ON-SITE PRODUCTIVITY EVALUATION THROUGH PRODUCTIVITYY ACHIEVEMENT RATIO

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Productivity only shows actual achievement without any regards to obtainable productivity. Therefore, productivity and change in its values do not provide adequate information for the management of construction productivity. This study aims to develop a productivity evaluation indicator that can consider obtainable productivity. For this purpose, this paper presents three renewed concepts of productivity transition. Based on these concepts, the study suggests Productivity Achievement Ratio (PAR) as a productivity evaluation indicator. PAR calculation is a longitudinal process conducted by multiple linear regression analysis. Because PAR includes obtainable productivity and is non-dimensional, it can be used to compare productivity management performances with different items and in different sites.

Keywords: productivity, productivity management, statistical analysis. .

INTRODUCTION

Productivity, defined as the ratio of output to input, is one of well-known performance indicators. There have been many studies conducted on construction productivity, and most of them focused on the productivity values of a single item and evaluated change or difference in measured values between two or more time spots. However, one of the most important things for productivity management is to know the amount of room for productivity improvement on each work and studies focusing on this seem rare.

Table 1:. Labour productivity values in apartment construction in S.Korea

Method	Labour (man·day)	Area (m^2)	Productivity (m^2/man·day)
Euro form sheet of plywood form	48,875	30,672	0.628
Gang form · partial PC	31,928	20,484	0.641
Prefabricated form	59,828	42,275	0.707

Table 1 shows a comparison of three engineering methods of labour productivity in apartment construction fields in South Korea. As shown, labour productivity of euro form·sheet of plywood form yields 0.628 sq. meter/man·day whereas prefabricated form yields to 0.707 sq. meter/man·day. However, these figures are irrelevant when managing productivity. The important factor is the amount of room for productivity improvement on each item. Construction managers should then pay attention to items with larger room for improvement to manage productivity successfully.

From this example, it is apparent that productivity alone and its change do not provide the contractors adequate information for managing productivity. For better productivity management, a new evaluation indicator considering the obtainable productivity is needed.

Kim, T-W, Yu, J-H and Lee, H-S (2003) On-site productivity evaluation through productivity achievement ratio. *In:* Greenwood, D J (Ed.), *19th Annual ARCOM Conference*, 3-5 September 2003, University of Brighton. Association of Researchers in Construction Management, Vol. 2, 467-76.

OBJECTIVES AND METHOD

This study aims to develop an indicator for productivity evaluation. An evaluation indicator should also include obtainable productivity in order to draw out important items to manage productivity. In addition, an evaluation indicator must meet the quantification requirement to measure in a practical manner. Considering the above, this study suggests the use of Productivity Achievement Ratio(PAR) as an evaluation indicator. PAR is the ratio of Actual Productivity(AP) to Obtainable Productivity(OP).

Productivity can be classified into labour productivity, material productivity, capital productivity, etc. according to the input type. Though the type of productivity is insignificant to the context of this study, labour productivity has been selected as the target of this research for practical purpose. Labour productivity used in this paper is as follows:

$$\mathrm{Pr}\,oductivity = \frac{Output}{Man \cdot Hour} \quad (1)$$

This research consists of four steps:

(1) Literature review is carried out on the productivity management and productivity indicators.

(2) Controversial points are presented and renewed concepts on productivity are proposed to solve the problems.

(3) On the basis of the proposed concepts, a new evaluation indicator for the productivity management, PAR, is suggested.

(4) An example is presented to show the implications of PAR and a verification study is performed.

LITERATURE REVIEW

Productivity management

Sumanth(1984) divides productivity management into these four steps: measurement, evaluation, planning, improvement. Table 2 shows the contents of each step.

Table 2: Productivity management cycle and the contents of each step

Step	Contents
Measurement	Focuses on measuring productivity value
Evaluation	Calculates the change in productivity values
Planning	Predicts future productivity and devises short-term and long-term plans
Improvement	Executes productivity improvement programs made in Planning

However, existing studies on productivity mainly focus on productivity measurement. Though they give a decent estimation of productivity, these studies do not evaluate the context of productivity manifestation and cannot assess important items for managing productivity. It is because neither change in productivity nor variation of productivity reflects the characteristics of each item. For example, some items have high productivity even without its huge potential for improvement, while others substantially have low productivity despite its successful performance. Therefore, an advanced productivity evaluation indicator that can partake the characteristics of each item is needed for expert management of productivity.

Functions of indicators for productivity management

Business Roundtable (1987) presents detailed functions of productivity indicators or measures in the construction industry as follows:

- Determine how effectively their projects are being managed.
- Detect adverse trends quickly so corrective actions may be taken.
- Determine the effects of changed methods or conditions.
- Identify both high and low areas of productivity and reasons for the differences.
- Compare the performance of different contractors.

Proposed functions will help owners and construction managers by providing a way of determining trends and levels of productivity and the response to corrective actions and/or inactions.

Therefore, existing productivity indicators can be verified using the criteria. And a new productivity evaluation indicator, suggested in this study, can also be verified using the criteria.

Productivity influence factors

Borcherding (1986) classifies causes of reduced productivity in construction work into five categories: (1) waiting or idle, (2) traveling, (3) working slowly, (4) doing ineffective work, and (5) doing rework. Crafts workers produce less output per unit of time due to one of these basic nonproductive activities. Activities are affected directly or indirectly by several other factors. Son and Lee (2002) gathered productivity influence factors and categorized into five sections. However, both of these studies have quantificational problems and can't be applied to mathematical approaches.

Kim (1994) explained productivity influence factors dividing into factors improving productivity and factors decreasing productivity. The research assumed the existence of a standard of judgment between improvement and decrease. However, construction technology is developing continuously and this makes the standard to be more vague. Therefore, it is needed to presume the best productivity in which everything is perceived as perfect. In this case, productivity influence factor can be defined as a factor that obstructs productivity from reaching the best productivity.

Alarcon and Ashley (1992) offer general performance model (GPM model) as an attempt to evaluate performance at a project level. The GPM model has sets of variables that are directly affected by project options: These variables, called drivers, include craft labour, engineer, owner, project manager, etc. and thus propagate the effects during the process, stimulating the four project outcomes of cost, schedule, value and effectiveness. These outcomes can be combined into one value according to the preferences of the decision maker. But it is too abstract and simplified to be used practically.

Indicators for productivity management

Thomas (1999) proposes a baseline productivity for productivity management. Baseline productivity is the value of unaffected productivity by disruptions. It can be set through a certain process from pre-constructed field DB. Regression analysis is utilized to figure out the relation of each disruption to productivity reduction, but this indicator merely serves as an estimation model and does not involve productivity evaluation. The approach assumes that baseline productivity is not going to change on a single construction field, but rather a certain obtainable productivity can fluctuate over the whole construction period.

Herbsman and Ellis (1990) also suggest a statistical model that establishes the quantitative relationship between influence factors and productivity rates. A regression equation can be calculated to show this relationship when productivity influence factors are determined and scored by past experiences, general knowledge, and other available methods. However, this model also does not appear to be a qualified evaluation tool and any corrective actions cannot be taken during the construction period.

RENEWED CONCEPT ON PRODUCTIVITY

Three types of productivity

On-site productivity transition generally includes one positive loop and one negative loop from a viewpoint of systems thinking. The methods of systems thinking provide us with tools for better understanding difficult management problems (Kirkwood 1998). A positive loop contains an even number of negative causal links and indicated by a + sign in parentheses. For example, as productivity rises, morale value at the site also increases. Likewise, if morale value at the site increases, on-site productivity would also rises. Therefore, morale and productivity form a positive loop. On the other hand, a negative loop contains an odd number of negative causal links and indicated by a – sign in parentheses. For example, the gap between limit and productivity decreases when productivity increases, which means a smaller gap between limit and productivity lowers productivity. Therefore, productivity and the gap form a negative loop. Figure 1 shows the relationship.

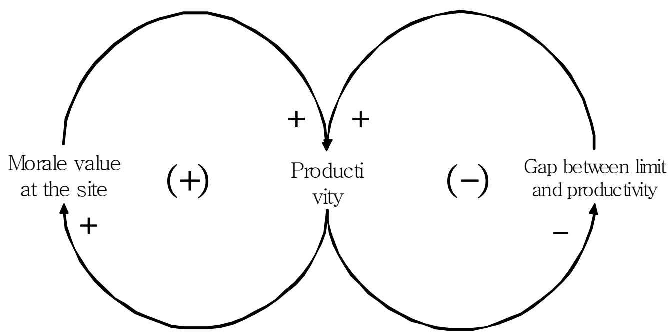

Figure 1:. Productivity causal loops based on systems thinking

Productivity transition of positive and negative loops is illustrated in figure 2. Pay attention to the horizontal axis in figure 2. Time is not a physical but a conceptual idea that places productivity as the last value of the vertical axis.

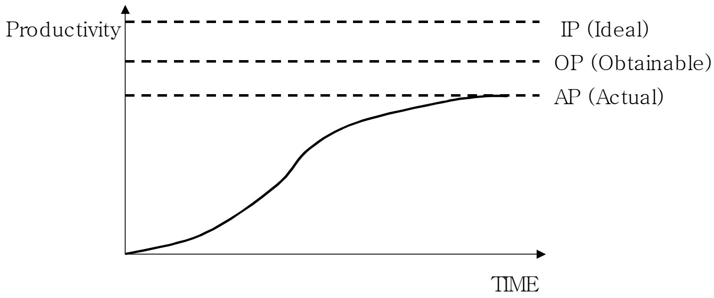

Figure 2:. Productivity transition graph

Based on the transition graph, this paper proposes three types of productivity.

The first type of productivity is Ideal Productivity (IP), in which everything is perceived as perfect. IP is not countable and not obtainable because various factors in the real world limit perfection.

The second type is Actual Productivity (AP). This is what the contractors in the construction fields usually acquire. AP value equals existing productivity value.

The last type of productivity is Obtainable Productivity (OP), which exists between AP and IP. OP is obtainable only by best performance. Thus, OP is the highest value of productivity contractors can obtain. It is noteworthy to mention that OP and AP fluctuate everyday.

Reduction factor

Reduction Factor (RF) is defined as a factor that obstructs productivity from reaching an IP value. Namely, RF is the origin of difference between IP and AP. This idea can be expressed by the following equation:

AP = IP – an amount of productivity loss caused by RF (2)

Reduction Factors are classified into four factors based on two criteria.

Can someone with a construction project perspective control the RF?

Factors such as "site layout plan" can be controlled in a project perspective. That is, these RFs obstruct AP from reaching OP. Other factors such as "weather conditions" cannot be controlled and cannot be stopped. Therefore, these RFs prevent OP from reaching IP. The former is referred to as Controllable-RF(C-RF) and the latter Uncontrollable-RF(UC-RF). These concepts are presented as the following equations:

OP = IP – an amount of productivity loss caused by UC-RF (3)

AP = OP – an amount of productivity loss caused by C-RF (4)

Figure 3 shows the relation of RFs and productivity effectively.

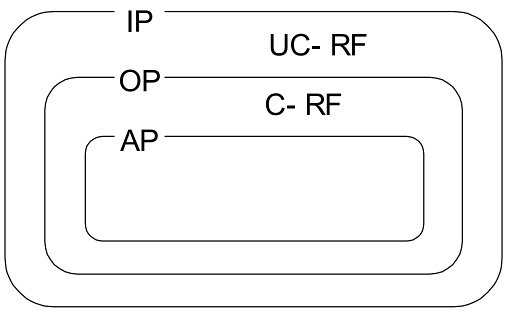

Figure 3:. Relationship of RFs and productivity

Can RFs be variable in a project period?
Certain RFs like “faithfulness of labors” undergo a daily change, while others like “insufficient drawings” remain unchanged during the construction period. The former is named Variable-RF(V-RF) and the latter is named Invariable-RF(IV-RF). Though IV-RF should be considered as RF when comparing different sites, it does not affect the change of the productivity value in one item of a construction field.

These two criteria form a 2 by 2 RF matrix as shown in figure 4. For example, “weather conditions” belong to the UC-V-RF dimension, and “work schedule planning” is a typical C-V-RF. “Conditions of site location” would be a UC-IV-RF and “site layout planning” would fall into the C-IV-RF category.

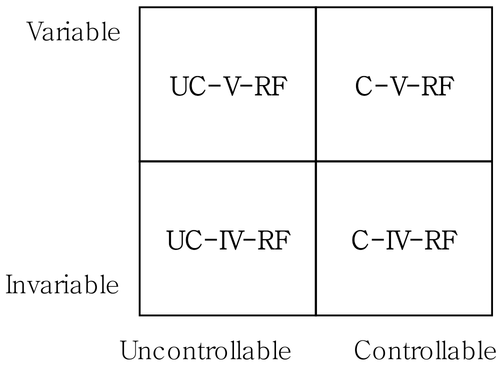

Figure 4: 2 by 2 RF matrix

Calculation of OP and AP
IP cannot be reached by effort in project level. Therefore, OP and AP should be calculated to carry out practical productivity evaluation. Based on labor productivity calculation, AP can be measured as shown below:

$$AP = \frac{Output(quantities)}{Man \cdot Hour} \qquad (5)$$

While OP is also a measurement of conceptual productivity and cannot be calculated, approximate quantity of OP can be computed by utilizing multiple linear regression analysis with a longitudinal process. This study determines that quantity as an OP value when calculating PAR. Detailed procedure is as follows:

1 RFs are listed and identified. The computation should be made based on expertise, experience and paper work. 2 by 2 RF matrix can be completed by locating RFs into the right dimension.

2 Quantification methods are determined by identified V-RFs. There is no need for IV-RFs, because OP calculation is a kind of longitudinal process. Quantification method includes direct quantification, indirect quantification and non-parametric ranking.

3 RFs and productivity data are collected periodically. Herbsman and Ellis(1990) recommends that the minimum number of observations should be at least three times the number of the V-RFs involved in a specific item. For example, if there are 10 V-RFs, then 30 or more cases should be collected.

4 Correlation analysis is conducted to determine whether each RF is mutually exclusive or not. In a case where some RFs are dependent on another, a ripple effect can be generated yielding an incorrect OP value at the end.

These are two possible solutions in solving the interdependency problem. First, RFs of similar constructs can be combined. Second, RFs can be gathered in a pattern to make new factors. This technique is called factor analysis.

5 A multiple linear regression analysis is conducted to figure out an OP value. In each case, RFs are explanatory variables and APs are dependent. The analysis should be verified by a significance test. These RFs that are not statistically significant should then be excluded.

The regression equation has the following construction:

$$AP = A - \sum_{n} B_{1,n} \cdot C - V - RF_n - \sum_{l} B_{2,l} \cdot UC - V - RF_l \quad (6)$$

where A is the y-intercept; $B_{1,n}$ is the regression coefficient for C-V-RF_n; $B_{2,l}$ is the regression coefficient for UC-V-RF_l.

6 OP during a certain period t is calculated as the equation below:

$$OP_t = A - \sum_{l} B_{2,l} \cdot UC - V - RF_{l,t} \quad (7)$$

where UC-V-$RF_{l,t}$ is the value of UC-V-RF_l at the period t.

That is, OP is the productivity value when C-V-RFs have not yet occurred. Mathematically, the value of C-V-RF is 0. Though an intercept A is supposed to be an IP value, it has to be proven if it's IP or not. Because a regression model is only statistically valid within the range of values observed for RFs (Betteley 1994).

The process to determine OP value gains more accuracy as more data are collected. Figure 5 shows the overall procedure.

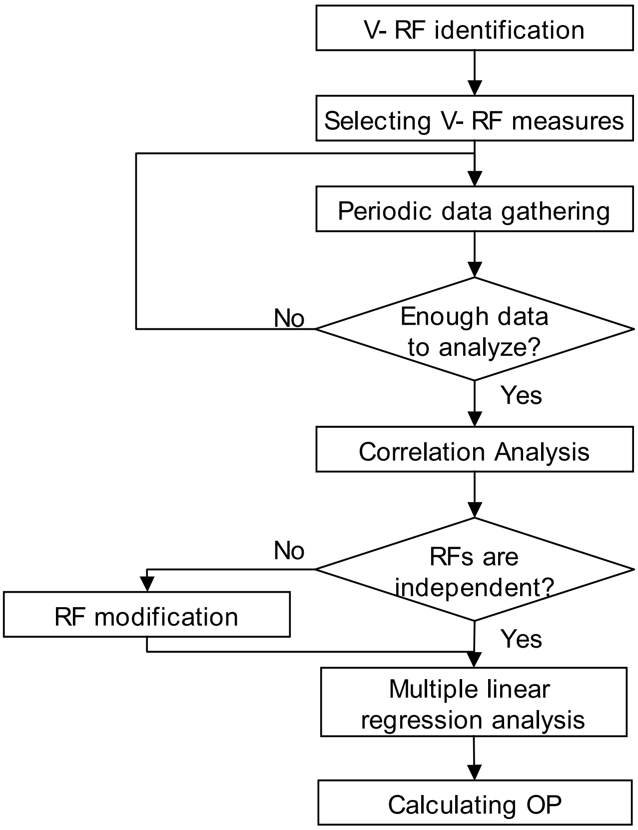

Figure 5: OP calculation procedure

PRODUCTIVITY ACHIEVEMENT RATIO

PAR as a productivity evaluation indicator

Productivity Achievement Ratio (PAR) can be represented as the quotient of the AP and the OP. This value can be used as a productivity evaluation indicator because it includes obtainable productivity. In other words, PAR informs what items are executed with low management capacity, and suggests what items a project manager should concentrate on to improve the AP. PAR is expressed as below:

$$PAR = \frac{AP}{OP} \times 100(\%) \tag{8}$$

where 0 ≤PAR ≤100.

High PAR indicates better management of productivity on a certain item. On the contrary, an item with low PAR should be supervised or studied to improve on-site productivity. Figure 6 explains this concept more clearly.

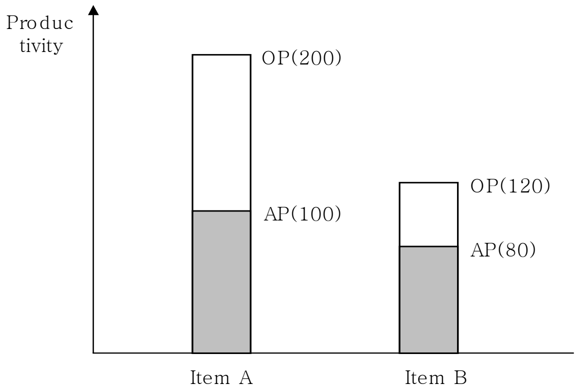

Figure 6: Productivity values of item A and item B.

In figure 6, although AP of item A is higher than that of item B, more attention should be paid to item A because PAR of item A is 50%, while PAR of item B is 67%.

PAR can also be used to compare equal items in different fields, since it is non-dimensional. For example, when PAR of steel fabrication is 70% in site A and 80% in site B, it is possible to say that site B manages steel fabrication productivity better than site A.

Verification of PAR

PAR meets the qualifications Business Roundtable(1987) suggested for productivity indicator.

Determine how effectively their projects are being managed.
PAR value and its change can signify how effectively on-site productivity is being managed. This is because PAR is not concerned about the change in productivity but about the change in effectiveness of productivity management.

Detect adverse trends quickly so corrective actions may be taken.
It is possible to determine which item has low PAR value when on-site data are collected periodically. As low PAR value means room for improving productivity, more supervisions or corrective actions are required.

Moreover, each standardized regression coefficient of the regression model generated in OP calculating process indicates the magnitude of RF's influence on productivity. This information can be used to take appropriate actions for productivity management.

Determine the effects of changed methods or conditions.
Contractors are able to calculate PAR values on certain methods or conditions. That is to say, accumulated PAR values are used as data to determine the effects of methods or conditions on productivity management. For example, if PAR values of steel installation in three apartment construction fields are 73%, 76% and 79%, it is possible to say that contractors are acquiring productivity equivalent to 76% of obtainable productivity when they execute steel installation works in apartment fields. This is the case with most of the methods.

Identify both high and low areas of productivity and reasons for the differences.
Because PAR values are calculated continually in a building period, the Highs and Lows can be taken to evaluate productivity management performance. In addition, the comparison between RF values of high PAR cases and low PAR cases explains which RF is the main reason for the differences.

Compare the performance of different contractors.
Despite the sameness of the items, methods, and conditions, different PAR values can be yielded according to the contractors. The difference accounts for the abilities of the contractors to manage productivity.

CONCLUSION

Productivity alone and its change do not provide contractors useful information to manage construction productivity. It is because productivity simply shows the actual achievement without measure of obtainable productivity. This problem obstructs a well-defined and balanced implementation of productivity management.

This study has suggested PAR as the productivity evaluation indicator that includes obtainable productivity, and compares productivity management performances with different items and in different sites. A verification study has been conducted based on literature study.

PAR makes it possible to gain significant information from data or facts regarding construction productivity. When PAR values are calculated and collected from many cases, a theory or knowledge on productivity management of construction can be derived by cross-sectional research.

ACKNOWLEDGEMENT

The writers thank the ‘NRL Program of Korean Government (Grant No. M10104000274-01J000012100)’ for supporting portions of the work presented here.

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