A METHOD FOR ANALYSING DELAY DURATION CONSIDERING LOST PRODUCTIVITY THROUGH CONSTRUCTION PRODUCTIVITY DATA MODEL

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A delay claim occurs due to the difference between the actual completion date and the contract completion date. Though the responsibility and duration of a delay is very important information on analysing a delay claim, it is generally difficult task because there are many factors complicatedly affecting the delay. Lost productivity or loss of productivity is one of major factors causing a delay. However, there are few studies on converting lost productivity into delay duration. Thus, to calculate fairly the delay duration of the liquidated damage, it is needed a calculating method related to many impact factors and their impacted productivity. This study proposes a method for analysing delay duration considering lost productivity by using strong points of schedule such as CPM, Bar chart consistent with the project phases and construction productivity database maintained data consistency and minimized data redundancy. The main outcomes of this study are: (1) a method of calculating delay duration caused by lost productivity, (2) a data model that is a basis of the database containing information regarding lost productivity. With these outcomes, delay durations and responsibilities could be more accurately calculated.

Keywords: claim, database, data model, delay, lost productivity.

INTRODUCTION

In construction contracts, like quality and cost of construction, construction duration is the basic component and the item, which should be managed importantly. If a contractor can work in the condition supposed to complete the construction project before constructing the structure, a contractor can finish timely the construction project. However, it is harder than any other industries to complete the construction project in which many construction trades participated during construction phase. In most cases, there are lots of unknown variables that occur during the construction process and hinder the timely completion of a project.

Lost productivity is also a major cause of a delay. However, there have been few studies on converting the lost productivity into the work delay duration. The schedule delay calculation related to the various, serial, complex delay impact factors and lost productivity must be a complicated problem hard to solve and prove. The established tools for calculating delay claims are usually CPM networks or Bar charts. But the tools have a limitation to calculate exactly. So Knoke and Jentzen argue that the computer-based As-Built Schedule Database is more useful tool for the investigation

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of project performance (1994). The facts recorded in the database may be used to identify actual sequential relationships between project activities and the time frames during which the activities were performed and analysing delay claims, productivity, scope change, payment issues, etc.

REVIEW OF PREVIOUS SCHEDULE DELAY CALCULATING METHODS

Many studies or methodologies directed at analysing delay and lost productivity have been reported (Kallo 1996; Bubshait and Cunningham 1998; Al-Saggaf 1998; Kartam 1999; Finke 1999; Reichard and Norwood 2001).The problems of delay calculating studies related to lost productivity can be summarized as three cases as follows. (1) Established calculating studies of delay related to lost productivity, which are limited to studies of converting lost productivity into cost using such as measured mile analysis and the productivity data published from CII, NECA and MCAA. (2) Delay causes are conceived as activity in a project schedule such as a method of “What-If” evaluation, “But-For” schedules, “affected baseline schedule” and “collapsed as-built analysis”. (3) The impacted activities are analysed in the form of activities that have non-impacted productivity. However, if some variables or impact factors impact the next work in the sequence, the impacted work must be lost productivity work. As a result, a study concerning methods of calculating schedule delay considering lost productivity is not sufficient.

BASIC CONCEPTS

Productivity may be defined as the quantity of work produced per man-hour, equipment hour, or crew hour (Finke 1998).As shown in Figure 1, it can be said that the lost productivity is the productivity impacted adversely by unexpected factors or impact factors. For example, a curtain wall crew consisted of 5 workers installing $34.65m^2$ per hour can be said to have a productivity rate of $6.93m^2$·man/hour under good conditions not influenced by any other impact factor. But if a work affected by any impact factor such as unexpected adverse weather, it will take some times or days for the impacted work productivity to be the un-impacted work productivity or the planned work productivity. The work productivity will be declined.

To calculate fairly the delay of the liquidated damage, it is needed a calculating method related to many impact factors and their impacted productivity. The following concepts are employed:

1. Planned Work Duration (PWD) is the work duration with the planned productivity.
2. Actual Work Duration (AWD) is the work duration with the actually un-impacted productivity obtained from the entire period of work duration.
3. Start Time Variance (STV) is the difference between the actual start time of a work and the finish time of the preceding work on an as-built schedule
4. Finish Time Variance (FTV) is the difference between the contractor's AWD and PWD.
5. Lost Productivity Quantity (LPQ) denotes the work quantity, which could be finished during un-impacted work duration.
6. Lost Productivity Duration (LPD) can be defined as opportunity duration could be worked as much as LPQ.

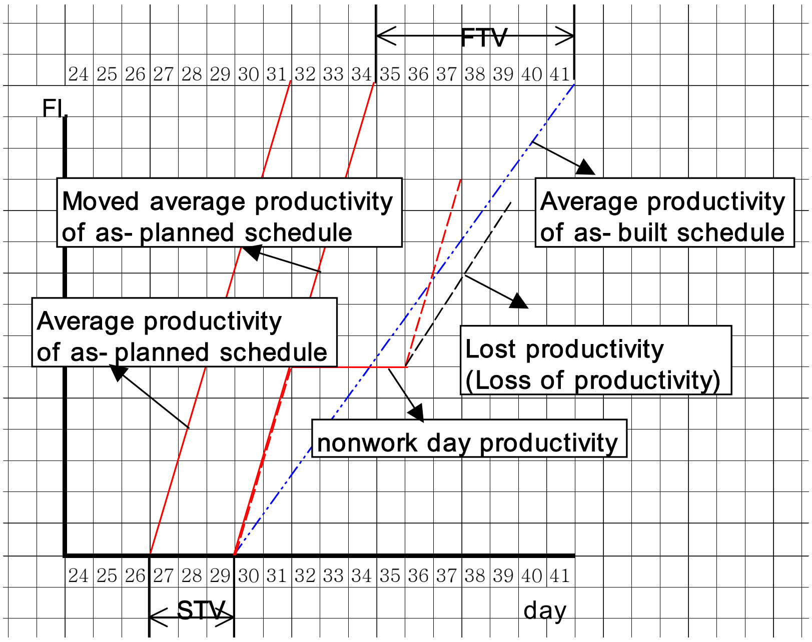

Figure 1: Lost productivity

PROCESS FOR DELAY DURATION ANALYSIS

A common method of calculating delay duration is performed by comparing as-planned schedule and as-built schedule written by CPM (Kraiem and Diekmann 1987; Bubshait and Cunningham 1998). Critical path is changed not commonly by schedule delay and acceleration (Arditi and Robinson 1995). The works on the critical path influence ultimately the delay of project completion.

Construction works consists of millions or thousands of works and the works might be performed usually in different conditions from the point of planning. Those works can be classified by two types. The one type is impacting works caused adversely by impact factors to the completion day. The other type is un-impacting works to the completion day. So it is needed to analyse which work impact the completion date of the project and its impact degree. And then we can examine the responsibility of the delay causes.

An analysis of the delay duration could be processed according to the following procedure. The method process of calculating delay duration considering lost productivity is shown in Figure 2.

EQUATIONS FOR CALCULATING WORK DELAY DURATION

Lost Productivity (LP) means the loss of productivity caused by unknown variable or Impact Factor (IF) occurring during the construction phase. Lost Productivity Duration (LPD) can be defined as opportunity duration as much as Lost Productivity Quantities (LPQ), which could be worked during un-impacted, works duration.

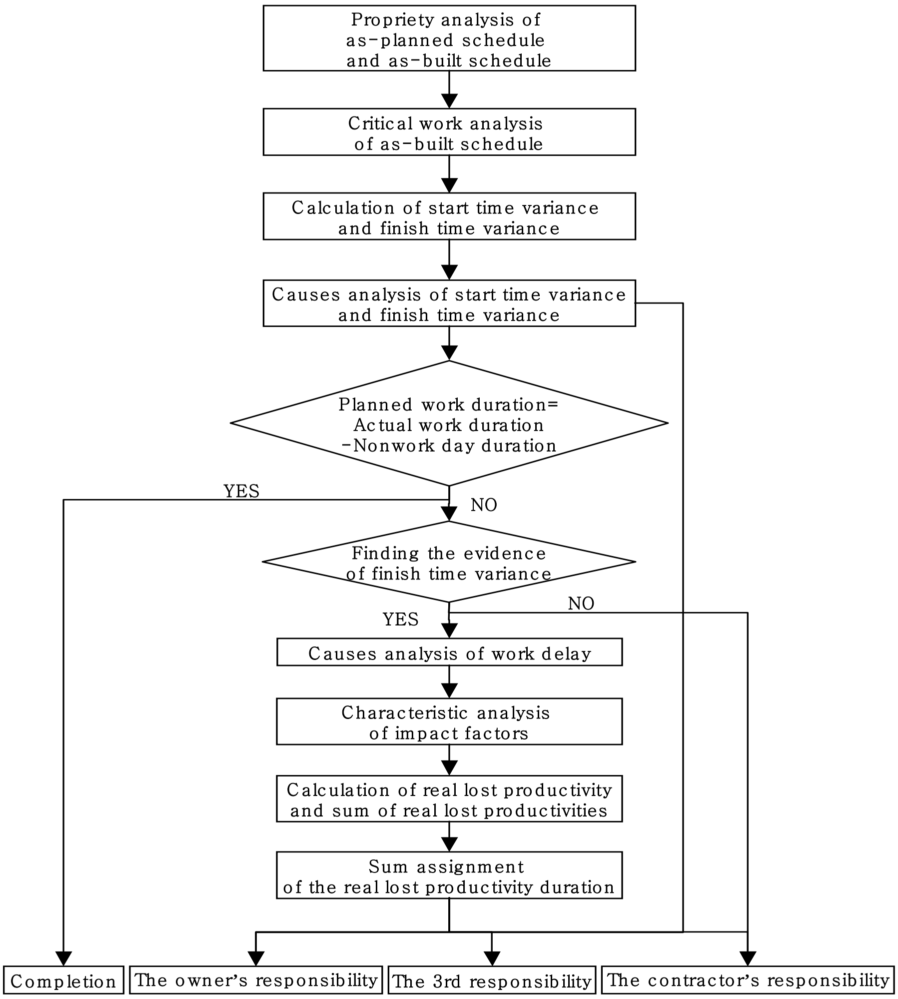

Figure 2: The calculation process of delay duration

Table 1: The variables used in equations

Work Status	Work Quantity	Work Productivity	Daily Average Labours	Work Duration
Planned work	Q_0	P_0	L_0	D_0
Work of unimpacted- duration	Q_u	P_u	L_u	D_u
Work of impacted duration	Q_i	P_i	L_i	D_i

The LP of some activity can be calculated like Eq. (1) by the difference between the un-impacted productivity of the activity and the impacted productivity of the activity. The LPQ can be calculated like Eq.(2) by LP multiplied by L_i(worked labours) during D_i(impacted work duration). The LPD can be calculated like Eq.(3) by LPQ divided by the product of daily average labours during impacted work duration and un-impacted productivity. The variables are in Table 1.

$$LP = (P_u - P_i) \quad \text{(1)}$$

$$LPQ = (P_u - P_i) \times L_i \times D_i \quad \text{(2)}$$

$$LPD = \frac{LPQ}{L_i P_u} = \frac{(P_u - P_i) \times L_i \times D_i}{L_i P_u} \quad \text{(3)}$$

Could Be Duration(CBD) denotes the duration within which a work could be finished with the daily average labours and the un-impacted productivity. This can be calculated by Eq.(4), where Q_0 denotes the planned work quantity, Q_u denotes the quantity worked in the normal and realistic work conditions of an un-impacted work duration, and Q_i denotes the quantities worked in the impacted work duration.

$$CBD = \frac{Q_0}{L_u P_u} = \frac{Q_u + Q_i}{L_u P_u} \quad \text{(4)}$$

Contractor's Duration Difference (CDD) compared with the P_0 and the P_u denotes the difference CBD and D_0 by Eq.(5), where P_0 denotes the planned work productivity and D_0 denotes the planned work duration.

$$CDD = CBD - D_0 = \frac{Q_0}{L_u P_u} - D_0 \quad \text{(5)}$$

Work Delay (WD) consists of CDD, LPD and ∀ as shown in Eq.(6), where CDD and LPD are independent variables and ∀ is an extraneous variable that accounts for any delays other than CDD and LPD.

$$WD = CDD + LPD + \varepsilon \quad \text{(6)}$$

CAUSE ANALYSIS OF WORK DELAY DURATION

After the FTV evidences are confirmed, the impact factors can be analysed by comparing the AWD with the PWD. WDs are classified into three cases: Including all contractors' cause and LPD; Including only LPD; Including LPD less CDD.

Including all contractor's cause and LPD

WD includes all delay caused by contractor's fault and LPD during impacted work duration as shown in Figure 3.

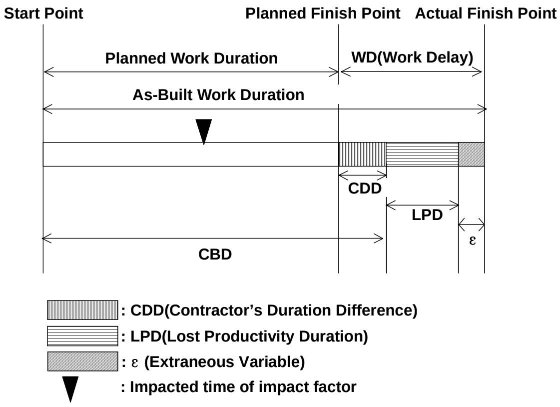

Figure 3: Including all contractor's cause and LPD

When CDD is larger than 0, as shown in Eq.7, the delay is caused by the contractor's mistakes such as allocation of lower labours and productivity than as-planned schedule. In that case the contractor could not be compensable and should compensate the owner for liquidated damage.

$$CDD = CBD - D_0 > 0 \quad \text{(7)}$$

Including only LPD
The work delay includes only LPD in the case that the actual work duration of the as-built schedule is equal to the work duration of the as-planned schedule as shown in Figure 4.

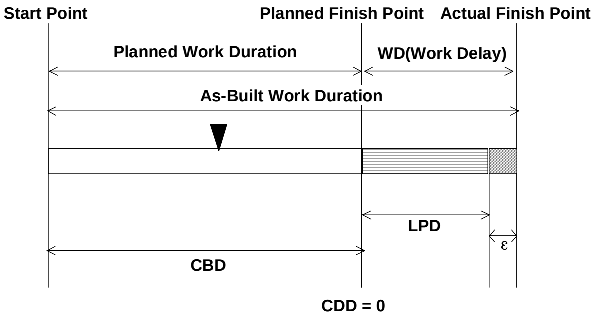

Figure 4: Including only LPD

When CDD is 0, as shown in Eq.8, the delay is caused by only lost productivity. Because the planned work productivity is equal to the actual work productivity, contractor doesn't have any responsibility.

$$CDD = CBD - D_0 = 0 \quad \cdots\cdots (8)$$

Including LPD less CDD
When CDD is smaller than 0, as shown in Eq.9, WD is calculated by only LPD. If it were not for the LPD, the actual work could be finished earlier than planned work duration, as shown in Figure 5.

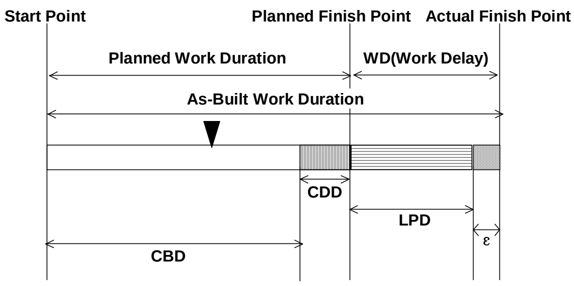

Figure 5: Including LPD less CDD

The CBD is shorter than the planned finish date. The work might be performed with acceleration or more labours and productivity than planned. But the effort cannot be recognized as a compensable delay.

$$CDD = CBD - D_0 \langle 0 \quad \cdots\cdots (9)$$

CONSTRUCTION PRODUCTIVITY DATA MODEL

The proposed calculating method is based on the construction productivity database which construction data can be cumulated in during the construction phase. Generally, the evident claim data such as contract documents, drawings, specifications, and any other documents related to contracts can be used to prove the direct impact causes, but they are not sufficient to prove the indirect impact causes such as lost productivity. The proposed calculating method requires a construction productivity database containing related data to be collected during a construction phase. The below are a conceptual and a logical construction productivity data model that were developed to be used conceptually in this study.

Previous study of construction claim database
The method for calculating schedule delay is based on the data. Database can be used to collect diligently the data, which cannot be cumulated during construction phase. However schedule delay studies using database are insufficient. Knoke and Jentzen (1994) pointed out the limitation of the CPM network schedule as delay calculating tool and emphasized the reliability of evidence maintained in the database during the construction phase.

Construction productivity data model
A typical implementation of the data model includes a collection and analysis of data requirements, conceptual data modelling and logical data modelling. Logical data modelling can be performed based on the real world and change a substance into a structured and detail information. Physical data modelling can be performed based on the system.

Collection and analysis of data requirements
The most important thing of data model is collection and analysis of the requirements. So the requirements are collected through the existing document, questionnaire and interviews with experts. The requirements can be summarized the entity or the attrib-tes of the entity: space, work, work day, method, subcontractor, drawing number, spec, check list, material, documents, labour, machine, impact factor and so forth.

Conceptual construction productivity data model
Conceptual data model is based on examining the relations of entities for making an ER Model through analysing the requirements. Conceptual data model for measuring the construction productivity can be drawn as Impact Factors (IF) impacts the Work_Space as a relation of Work and Space like Figure 6. The works are associated with the Spec., Drawing, Machine, Material, Checklist and performed according to the space order. Work_Space has documents related to as participants' change orders and subcontractors' labours, labour information, IF information, space, etc.

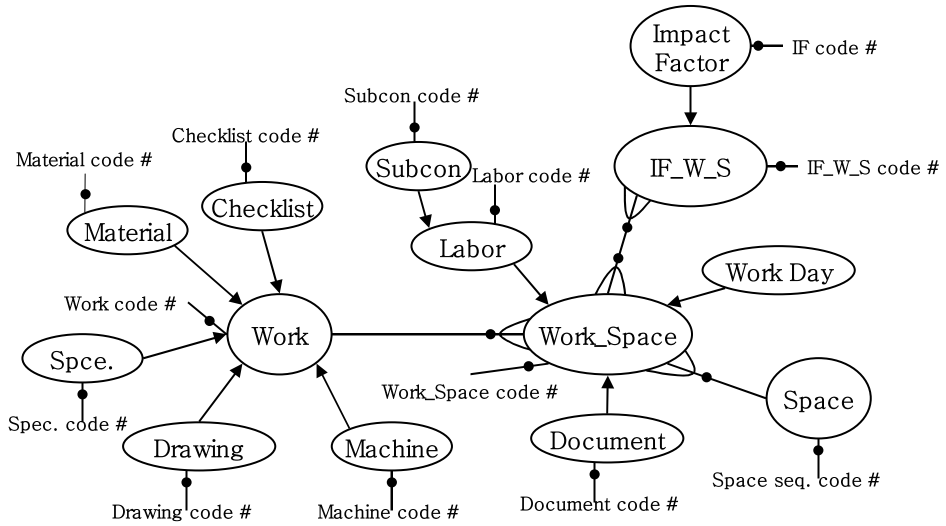

Figure 6: Conceptual construction productivity data model

Logical construction productivity data model
Logical data model can be defined as a describing process for ER Model of conceptual data modelling output to match systems such as DBMS (Data Base Management System). Logical construction productivity data model can be designed like Figure 7

through the definition of entities, attributes, identifiers and relations, normalization and generalization.

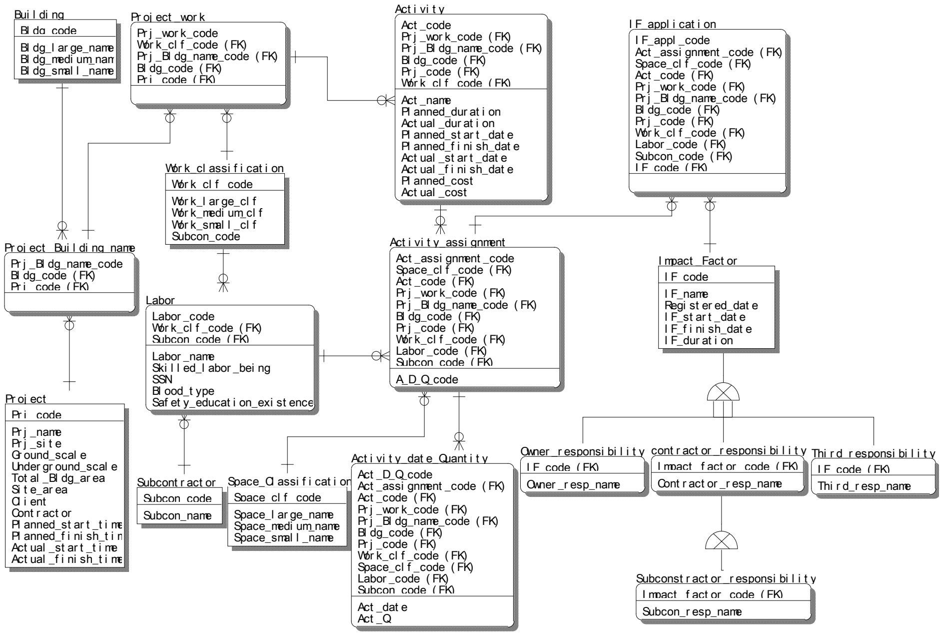

Figure 7: Logical construction productivity model

CONCLUSIONS

The purpose of this study is a method for calculating delay duration considering lost productivity by using strong points of schedule such as CPM, Bar Chart consistent with the project phases and construction productivity database maintaining data consistency and minimizing data redundancy. The main outcomes of this study are as follows. (1) The analysing process and the calculating method was presented for calculating delay duration considering lost productivity. (2) Data model was developed for recording and managing the items hard to be expressed in detail schedule on construction phase. The required information for construction productivity database was analysed and then construction productivity data model was developed through a conceptual and a logical data model by extracting the entities and attributes from the required information.

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REFERENCES

Abdulaziz A. Bubshait, Member (1998) Comparison of Delay Analysis Methodologies, *Journal of Construction Engineering and Management*, Vol.124, No.4, 315-322.

Abdul-Malak, M A U, El-Saadi, M M H and Abou-Zeid, M G (2002) Process model for administrating construction claims, *Journal of Management in Engineering*, ASCE, 18(2), 84-94

Al-Saggaf, H A (1998) The five commandments of construction project delay analysis, *Cost engineering*, 40(4), 37-41

Arditi, D and Robinson, M A (1995) Concurrent delays in construction litigation, *Cost engineering*, 37(7), 20-30

Bubshait, A A and Cunningham, M J (1998) Comparison of delay analysis methodologies, *Journal of Construction Engineering and Management*, ASCE, 124(4), 315-322

Cox, R K (1997) Managing change orders and claims, *Journal of Management in Engineering*, ASCE, 13(1), 24-29

Finke, M R (1998) A better way to estimate and mitigate disruption, *Journal of Construction Engineering and Management*, ASCE, 124(6), 490-497.

Kallo, G G (1996) Estimaing loss of productivity claims, *Journal of Management in Engineering*, ASCE, 12(6), 13-15

Kangari, R (1995) Construction documentation in arbitration, *Journal of Construction Engineering and Management*, ASCE, 121(2), 201-208.

Kartam, S (1999) Generic methodology for analysing delay claims, *Journal of Construction Engineering and Management*, ASCE, 125(6), 409-419

Knoke, J R and Jentzen, G H (1994) Facilitate delay claim with as-built schedule databases, Computing in civil engineering, Khozeimeh, K, ed., ASCE, Reston, Va., 2104-2111

Kraiem, Z M and Diekmann, J E (1987) Concurrent delays in construction projects, *Journal of Construction Engineering and Management*, ASCE, 113(4), 591-602

Reichard, D D and Norwood C L (2001) Analysing the cumulative impact of changes, AACE International Transactions

Shi, J J, Cheung, S O and Arditi, D (2001) Construction delay computation method, *Journal of Construction Engineering and Management*, ASCE, 127(1), 60-65

Vidogah, W and Ndekugri, I. (1997) Improving Management of Claims, *Journal of Management in Engineering*, Vol.13, No.5, 37-44.

Wickwire, J M and Smith, R F (1974) The use of critical path method techniques in contract claims, *Public Contract Law*, 7(1), 1-45.