Improvement of Productivity through the Control of Continuity and Variation of Work Flow in Building Space

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Abstract
The majority of currently used construction productivity management systems rely on result-based management techniques, which have difficulties in managing in uncertain environments. Massive amounts of time and resources are wasted due to conflicts between works and constraints in space, etc. Hence, we need to recognize the limitations of existing result-based management systems and suggest a productivity management index that is expected to ensure that the issues of productivity reduction are properly controlled.

Work flow refers to the progression of work in a limited time and space. Schedule delay and expense waste can be controlled by managing the work flow. Measurement of work flow is evaluated using 3 indices: Continuity Index, Variation Index, and Productivity Index. Therefore, this research suggests an evaluation and measurement system for work flow that shows the productivity of construction work both directly and indirectly, and thereby aims at an improvement in project performance by using a target index.

Keywords: work flow; Variation Index; Continuity Index; productivity; Lean Construction

1. Introduction
The productivity of construction work is influenced by various factors including construction workers, design documents, the nature of construction work, and external factors of construction, etc. In addition, the factor of uncertainties in the construction process brings difficulties to project productivity management.

The occurrence of uncertainties in construction work is inevitable since most current project management systems operate in a top-down manner in which the lower level plan is determined by the upper level plan (Tommelein, 2002).

Researchers and site engineers in construction have tried to develop appropriate methods of productivity measurement. (Han, 2010) The performance-based productivity management techniques for a project provide unreliable outcomes on scheduling for a project's stakeholders since they do not consider the environment of construction work that is interdependent and has various uncertainties (Ballard and Howell, 2003).

Inappropriate project management frequently causes inconsistencies between the planned work process and the actually executed work process on construction sites. Consequently, a reduction in productivity is often observed, such as discontinuous progression of works, delays in works, interference between works, and loss of materials.

Therefore, the various limitations of the result-based management approach currently used need to be recognized and efforts need to be made to improve such management practices.

The concept of Lean Construction, in the context of productivity improvement, adopts the next generation of procurement management technique, schedule management technique, and performance management technique based on productivity waste management. Lean construction reduces construction cost, improves productivity, and thus aims to maximize customers' value by minimizing all ever-present factors that may cause waste, which always exist during the construction process.

Management of uncertainties by using the Last Planner System (LPS) was recommended by the Lean Construction Institute (LCI). However, the LPS model provides a simple evaluation on the ratio of the execution of the plan without the process of quantitative analysis. The weakness of LPS is that it allows neither the analysis of the productivity of the current works nor the proposal of a specific management goal.

Hence, in the present progressive view, an objective technique of measurement, evaluation, and control for productivity of work flow is required in order...
to prevent issues of productivity reduction such as schedule delay and excessive input of resources, etc.

Approach methods in the context of work flow are actively used in developed countries including the USA and some countries in Europe and are evaluated as successful methods. Also, the construction scheduling technique has progressed drastically as scheduling software has become commercially available to project participants. (Choi, 2012)

Therefore, this research proposes a method for the measurement of work flow that directly and indirectly presents a productivity index of construction work. In addition, a work flow variation rating system is proposed in order to support continuous improvement in performance on actual construction sites. In this study, the method of work flow measurement and case analysis of the doctorate thesis written by Park, S. J. (2006) is cited and re-analyzed.

2. Methods and Scope
A methodology for the measurement of work flow that indicates the productivity of the construction process was proposed in this research. In addition, a case analysis was performed via the establishment of a system. In the case analysis, an improvement method for the performance of a project was offered by using a target control for Variation Index. This research was performed with the following procedure.

(1) Discussion on related researches
The direction of the research was proposed through investigations on literatures related to flow production theory, work flow variation, and work flow continuity.

(2) Measurement method for work flow
Various index functional formulas related to productivity were proposed based on the concept of Percent Plan Complete (PPC) and that of work flow evaluation.

(3) Development of system prototype
A prototype and operation process for the system was proposed based on the suggested measurement method.

(4) Validation through case study
Work flow variation was measured based on works on an apartment housing unit and an improvement method was proposed by setting the target index.

(5) Conclusions
The results from this research are summarized and a method for future studies is proposed.

3. Discussion on Related Researches
Walker (1985) introduced the concept that "Production process is the conversion process of input elements including resources, labor, and equipment to output elements as products" from production theory of the existing manufacturing industry to productivity analysis in the construction industry.

Koskela (1992) identified the limitation that 'Walker's model was able to improve the productivity or to reduce the cost only upon the adoption of new technology' since the model recognized the behavior of production as a set of 'operation processes'.

Koskela (1992) categorized the production process into 4 steps including moving, waiting, operation, and inspection, and thereby proposed a production theory that was understood by the cyclic process.

Variation of work flow in flow production theory was argued to worsen the waste in the production process and to lengthen the cycle time by increasing non-value actions including moving and waiting.

'Variation' is the phenomenon caused by uncertain status. Ballard and Howell (1998) insisted that such variation could be controlled by managing reliability. They also argued that the method of approach used for existing process planning 'was not able to ensure the reliability of work order existing between works and reliability in work flow.'

Ballard (2000) recognized the limitation of project management when it is centered on result evaluation; they therefore introduced concepts of flow production and LPS. Fig. 1. below shows a fundamental concept diagram of the Last Planner System (LPS).

LPS differs from the traditional management system that was processed in a work order-centered manner. The works documents should be performed ('Should' in Fig. 1.) in a work plan, confirming the work order ('Will') based on the constraints that the workers are able to perform ('Can'), and check the execution status ('Did') through Percentage of Plan Completed (PPC).

LPS is the method of productivity management that is able to control the variations in plan by execution.

Ballard and Howell (1998) emphasized the importance of variation control in a construction production system by mentioning that "The first goal of Lean Construction is to understand the dynamics of construction production, the influence of mutual interdependency and variation in resource procurement and production chain".

In Parade Game, Tommelein (1999) analyzed the influence of variation in work flow on the performance of the entire project through simulation and confirmed...
the increase of stock occurring between works and time delay due to higher variability.

Alarcon (1999) evaluated the influence of variation in work flow on the cost and schedule of the project through a simulation called Playing Games.

Kim (2001) understood the Lean Principle that "Enhancement of reliability in schedule management contributes improvement in work flow, productivity, and quality" and proposed a schedule information model that can be utilized in the detailed planning stage and a subsequent method for variation control.

Thomas (2003) analyzed the data of an inefficient work process through investigation of a case project, and verified that the enhancement of reliability on labor flow contributed to improved productivity.

Bashford (2003) proposed two methods of uniform work, one based on a single unit task and the other based on a start point, as strategies for securing the work continuity by recognizing the similarities existing between the manufacturing industry and construction works.

Yoo (2004) presented the labor factors among the factors influencing both work flow and its continuity and proposed indexes listing the measurement of such labor factors. In addition, the correlation between continuity of work flow and labor factors was analyzed through correlation analysis.

Kim (2005) proposed detailed guidelines for management as an operation method for a Lean System in order to effectively perform Lean Construction in the domestic industry.

Lee (2008) proposed a method of schedule delay analysis using learning effect and linear scheduling since cessations and changes of works in the construction industry cause reduction in productivity.

Moon (2009) suggested an evaluation method on Percent Plan Complete (PPC) with consideration given to the variation of work flow.

Kim (2009) presented a real-time progress management system for steel structure construction.

Cecília Gravina da Rocha (2013) conducted an analysis on the causes of delay in works by using a Line of Balance (LOB) technique.

As listed above, numerous studies aiming at improvement in inefficiency and low productivity in the construction industry by controlling variation and continuity of work flow have been reported through LCI and the International Group of Lean Construction (IGLC).

The authors’ discussion on existing studies indicates that consultations at a stage prior to the execution and analyses of constraints on space for the purpose of the management of uncertainties in construction sites can enhance reliability of the plan. However, difficulties arise in tracing the productivity of works that are currently ongoing and setting a target variation index due to the absence of a quantitative method for measuring the status of a plan by execution.

4. Control of Productivity Variation

The variation of work flow can be distinguished as the variation of labor work and that of work in space. The difference between the execution plan and the completion work is developed while conducting operation management on site.

Establishment of successful productivity and continuous improvement in productivity are possibly achieved when the Continuity Index of space work are controlled within the range of target management.

The weakness of the existing LPS is that it does not present the analysis on productivity in terms of the work continuity for currently ongoing work.

The productivity can possibly be improved by securing the work continuity since the work continuity serves as a management index indicating an optimal productivity of currently ongoing work. Hence, this study grafts a concept of variation management for labor work and work in space onto LPS in order to analyze the factors decreasing productivity and control the work continuity (Refer to Fig. 2.).

The schedule manager can reset the achievable target in the present progressive view by using a variation index for work flow. This directly leads to the improvement in productivity.

Low continuity of work can be reflected in the improvement in productivity by workers on site by adjusting the resources since it indicates the work problems on site.

5. Measurement for Work Flow Indexes

In this section, the concept of the PPC and the work flow measurement for enhancement of productivity in construction work will be explained in terms of flow production.

First, the PPC presents the degree of achievement compared to the planned target and refers to the ratio of the current status to the ideal (the best target) status. Continuous improvement can be reached by continuous removal of possible causes that may impede moving forward from current status to ideal

![Fig.2. Control of Productivity Variation](image-url)
status. For evaluation using the PPC, the ideal status in relation to the given condition is measured, followed by the measurement of current status.

In this research, continuity and variation of work flow are measured by using the concept of PPC. By comparing the variation of work flow in the current status and that in the ideal status, the process and causes that lead to current productivity are measured. Furthermore, the users can improve productivity continuously by setting appropriate target indexes.

In business, there is an oft-repeated statement: 'If you don't measure it, you can't manage it'; the productivity-related-index that quantitatively presents the current status is essential to effectively managing the production system in construction. The measurement indexes systematically present the target to be achieved in the project, and provide a quantitative level of achievement. The properties of work flow include Continuity Index and Variation Index, and the measurement methods for each index are as follows.

The CWF (Continuity of Work Flow) is classified into Work Flow Continuity in Space (WFCS) and Work Flow Continuity on Work (WFCW). The WFCS means the degree of sequential execution without spare time or waiting time in each work per unit space. This can be expressed as the following formula (1).

\[
WFCS = \frac{CSW}{TCSW}
\]  

\(WFCS\): Work Flow Continuity in Space  
\(CSW\): Count of Space on Working  
\(TCSW\): Total Count of Space on Possible Working

The Continuity Index for ideal work space is 100%, meaning that the work is in progression in every work space where the work is possibly performed.

The WFCW means the degree of sequential execution of a work. The number of days for waiting is measured based on every space in which the work of 'i' is in progression 'for a certain period'. This can be expressed as the following formula (2).

\[
WT_{i,j}(x,y) = (y-x+1 - NWD_{i,j} - AWA_{i,j}(x,y)) \quad \ldots \ldots \ldots \ldots \ldots (2)
\]

\(WT_{i,j}(x,y)\): Number of days for waiting in work 'i' during measurement period (date x ~ date y)  
\(AWA_{i,j}(x,y)\): Actual number of days for work in work 'i' during measurement period (date x ~ date y)  
\(NWD_{i,j}\): Number of days on which the execution was impossible due to non-manageable factors including weather during measurement period (date x ~ date y)

\(WT_{i,j}(x,y)\) is defined as WFCW (Work Flow Continuity on Work). The ideal WFCW value is '0', meaning continuous execution of work without waiting days during the measurement period. This can be expressed as the following formula (3).

\[
WT_{i,j}(x,y) = \sum_{j=1}^{n} WT_{i,j}(x,y) \quad \ldots \ldots \ldots \ldots \ldots (3)
\]

\(WT_{i,j}(x,y)\): Number of days for waiting in space j where the work of 'i' is possibly done during measurement period (date x ~ date y)

The Variation of Work Flow (VWF) increases the 'non-value actions' during the construction process, resulting in lengthening of cycle time and reduction of production capacity. Hence, it is measured in order to control such results.

Such variation can be classified into Variation of Input Resource (VIR) and Variation of Operation Process (VOP) based on the behavior of the production. The variation in input resources can be measured by analyzing the changes in planned input resources during a planned period of specific work. The amount of VIR can be expressed by the formula (4) below.

\[
VIR_{i,j}(x,y) = \frac{\sum_{n=1}^{y} \sqrt{nIR_{i,j}(x,y) - AIR_{i,j}(x,y)^2}}{y-x+1} \quad \ldots \ldots \ldots \ldots \ldots (4)
\]

\(VIR_{i,j}(x,y)\): Variation in input resources of work 'i' performed at 'j' space during work period (date x ~ date y)  
\(IR_{i,j}(x,y)\): Amount of input resources at nth work day of work 'i'  
\(AIR_{i,j}(x,y)\): Average amount of input resources during work 'i'  
\(AIR_{i,j}(x,y)\): period (date x ~ date y)

The direct comparison of VIR between different works or different projects is impossible since the VIR changes with the amount of planned input resources. For standard comparison, the Coefficient of Variation in Input Resource (CVIR) of subject work classification can be measured by calculating the function in the formula (5) below.

\[
CVIR_{i,j}(x,y) = \frac{VIR_{i,j}(x,y) \times 100}{AIR_{i,j}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5)
\]

VOP is the variation of execution in relation to the plan. It is called PPC in LPS and is used in LCI. In this study, it is defined as the variation in the amount of work (labor). The value of such variation is obtained by dividing the planned amount of work by the actually executed amount of work.

It is also used as performance indicators that measure the reliability of the subject work. The VOP is expressed as the formula (6) below.

\[
VOP_{i,j}(x,y) = \frac{\sum_{n=1}^{y} NPW_{i,j}(x,y) \times 100}{AIR_{i,j}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6)
\]

\(VOP_{i,j}(x,y)\): Variation in operation processes of work 'i' performed at 'j' space during work period (date x ~ date y)  
\(NPW_{i,j}(x,y)\): Amount of work that was planned for nth work day at 'j' space  
\(AIR_{i,j}\): Amount of work that has been actually executed on nth work day at 'j' space

The direct comparison of VOP between different works or different projects is impossible since the VOP changes with the amount of work space. Coefficient of Variation of Operation Process (CVOP) for subject
work can be measured by calculating the following formula (7).

\[ CVOP(x,y) = \frac{\sum_{i=1}^{n} VOP_{i,y}}{n} \]  

(7)

In general, productivity refers to performance and it is 'Productivity = Output/Input'. The productivity used in this research was mainly focused on productivity in relation to labor. The amount of Productivity Variation (PV) can be obtained by calculating the following formula (8).

\[ PV_{i}(x,y) = \frac{\sum_{i=1}^{n} LP_{i,y} - ALP_{i,y}}{ALP_{i,y}} \]  

(8)

PV\(_{i}(x,y)\): Amount of variation in productivity of work 'i' during work period (date \(x\) – date \(y\)),
LP\(_{i}(x,y)\): Productivity of work 'i'
ALP\(_{i}(x,y)\): Average productivity of work 'i'

For standard comparison, the Coefficient of Productivity Variation (CPV) can be measured by calculating the following formula (9).

\[ CPV_{i}(x,y) = \frac{PV_{i}(x,y) \times 100}{ALP_{i}} \]  

(9)

6. Relationship between Work Flow and Productivity

A higher continuity of space means a sequential progression of multiple works in a limited space. This reduces the duration of the construction along with a reduction in variation in work load.

A greater continuity of work means the reduction of variation in input resources through continuous work and improvement in productivity upon learning the effects.

As a result, the reduction of variation in work flow greatly influences the construction duration.

The influence of continuity and variation of work flow on productivity is schematized and shown in Fig.3.

7. System Prototype

Developing a system that allows for automation of input/output information and the integrated operation of an application program is required in order to measure work flow and effectively perform productivity management. In terms of developing a system, the present study is confined to the measurement for construction work flow.

Basic information on the work plan is provided by the Project Management Information System. Schedule analysis and causal analysis for schedule delay are supported by the Schedule Management System and LPS. Statistical analysis is performed by SPSS, the statistical analysis program. Each system provides a unique function according to its own purpose and interoperates with the Work Flow Evaluation System (WFES) prototype in this research.

Practically, the WFES suggested in this research allows mutual interoperation by using data tables in MS-EXCEL.

The operation algorithm for the system is as the following Fig.4. Initial plan (Should) and feasibility plan (Can) are prepared based upon the schedule program. Next, action plan (Will) is determined through discussion between the stakeholders for rationalization of schedule planning. Once an action plan is determined, variation in work flow and continuity of work flow are measured by utilizing the WFES system on work flow from the present progressive point of view.

Work flow is assessed by evaluating the earned value for continuity in space. The subjects of evaluation such as work flow continuity in space, labor efforts, and variation are measured based on the concept of PPC. Causes of delay are determined by analyzing Variation Index and enhanceable productivity is predicted by adjusting a target variation index.
8. Case Study

In this section, the measurement method for work flow is validated through case analysis and field applicability is reviewed in the WFES. For the case study, data on formwork scheduling and its execution status was collected from the case construction site of a construction firm. Variation and productivity were measured using the measurement technique.

Table 1. shows the results of work flow measurement of the formwork. Input labor and productivity were measured on a daily basis. And these were aggregated again on a weekly basis. Approximately 32% of the difference between the minimum labor productivity of 66.14% and the maximum labor productivity of 98.72% was presented.

(1) Evaluation of VIR

The VWF was categorized into VOP and VIR. For the self-variation as VIR, variation in labor effort, and variation in productivity were measured for the subject work within a certain period. Fig.5. below shows an example of the measurement of VIR (5.73) and CVIR (46.54) for Laminating Work.

(2) Improvement in productivity by using WFCS

The duration of construction work is predicted by CWF and the improvement effect of productivity is estimated by adjusting the VIR and the VOP. The prediction of duration for the construction work can be obtained by adjusting the WFCS. Fig.6. shows the WFCS measured as 41.67% over 27 days performed from the 7th floor to the 10th floor of an apartment housing unit. At this point, it was predicted that the adjustment of WFCS to 50% could reduce the work duration by 4 days (Fig.6.). The vertical and horizontal axes of the cell in Fig.6. represent the space and the days of work, respectively.

(3) Improvement in productivity by CVOP

For prediction of productivity, the CVIR, the CVOP, and the CPV were measured once after the selection...
of duration of work for the subject work. Formula (7) was applied in order to calculate the CVOP. The CVOP of the target index was reset based on the analyzed coefficient of variation in order to estimate the improvement effect. In the case of the construction site in this case study, the CVOP was measured as 26.64 by measuring the variation of work flow for concrete work during 6 days between October 17th and October 22nd 2010. Improvement in productivity by 16.83% was estimated by lowering the CVOP concerning labor effort to target level 10.0. Fig.7. presents the prediction of productivity through the adjustment of variation on the construction site of the case study.

9. Conclusion
This study proposed a method for improvement in productivity by measuring the variation in continuity of work flow and controlling this variation in the space where construction work is repeatedly conducted. It is possible to determine whether the productivity of work is progressing effectively or inappropriately by using the Variation Index and Continuity Index of work flow. Existing studies were not able to propose a method for improvement in productivity in the present progressive view since these studies evaluated productivity of completion versus execution plan as they focused on analyzing outcomes.

For commercialization, this study reviewed the on-site-applicability through a case study. WFES evaluated the continuity of space work by accepting the execution plan and completion data on site from the interface system. On-site-engineers can reset possible productivity by controlling a variation index.

This study took an academic approach to the concept of LPS productivity in view of site monitoring. The concepts of WFCW and WFCS per unit space were proposed as the information model for productivity improvement. WFCW and WFCS are the major elements of the productivity variation. In the case of space work, variation in continuity of space work is inevitable since multiple works are conducted in one constrained space. Moving to another space or waiting should be ordered when conflict among two or more works in the same space occur.

In this study, the status of multiple works in space and the management index on information systems were proposed in order to prevent reduction in productivity and schedule delay. Furthermore, the developed WFES allows determination of the factors decreasing productivity since it promptly provides the information of variation in continuity of space work.

The principal results obtained from this research are summarized as follows.

(1) This research suggested a measurement method for continuity in space, continuity in work, and variation in relation to work flow in the construction phase. Work flow presents the operation process of work in a limited time and space and the factors causing schedule delay and productivity reduction can be prevented by managing the variations related to work flow.

(2) The continuity and variation in work flow changes with sensitivity upon the adjustment of input resources and work (labor) effort.

(3) The system prototype in this study enables measurement of WFCS, WFCW, and VWF. This system can predict the duration of the project by
changing the target index. As a result, analysis on the status of productivity reduction and continuous enhancement of productivity is made possible.

(4) WFCS was evaluated by inputting the planned and executed information for each day during 27 days of the construction work and was revealed to be 41.67%. At this point, it is possible to reduce the construction term by 4 days by readjusting the WFCS to 50%.

Future study will analyze the enhancement of productivity across construction works and analyze major works that may reduce the productivity, such as steel structural works, civil works, etc.

To do this, case-based information on the productivity of the construction site should be required to be collected and recycled in a database.

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