

Productivity Management Methodology Using Productivity Achievement Ratio

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Abstract

Although construction productivity has received a great deal of attention from construction practitioners and researchers, few research efforts have specifically evaluated productivity in the context of the productivity management cycle. Consequently, there is still a lack of useful indicators for determining which items should be prioritized and improved upon in order to yield the highest benefits from productivity management. In an effort to address this issue, this study proposes the Productivity Achievement Ratio (PAR), which is a productivity evaluation indicator that will assist in the selection of the most appropriate management items for construction productivity enhancement. Using a multiple linear regression analysis, the process for calculating the PAR is developed, and the applicability of the proposed indicator is verified through a case study of steel erection work. The results of this study indicate that the PAR can aid construction practitioners in achieving more balanced and effective productivity management, even when management resources are limited.

Keywords: *productivity, productivity management, reduction factor, productivity achievement ratio, regression analysis*

1. Introduction

Productivity -one of the major factors used in measuring industry outcomes- is defined as the relation between a production system output and the input set in that system. The importance of managing productivity has long been emphasized in the construction industry, and a considerable amount of research has been conducted on the issue. Sumanth (1984) argued that both managers and employees should pay close attention to productivity management and that the productivity management cycle has four phases: measurement, evaluation, planning, and improvement, as depicted in Table 1.

There have been many research efforts to examine productivity measurement and consequently contribute to the better

productivity management (Heap, 1987; Herbsman and Ellis, 1990; Thomas and Završki, 1999). However, despite yielding decent estimations of productivity, these studies have rarely identified which items require the most attention for optimal productivity management. Indeed, productivity has commonly been estimated by the ratio between system output and input without consideration of the particulars of each work item.

Considering each work item when measuring productivity is a complex process. For instance, it must be taken into account that work items associated with low productivity do not always have high potential for improvement. As well, a minimal change in productivity does not necessarily signify the presence of a work item linked with a poor management performance. To deal with these complexities, an advanced productivity indicator, which can account for the unique characteristics of each item, is needed.

For example, Table 2 shows the labor productivity associated with several types of formwork in an apartment project in Korea (Jung *et al.*, 1995).

As seen in Table 2, the labor productivity of the euro form · plywood form is 0.628 M²/Man·Day, while that of the prefabricated form is 0.707 M²/Man·Day. However, this fact does not directly indicate that the productivity management of the prefabricated form is better than that of the euro form · plywood form. It would also be inappropriate to conclude that the euro form û

Table 1. Work in Each Phase of Productivity Cycle

Cycle	Contents
Measurement	Focusing on calculation of productivity value by measurer's definition and scope.
Evaluation	Estimating the amount of productivity change between two discrete periods.
Planning	Devising short and long-term plans in regards to future productivity
Improvement	Performing actual productivity improvement process using several methods.

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Table 2. Labor Productivity of Several Types of Formwork in an Apartment in Korea

Method	Labor (Man·Day)	Floor Area (M ²)	Productivity	
			Labor (Man·Day/M ²)	(M ² /Man·Day)
Euro Form · Plywood Form	48,875	30,671.74	1.59	0.628
Gang Form · Partial PC	31,928	20,483.94	1.56	0.641
Prefabricated Form	59,828	42,275.04	1.42	0.707

plywood form has higher potential for improvement than the prefabricated form. Instead, it must be determined which items should be focused on during the planning and improvement phases of the productivity management cycle. These items should not be chosen merely by estimating productivity without considering the potential effects of management activity. Although conversion factors can be used to account for different labor resources and conditions required for the outputs (Thomas *et al.*, 1999), they still do not provide clear information regarding the potential effects of management activity. Thus, this research aims at developing a productivity evaluation indicator that takes management aspects into account so that the most appropriate items for management activity are selected, and so that the benefits of productivity are maximized.

2. Productivity Management Indicators

Many researchers have already identified and recognized the effects of productivity influence factors to secure the applicability of productivity indicators in the actual construction process. Borchering *et al.* (1986) has classified the causes of productivity decrease in construction work into five categories: (1) waiting or idle; (2) traveling; (3) working slowly; (4) doing ineffective work; and (5) doing rework. Craft workers produce less output per unit of time due to one or more of these basic nonproductive activities. Their work also tends to be affected directly or indirectly by several other factors. Son and Lee (2002) have identified and categorized productivity influence factors into five sections: (1) labor problem; (2) design management problem; (3) construction management problem; (4) resource problem; and (5) project characteristics and external factors. However, both of these studies have quantificational problems and cannot be applied to mathematical approaches.

Kim (1994) has divided productivity influence factors into factors that improve productivity and factors that decrease productivity. Kim's research has assumed the existence of a standard of judgment between improvement and decrease. However, because construction technology has continued to develop over time, this standard has become increasingly outdated. Therefore, the standard should be presumed as the best productivity where every condition is perceived as perfect. In this case, factors

obstructing the achievement of optimal productivity should be identified.

Alarcon and Ashley (1992) have developed a General Performance Model (GPM) to evaluate performance at the project level. The GPM is composed of sets of variables that are directly affected by project options. These variables, or "drivers," include craft labor, engineer, owner, and project manager. During the production process, these variables propagate effects and consequently generate four project outcomes: cost, schedule, value, and effectiveness. According to the decision maker's preference, these outcomes can be combined into one value. However, this model is too abstract and simplified to be used in practice.

Different productivity influence factors are also mentioned in the works of Adrian (1987), Oglesby *et al.* (1989), and Heap (1987). Yet, there is still a considerable shortage of research examining precisely how influential these factors are and whether they actually impact productivity in reality.

Based on these influence factors, many researchers have devised productivity indicators. However, these indicators cannot concurrently track, over time, changes in productivity and the influence factors that impact productivity, and, thus, lack applicability and utility for actual on-going construction projects. For instance, Thomas and Završki (1999) has proposed baseline productivity to be used as an indicator for productivity management. Baseline productivity is the value of productivity unaffected by disruption. It is determined basically as the median of the daily productivity values in the baseline subset (Thomas *et al.*, 1999). And regression analysis was utilized to determine the relation between each disruption and productivity reduction. Nevertheless, this indicator merely serves as an estimation model and does not involve productivity evaluation. Furthermore, Thomas's approach assumes that baseline productivity is not going to change over the course of a single construction project, but rather that a certain obtainable productivity fluctuates over the entire construction period.

Herbsman and Ellis (1990) have also suggested a statistical model that establishes the quantitative relationship between influence factors and productivity rates. A regression equation can 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 because it does not assist in the selection of corrective actions during construction.

In addition, Oglesby *et al.* (1989) have proposed the labor utilization factor (LUF) to measure work effectiveness. The LUF aims at determining how workers contribute to overall project performance based on activity sampling. Although LUF proposes an indicator to monitor the number of workers engaged in effective work, activity sampling generally does not yield a measure of productivity because the output is not recorded in a usable form (Thomas *et al.*, 1990). Furthermore, it is not necessarily true that a direct improvement to productivity occurs from allocating more laborers to doing effective work rather than to doing essential contributory work, or to doing ineffective work.

3. Definitions

3.1 Productivity

This research assumes that there exists productivity yielded under an ideal situation. Such productivity is defined as Ideal Productivity (IP). In contrast, Actual Productivity (AP) is yielded in reality where various factors can prevent the attainment of IP. In addition to IP and AP, there exists Obtainable Productivity (OP). OP is the maximum productivity that can be attained through the adequate management of controllable variables. The differences between OP and Thomas’s (1999) baseline productivity are determined, as shown in Table 3.

Table 3. Comparison of Baseline Productivity and Obtainable Productivity

Baseline productivity	Obtainable productivity
The maximal productivity (or top 10%) obtained within the project	Productivity obtained from the most controllable situation.
1:1 function to event	Focusing on factors, not events
Pre-set from existing data and therefore unchangeable over time.	Calculated by current site data. As time passes and data is accumulated, accuracy increases.

Fig. 1 illustrates those differences. Dots in the figure represent the daily results of productivity (AP). The Y axis is productivity as a unit-rate. That is, if less amount of input is required for one unit-work, a higher productivity is yielded. The daily amount of productivity is constantly changing. Regardless of changes in project circumstance, baseline productivity is set by the median of the daily productivity values in the baseline subset which is 10% of the total workdays. However, OP is changing on a daily basis according to changes in project circumstances. It is notable that OP does not necessarily follow the same pattern as the actual productivity curve.

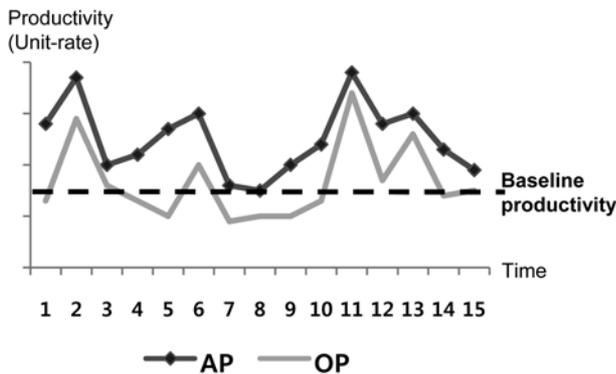


Fig. 1. Comparing Baseline Productivity with Obtainable Productivity (Modified based on Thomas and Završki (1999))

3.2 Reduction Factor

A Reduction Factor (RF) is defined as a factor that prevents productivity from reaching an IP value. Namely, an RF makes the difference between IP and AP. This idea is formalized in the

following equation:

$$AP = IP - \text{an amount of productivity loss caused by RF} \quad (1)$$

RFs can be clearly explained by the “Factor-Event-Outcome” model based on the GPM (general performance model) of Alarcon and Ashley (1992). Only a factor can be an RF, not an event. For example, although “overtime” causes productivity to decrease, it cannot be called an RF because it is an event. In this case, “insufficient time” is considered a factor and therefore an RF.

Reduction Factors are classified into four factors based on the following criteria.

3.2.1 Can the RF be Controlled by Anyone Working on the Construction Project?

Project managers can control factors, such as “site layout plans,” that can potentially obstruct AP from reaching OP. However, other factors, such as “weather conditions,” cannot be controlled or stopped, therefore preventing OP from reaching IP. While the former factor type is referred to as a Controllable-RF (C_RF), the latter is referred to as an Uncontrollable-RF (UC_RF). These concepts are presented in the following equations:

$$OP = IP - \text{an amount of productivity loss caused by UC_RF} \quad (2)$$

$$AP = OP - \text{an amount of productivity loss caused by C_RF} \quad (3)$$

Fig. 2 visualizes the relationship between RFs and productivity.

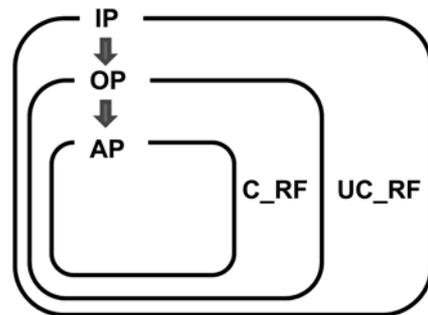


Fig. 2. Relationship of Reduction Factors and Productivity

3.2.2 Can the Value of an RF Change During the Project Period?

While some RFs, such as “worker faithfulness,” change from day to day, other RFs, such as “insufficient drawings,” remain unchanged over the course of construction. The former RF type is called a Variable-RF (V_RF), while the latter is called an Invariable-RF (IV_RF). Though an IV_RF should be considered an RF when comparing different work sites, it does not impact changes in the productivity value of one construction field.

These two criteria form a 2x2 RF matrix, as shown in Fig. 3. For example, “weather conditions” belong to the UC_V_RF dimension, while “work schedule planning” is a typical C_V_RF. Furthermore, “site location condition” is considered to be an UC-IV-RF and “site layout planning” fall into the C_IV_RF category.

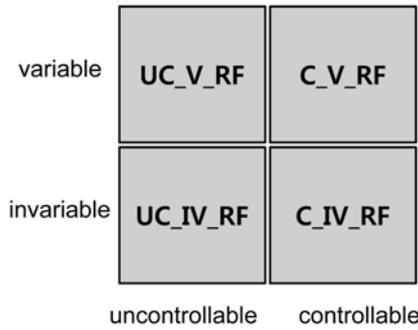


Fig. 3. RF Matrix

3.3 Calculating OP and AP

Because IP cannot be attained through efforts at the project level, the OP and AP should be calculated for the purpose of a practical productivity evaluation. Based on the labor productivity calculation, AP is measured as follows:

$$AP = \frac{\text{Output(quantities)}}{\text{Man} \cdot \text{Hour}} \quad (4)$$

OP is a measurement of conceptual productivity and cannot be directly measured. However, given the RFs and using regression analysis, the best-fit line can be drawn where the sum of each residual's square value is a minimum. Thus, the approximate OP is the fitted value for the given RF values. This procedure involves the following steps:

1. RFs are listed and identified through computations performed by an expert, and then recorded in the corresponding paperwork. Then, the 2x2 RF matrix is completed by inserting the RFs into the appropriate dimension.
2. Quantification methods are determined by the identified V_RF. There is no need for IV_RF because they remain unchanged in a project and therefore do not affect changes in the productivity value during the OP calculation. The quantification method includes direct quantification, indirect quantification, and non-parametric ranking.
3. RFs and productivity data are collected periodically. Herbsman and Ellis (1990) have recommended that the minimum number of observations should be at least three times the number of the V_RF. For example, if there are 10 V_RF, then 30 or more cases should be collected.
4. A correlation analysis is conducted to determine whether each RF is mutually exclusive or not. When an RF is dependent on another RF, a ripple effect can be generated, yielding an incorrect OP value at the end of the analysis. To solve this interdependency problem, RFs with similar constructs can be combined. Or, RFs can be gathered into a pattern to make new factors. The latter technique is known as factor analysis.
5. A multiple linear regression analysis yields an OP value. In each case, RFs are explanatory variables and APs are dependent variables. This analysis should be verified by a significance test; then, the RFs that are not statistically significant should be excluded. The regression equation is as follows:

$$AP = A - \sum_n B_{1,n} \cdot C_V_RF_n - \sum_l B_{2,l} \cdot UC_V_RF_l \quad (5)$$

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 $UC_V_RF_l$.

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

$$OP = A - \sum_l B_{2,l} \cdot UC_V_RF_{l,t} \quad (6)$$

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 the C_V_RF. has not yet occurred. Mathematically, the value of the C_V_RF is 0. The process for determining the OP value becomes increasingly accurate as more data are collected. Fig. 4 shows the overall procedure.

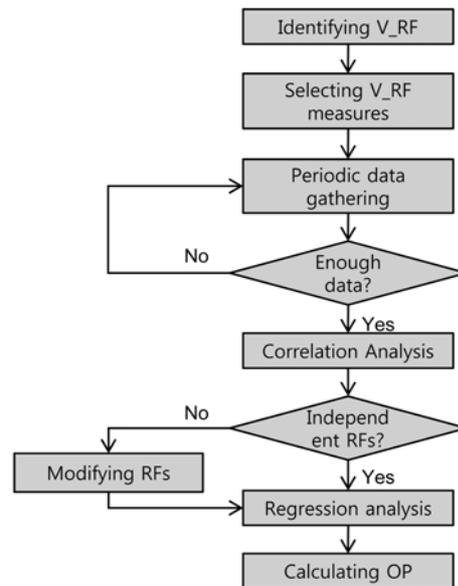


Fig. 4. OP Calculation Procedure

4. Productivity Achievement Ratio (PAR)

The Productivity Achievement Ratio (PAR) can be represented as the quotient of AP and OP. This value considers the potential effect of improvement and therefore can be used as a productivity evaluation indicator to determine the main items that should be focused on during construction. The PAR is formulated as follows:

$$PAR = \frac{AP}{OP} \times 100(\%) \quad (\text{where, } 0 \leq PAR \leq 100) \quad (7)$$

An item with a high PAR indicates that the item's productivity has been managed effectively. On the contrary, an item with a low PAR should be carefully monitored and studied to improve on-site productivity. For example, in Fig. 5, though the AP of

item A is higher than that of item B, item A should be prioritized by site management because the PAR of item A is 50%, while the PAR of item B is 67%. Site management should investigate the main culprit of the productivity loss and make efforts to reduce or minimize the cause.

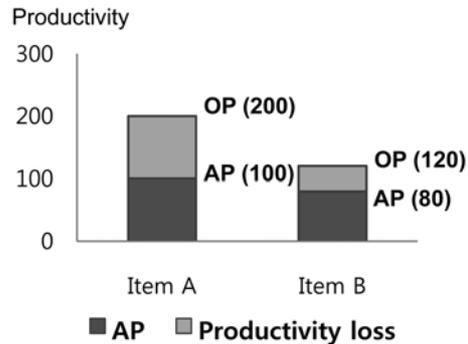


Fig. 5. Comparison of Productivity between Item A and Item B

Since it is non-dimensional, the PAR can be used to compare the same items among different sites with different C_RFs. For example, when the PAR of steel fabrication is 70% in site A and 80% in site B, it can be inferred that site B manages steel fabrication productivity better than site A.

4.1 Verification

The verification of the PAR was performed according to the Business Roundtable's (1987) suggested qualifications for productivity indicators. It has suggested that productivity indicators should implement the following functions: (1) Determine how effectively projects are being managed; (2) Detect adverse trends quickly so that appropriate corrective actions can be performed; (3) Determine the effects of changed methods or conditions; (4) Identify both high and low areas of productivity and the reasons for differences in their productivity; and (5) Compare the performance of different contractors.

Not only did the PAR meet these qualifications, its applicability was further tested in a real construction site (described in a later section of this paper). The initial verification is as follows:

4.1.1 Determine How Effectively Projects are Being Managed

Because the PAR deals with changes in productivity management effectiveness, not changes in productivity, the PAR value and its variations can indicate how effectively on-site productivity is being managed.

4.1.2 Detect Adverse Trends Quickly so that Corrective Actions may be Taken

When on-site data are collected periodically, it is possible to determine which items have a low PAR value. Because a low PAR value indicates that there is room for productivity improvement, it can also alert managers that supervision or corrective

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

4.1.3 Determine the Effects of Changed Methods or Conditions

Using accumulated PAR values, contractors are able to calculate the PAR values of certain methods or conditions and determine their effects on productivity management. For example, if the PAR values of steel installation in three apartment construction projects are 73%, 76%, and 79%, respectively, it can be inferred that contractors are acquiring a productivity equivalent of 76% of obtainable productivity when they execute steel installation works in apartment projects. This is the case with most construction methods.

4.1.4 Identify Both High and Low Areas of Productivity and the Reasons for Differences in Their Productivity

Because the PAR values are calculated continually during construction, both high and low areas of productivity can be used to evaluate productivity management performance. Additionally, a comparison between the RF values of high and low PAR cases can identify the RF that is the main reason for discrepancy between these values.

4.1.5 Compare the Performances of Different Contractors

Despite the sameness of items, methods, and conditions, different contractors often yield dissimilar PAR values because of different levels of ability and expertise in managing productivity.

4.2 Productivity Management Using the PAR

As a productivity evaluation indicator, the PAR can assist construction practitioners in identifying the management items that require productivity improvement the most. The PAR does this by focusing on an item's potential for improvement. In Fig. 6, although item B has a better productivity value than item A, more intensive management is required for item B. Therefore, causes of the productivity loss of item B can be investigated and short-term and long-term plans can be established to reduce the productivity loss. Then, the process for improving the actual productivity of item B can be performed to acquire higher PAR. Likewise, the PAR can be used for a comparison of the same items from different sites and for a comparison of different items at the same site.

It must be taken into account that the prioritization of PAR improvement can be affected by factors other than productivity itself. For example, when it is relatively expensive to improve the PAR of an item, the current production system might be kept in place for the sake of cost-effectiveness.

From an organizational perspective, an RF can be understood as a monitoring object. In other words, once RFs seriously affecting the PAR of an item are identified, construction companies

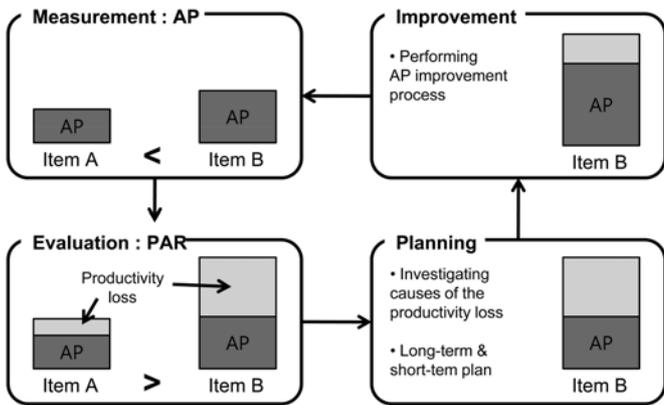


Fig. 6. Productivity Management Model using PAR

can monitor values of the RFs and company-wide effort to reduce them. In addition, in the process of indentifying RFs, tacit knowledge about influential factors on each item can be turned into explicit knowledge. This output could be used to establish a comprehensive productivity management manual for construction companies.

5. Case Study

5.1 Data Gathering

To verify the applicability of the PAR, a case study examining steel erection work was conducted. As detailed in Table 4, data on the number of workers, quantity of work done, value of every V_RF, and outliers such as civil petition, rework, accident, and severe weather, were collected on a daily basis with help from a

Table 4. Data Description

Classification	Contents
Subject	Apartment project, Seoul, S.Korea
Type	Steel erection on typical floor
Form Method	Combination of gang form and euro form
Duration	MAR 1 2003- MAY 10 2003 (40 days)
Contents	Number of workers, quantity of work done, value of each V_RF, other factors causing productivity to decrease

Table 5. Case Study Reduction Factors and their Quantification Methods

No.	RF	Definition	Quantification method
RF1	Workers' Responsibility (Motivation)	Did workers do their jobs responsibly?	Likert scale (1 to 5) *When calculating the PAR, it is converted to (5 - Likert Scale)
RF2	Order and delay of approval	Was there proper order and manager response?	Likert scale (1 to 5) *When calculating the PAR, it is converted to (5 - Likert Scale)
RF3	Intervention between items	Was there anything that keeps workers away from their main work?	Intervening hours between other works
RF4	Delay of material delivery	Did materials arrive at the work-site on time?	Idling hours caused by the delay of material delivery
RF5	Stoppage	Had there been any work stoppage in the previous day?	1 if work was stopped. If not, 0.

field engineer after a series of interviews with four site engineers.

Through interviews with experts of the case project, an analysis of monthly meeting minutes, and daily work records, the RFs were identified and set. Each RF and its quantification method are shown in Table 5. The Likert scales of RF1 and RF2 were converted to (5 - Likert scale of 1-5) to make all the values of RFs aligned in one direction. In other words, the more the value of an RF increases, the more the magnitude of the RF increases. Also, zero value of an RF means that there is no productivity loss caused by the RF on that day.

Outliers were excluded from the analysis. Those were caused by the following reasons: (1) rain; (2) specific rework assigned by supervisors; (3) training on safety and physical checkup; (4) steel unloading work; (5) check by head office; and (6) trouble with tower crane operator. Although these are rather common in construction sites or seem like uncontrollable RFs, they generated skewed effect on productivity of steel erection work and therefore had to be excluded in the examination. Consequently, 28 out of 40 days were chosen for analysis; the results are shown in Table 6.

5.2 Calculation of PAR

A correlation analysis was conducted to confirm that the factors are not significantly related to each other. If the correlation between factors is over 0.8, this may be an indication of multicollinearity. The results of the correlation analysis are shown in Table 7. The distinguishing relationship is not shown.

A multiple linear regression analysis was conducted by setting the RFs as independent variables and the AP as a dependent variable using stepwise method. RF2 and RF3 were excluded because they are statistically insignificant (p-values for RF2 and RF3 are 0.689 and 0.930 respectively). The equation is shown below. Significance levels of coefficients of constant, RF1, RF4, and RF5 are 0.000, 0.011, 0.012, and 0.019 respectively.

$$AP = 1.031 - 0.064 \cdot RF1 - 0.063 \cdot RF4 - 0.094 \cdot RF5 \quad (8)$$

The R² value is 0.494, and the adjusted R² is 0.431. R² value is called the coefficient of determination and is the percentage of the total variation in y, which is explained by regression (Betteley et al., 1994). In this case study, this means that 49.4% of the total variation in AP is explained by the regression model.

Table 6. Results of Steel Erection Work on Typical Floor

Record No.	AP (Ton/Man·Day)	RF1 (Workers' attitude)	RF2 (Order and delay of approval)	RF3 (Intervention between items)	RF4 (Delay of material delivery)	RF5 (Stoppage)
1	0.81	1	2	1	0	1
2	0.83	1	1	0	0	1
3	0.81	0	1	1	2	0
4	0.95	2	2	0	0.5	0
5	1.14	0	0	1	0	0
6	0.80	1	1	0.5	0	0
7	0.88	0	2	0	1	1
8	0.79	1	2	0.5	0	1
9	1.11	0	2	0	1	0
10	0.83	2	2	0	0	1
11	0.77	1	1	0.5	1.5	1
12	0.85	1	2	0	1	0
13	0.97	0	1	0	0.5	0
14	0.82	1	1	0	0	1
15	0.99	1	1	0	0	0
16	0.71	3	1	1	3	0
17	0.74	2	1	0.5	1	0
18	1.13	0	1	0	0	0
19	0.88	1	1	0	0	0
20	0.97	1	1	0.5	0	0
21	0.90	1	2	0	0	0
22	0.93	1	2	0	0	0
23	0.81	0	1	1.5	2	1
24	1.03	2	2	0	0	1
25	1.19	0	1	1	0	0
26	0.95	2	2	0.5	0	0
27	0.84	1	2	0	0.5	1
28	0.88	1	1	0	0	0

When additional proper factors are considered, the R² value and adjusted R² will be increased. However, the regression equation satisfied the significance test with the result of 7.815 for the F-value and 0.01 for the significance level.

Through a discussion with experts, “workers’ responsibility” (RF1) and “delay of delivering materials” (RF4) were set as controllable RFs; “stoppage” (RF5) was set as an uncontrollable RF because it is a factor that has already occurred. OP on the 28th day is calculated as follows:

$$OP = 1.031 - 0.094 \cdot 0 = 1.031 \text{ Ton/Man·Day} \quad (9)$$

The value of AP on the day is 0.880 Ton/Man·Day. Correspondingly, the PAR on the 28th day is 0.880/1.031 = 0.854. Thus, on the 28th day, the steel erection work approaches 85.4% of

Table 7. Correlation Analysis Results

		RF1	RF2	RF3	RF4	RF5
RF1	Corr.	1.000	.280	-.120	.088	.034
	Sig. N	.28	.150	.543	.655	.868
RF2	Corr.	.280	1.000	-.394	-.123	.277
	Sig. N	.150	.28	.038	.531	.153
RF3	Corr.	-.120	-.394	1.000	.464	.018
	Sig. N	.543	.038	.28	.013	.928
RF4	Corr.	.088	-.123	.464	1.000	.000
	Sig. N	.655	.531	.013	.28	1.000
RF5	Corr.	.034	.277	.018	.000	1.000
	Sig. N	.868	.153	.928	1.000	.28

Table 8. Calculation of the PAR in Steel Erection Work using Regression Analysis

Record No.	AP (Ton/Man·Day)	OP (Ton/Man·Day)	PAR	R ²	Significance level
13	0.97	0.947	102.4%	0.306	0.050
14	0.82	0.818	100.2%	0.323	0.034
15	0.99	0.952	104.0%	0.352	0.020
16	0.71	0.950	74.7%	0.287	0.033
17	0.74	0.951	77.8%	0.329	0.016
18	1.13	0.974	116.0%	0.378	0.007
19	0.88	1.007	87.4%	0.515	0.003
20	0.97	1.011	95.9%	0.518	0.002
21	0.90	1.009	89.2%	0.517	0.001
22	0.93	1.010	92.1%	0.519	0.001
23	0.81	0.977	82.9%	0.620	0.000
24	1.03	0.929	110.9%	0.467	0.005
25	1.19	1.036	114.9%	0.510	0.002
26	0.95	1.037	91.6%	0.507	0.001
27	0.84	0.937	89.6%	0.512	0.001
28	0.88	1.031	85.4%	0.494	0.001

obtainable productivity.

OP can be calculated with the same method on the other days. PAR can be calculated by dividing AP by OP on a day. 13th day was the first to satisfy the significance test. Results are shown in Table 8.

5.3 Implications

As discussed earlier, existing productivity evaluation methods measure the amount of change in AP. Thus, it can be argued that productivity on the 28th day jumps as much as 0.040 Ton/Man·Day from 0.840 Ton/Man·Day to 0.880 Ton/Man·Day. However,

the existing methods do not provide information regarding productivity achieved out of obtainable productivity. On the contrary, the PAR on the 27th day is 89.6% and the PAR on the 28th day is 85.4%. It implies the PAR decreases as much as 4.2%p for two days despite the productivity increase. Consequently, it can be said that productivity management is better on the 27th day than the 28th day. Likewise, when the PARs of different items in a field are measured and monitored, the main items requiring prioritization for effective productivity management can be identified.

Fig. 7 shows values of PAR, R^2 , and the significance level during the observation (from 13th day to 28th day). Though the significance level is less than 0.050 in the duration, R^2 value continuously increases from 0.306 (13th day) to 0.494 (28th day) while the significance level continuously decreases from 0.050 (13th day) to 0.001 (28th day), which mean in reality the PAR can be utilized after productivity data are gathered in some duration.

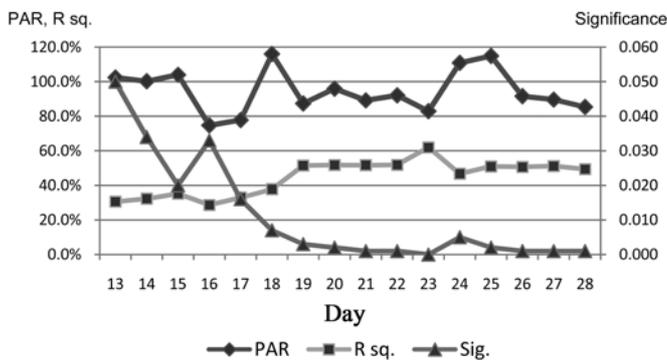


Fig. 7. PAR, R^2 and Significance Level during the Observation

Also, observations on some days (e.g., 18th, 24th, and 25th day) show that AP is higher than OP, which ends up with the PAR being higher than 100%. It is because the variables considered here explain around 50% of total variation in AP. Regression analysis yields best-fit line based on the given data. OP, calculated by regression analysis, is the fitted value (or estimated value in a practical sense) for the given RF values and therefore has inherent discrepancy. The discrepancy has to be discussed in the productivity management and reduced with future research effort. Nonetheless, it can be still argued that higher value of PAR means more effective productivity management.

6. Conclusions

Because productivity simply shows actual achievement without taking obtainable productivity into account, it alone does not provide contractors with sufficient information to manage construction productivity to an optimal level. There is still a lack of useful indicators for determining which items should be prioritized and improved upon in order to yield the highest benefits from productivity management. To address this issue, this research proposes the Productivity Achievement Ratio (PAR) to be utilized as a productivity evaluation indicator. This research

also demonstrates how the PAR identifies which items should be prioritized during the planning and improvement phases of the productivity management cycle.

The PAR enables construction organizations and site management to manage productivity in a timely and effective manner. The potential contributions of this research are as follows:

1. Three types of productivity, AP, OP, and IP, were defined, and the productivity evaluation indicator, PAR, was suggested as the quotient of AP and OP.
2. The PAR calculation process was suggested to enhance the applicability of the indicator.
3. The RF classification criteria, controllability and variability, and RF matrix were suggested for the effective application of the PAR calculation.
4. The validation and applicability of the PAR was verified using the detailed productivity indicator functions that have been suggested by the Business Roundtable.
5. A case study on the PAR was conducted in the steel erection work of an actual project and implications were drawn. In the case study, the PAR on the 27th day was 89.6% and the PAR on the 28th day was 85.4%. It can be said that productivity management of the steel erection work was better on the 27th day than the 28th day.

However, despite its potential contributions, this research still has several limitations. First, every RF should be classified objectively to be put into the RF matrix. Second, many RFs cannot be clearly classified as totally controllable or totally uncontrollable. For example, “workers’ responsibility” is neither totally controllable nor totally uncontrollable. Thirdly, it must be taken into account that defining the controllability of certain RFs is dependent on relevant subjects. For instance, an “irrational site arrangement plan” is an uncontrollable factor for the worker’s group and a controllable factor for the site manager’s group. Thus, further research effort should be put into identifying and quantifying uncontrollable reduction factors to yield more accurate values. In addition, there is potential for this suggested model to be transferable to other sites with same or similar work because productivity of a work seems to be affected by some common factors derived from the characteristics of the work; however, the further research effort should be put to clarify the transferability issue. Finally, future research should also focus on elaborating the OP calculation to improve the applicability and accuracy of the PAR.

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