.

B. Limitations of the Conventional Window Cleaning Method

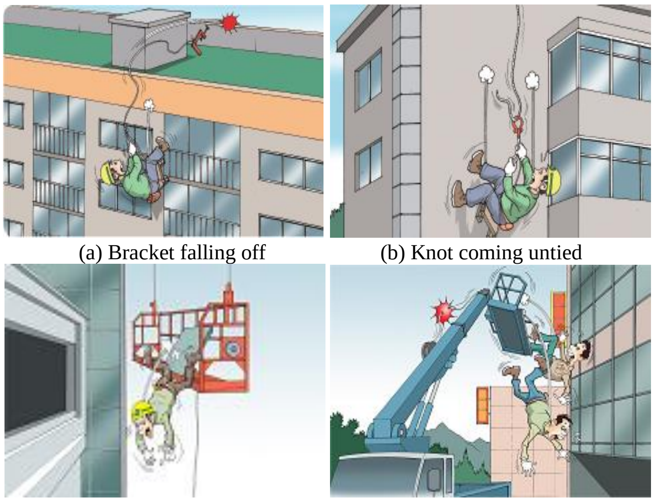
The underlying limitation of conventional window cleaning work is that it is highly labor-dependent. In other words, a worker hung with a rope does the work, moving up, down, right and left, putting the worker in physical danger and limiting productivity as well.

In addition, the skilled workers in this field are aging, and are not being replaced by young workers due to the perception of window cleaning as one of the so-called '3D' (difficult, dirty and dangerous) jobs. For example, according to data reported by the Ministry of Land, Transport and Maritime Affairs on the National Land Transportation Act, as of the end of 2014, the total number of construction workforce in Korea is about 1.33 million, of which more than 1.07 million are over 40 years old. This is 80.8% of the total. On the other hand, the proportion of those in their 30s dropped from 19.8% in 2009 to 13.1% in 2013, while the proportion of those in their 20s dropped from 6.0% to 4.9%.

This has caused an imbalance in the supply and demand for workers, leading to increases in labor and construction costs, deteriorations in construction quality, delays in the construction duration, and a higher risk of safety accidents at construction sites. In particular, the lack of skill of new workers has resulted in mistakes, leading to frequent fatalities. For example, in 2008, the number of accidents per 1,000 construction workers was 6.39, up from 9.19 in 2013. The safety accidents in 2015 from the industrial accident statistics are in Table I [4]. In addition, the possible risks of the conventional cleaning method are diagrammed in Fig. 2 [4].

TABLE I: TYPES AND CAUSES OF ACCIDENT WHILE WINDOW CLEANING WORKS [4]

Accident Type	Causes
Falling to death	- A bracket fell off a hanging scaffold (October 2015) - A knot that was supporting the hanging scaffold came untied (November 2015) - A worker lost his balance while cleaning on a movable ladder at a height (October,2015)



(a) Bracket falling off (b) Knot coming untied

(c) Gondola moving with the safety rail off (d) Wire rope rupture

Fig. 2. Causes of falls while window cleaning works [4].

From a specific window cleaning perspective, there is one more limitation to applying conventional cleaning methods here. This is because in the conventional method, a worker uses a rope that is attached to a rooftop and moves down from top to bottom while cleaning the windows of the same row one by one, which is an advantageous way to clean the entire building.

For example, if only a specific window on the third floor needs to be cleaned, it is difficult to clean from the middle of the building by the conventional method. So, a worker should start cleaning work from the rooftop. This makes it very inefficient to clean certain windows. Also, in the above example, the contaminated water that cleaned the window glass may pollute the glass of the lower floor. There is a concern that complaints are raised and cleaning work cannot be performed, if the polluting is happened

III. MACHINE CLEANING METHOD

When the conventional cleaning method is replaced with the machine cleaning one, productivity is generally analyzed as below. First, the detailed working process of each method is analyzed. Then, the two results are compared to find out which jobs are newly included and excluded. Next, the productivity of the two is compared in terms of productivity against unit workload or productivity against unit working time. Therefore, in this study, the cleaning method by the cleaning device compared with the conventional cleaning method was analyzed and the result is shown in Figure 3.

However, the window cleaning device that this study intends to develop changes the working process itself; as such, it is not easy to perform a productivity analysis in a conventional fashion. In other words, all working processes from phase 1 through phase 3 are repeated whenever the cleaning is done in a conventional way. However, in the case of cleaning by a cleaning device, phase 1 and phase 3 are performed only once when mounting or demounting the device, and only phase 2 is repeatedly performed at normal times. Thus, it is hard to say that it is desirable to derive the productivity by directly comparing and analyzing the two methods. For this reason, the productivity is estimated under an assumption that a specific area of windows is repeatedly cleaned.

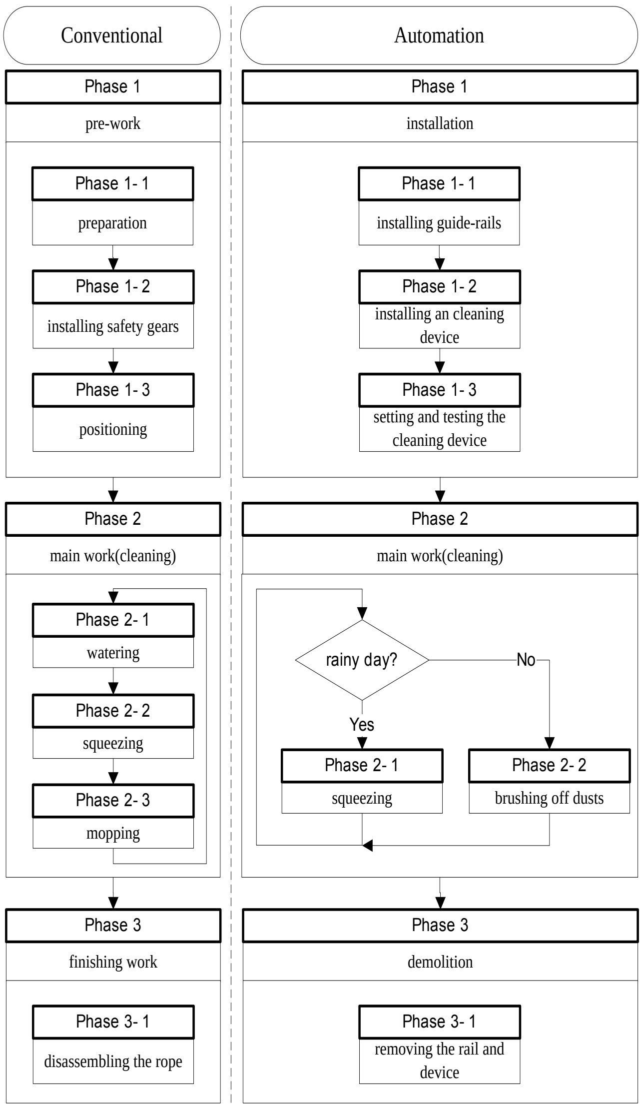


Fig. 3. Comparison between the two working processes.

IV. Economic Feasibility Analysis

When a device is introduced, engineers consider it from various perspectives in order to save energy and increase its economic feasibility. If the cost of introducing a device is less than or equal to the reduction in cost it achieves, the device can be introduced. However, in the past the economic feasibility was determined based on the initial cost. This can be problematic if the initial cost was low but the operation and maintenance cost is high, which would frequently result in huge damage to management. Therefore, Life Cycle Cost from the planning and the final disposal phase rather than the initial cost has been used as the criterion to determine the economic feasibility. This cost is called LCC, and the analysis of the LCC is called Life Cycle cost Analysis (LCA). In this study, economic feasibility is estimated through LCA.

A. Conventional Cleaning Method

The form of the windows analyzed in this study is illustrated in Fig. 4. The window is 1,635mm in length and 1,375mm in height, and 8mm thick glass is used. The windows are divided into upper and lower parts, the upper part is the fixed window and the lower part is the projector window. There is also a window frame in the middle of the length. Therefore, the length of the upper glass is 750mm, the height is 650mm, the length of lower glass is 598mm, and the height is 400mm.

When cleaning this type of window with a mechanical device, it is important to note that the size of the upper window differs from the size of the lower window. This is because the bottom window is the project window for open. In other words, there is a separate frame to open the project window, and the size of the glass inside the frame becomes smaller than the upper side. As a result, the start point of the upper glass cleaning is different from the start point of the glass cleaning. Similarly, the end point of the upper glass cleaning is different from the end point of the lower glass cleaning.

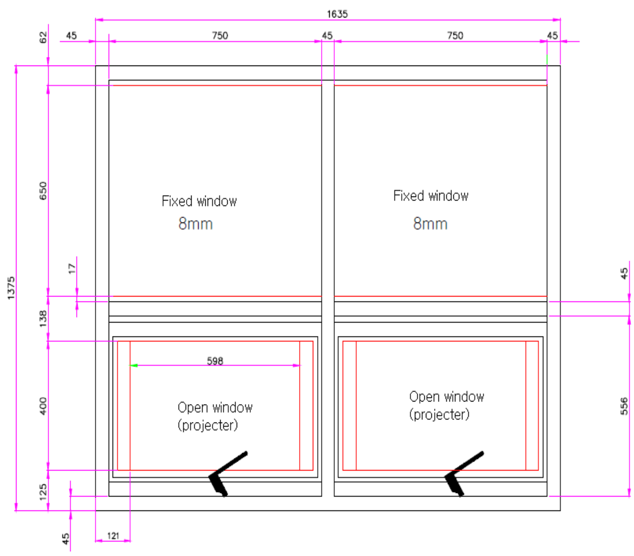


Fig. 4. Windows for the analysis.

It is hypothesized that six windows are connected in a row for this analysis. Therefore, the length of the target window is

9,810mm, and the window area including the window frame is about 18 square meters. The reason for not calculating only the area of glass here is that the size including the window frame is usually used when estimating the window cleaning area in Korea,

B. Conventional Cleaning Method

To analyze the LCC, initial cost, operation cost, maintenance cost, disposal cost and salvage value must be calculated accurately. To do this, the analysis model is (1). However, this study is being performed to estimate economic feasibility at the development phase, so it is difficult to calculate most of the costs accurately. Therefore, the analysis value was set based on hypothesis. Table II indicates the hypothesized values set for the analysis.

$$LCC_{CD} = IC + [MC_n / (1+i)^n] + (DC-SV) / (1+i)^n \qquad (1)$$

LCC_{GR}: Life Cycle Cost of the Cleaning Device

IC : Initial Cost

MC_n: Maintenance Cost in the nth year

DC: Disposal cost after the service life

SV: Salvage value after the disposal

i : Discount rate

TABLE II: HYPOTHESES FOR AN ANALYSIS

Item	Hypotheses
Cleaning area	18.05㎡ (based on an office with 8 windows, each of which has a size of W1.6m ✕ H1.4m)
Analysis period	20 years
Discount rate	5.50%
Annual cost of the conventional method	KRW 2,123,197 won -Unit cost: KRW 3,038 won/ ㎡ - Cleaning frequency: once a week
Initial cost of the cleaning device	KRW 8 million won
Maintenance cost of the cleaning device	10 percent of the initial cost (repair cost 5%/ year, operation cost 5%/ year)
Remaining value of the cleaning device	10 percent of the initial cost (no disassembly cost)

C. Conventional Cleaning Method

LCC estimates were compared between the conventional cleaning method and the machine cleaning one based on the hypotheses. As a result, as illustrated in Fig. 5, the cost of the machine cleaning method begins to drop below the cost of the conventional cleaning method in the seventh year. Therefore, it can be seen that the cleaning by the cleaning device is more economical after about 7 years under the above assumption.

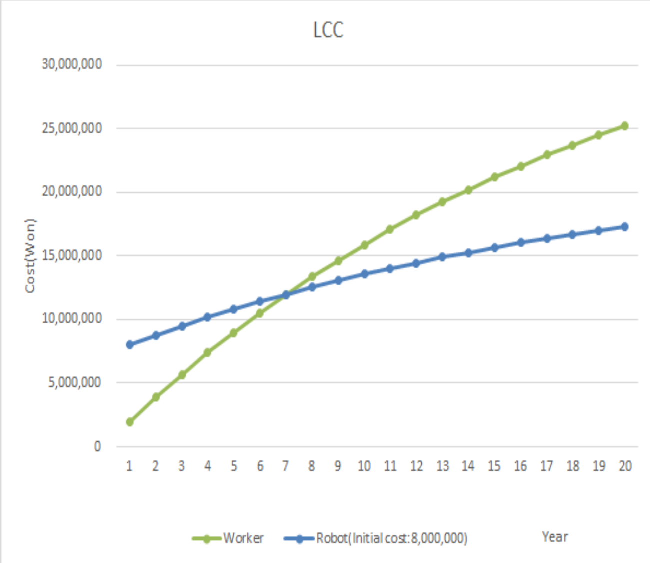


Fig. 5. LCC estimate results.

V. RESULTS

To satisfy the demands of clients to keep their environment clean, efforts have been made to develop a specific window cleaning device. But in reality, the economic feasibility has not yet been accurately determined. If economics feasibility is not quantified, it becomes very difficult to judge whether or not to develop. Taking this fact into account, this study estimated the economic feasibility of a window cleaning device through an LCC analysis.

To accomplish this, a comparative analysis was first performed for the working process of each cleaning method. In addition, an LCC analysis model was considered, and its hypotheses were set. As result, it was estimated that break-even point would be reached at seven years after the installation of the window cleaning device. In a future study, a more detailed analysis model will be developed, and more concrete data will be collected in order to derive more reliable analysis results.

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