S13-2

AN EXAMPLE OF REPRESENTING THREE LEVEL'S SCHEDULES WITHIN SCHEDULE HIERARCHY BY BDM TECHNIQUE

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ABSTRACT: The schedule hierarchy in construction project is generally composed of three levels. The highest level is a milestone schedule and represented by Bar Chart format. The middle level is an integrated project schedule (IPS) and represented by CPM (Critical Path Method) format. The lowest level is a detail working schedule and usually represented by Bar Chart. The traditional scheduling techniques such as ADM (Arrow Diagramming Method) or PDM (Precedence Diagramming Method) cannot represent all kinds of schedule within schedule hierarchy as identical schedule format. However, the BDM (Beeline Diagramming Method) technique can represent all kinds of schedule within schedule hierarchy as identical CPM format. This paper describes the basic concept, principle, interpretation methods, and schedule computation methods of the BDM as a new networking technique that can represent all kinds of overlapping relationships between activities, and then presents an example of representing three level's schedules within schedule hierarchy by the BDM technique.

Keywords: Schedule Hierarchy, Bar Chart, Critical Path Method, Arrow Diagramming Method, Precedence Diagramming Method, Beeline Diagramming Method

1. INTRODUCTION

Network schedules have contributed significantly to the planning, control, and on-time completion of construction projects [1]. The Critical Path Method (CPM) has gradually increased in importance in the construction industry over the last several decades. It integrates overall project management functions, such as scheduling, cost control, and resource planning.

By the middle of the 1980s, the CPM was widely applied in the construction industry based on the Arrow Diagramming Method (ADM) first introduced by Du Pont in 1956. The ADM has since been replaced by the Precedence Diagramming Method (PDM) proposed by Fondahl [2] in 1961. In the PDM, overlapping relationships between activities are represented by four combinations that connect the starting and finishing points of two consecutive activities [4]. Confining overlapping relationships to the starting and finishing points is limiting, however, since the overlapping could happen at any point during the activity's duration. If overlapping relationships occur at any middle point, the PDM cannot properly show the relationships.

The scheduling technique must represent all kinds of relationships between activities realistically and efficiently. This paper thus describes the basic concept, principle, interpretation methods, and schedule computation methods of the Beeline Diagramming Method (BDM) as a new networking technique that can represent overlapping relationships at any middle point of activities and not limit the relationships to the starting and finishing points [5]. This new networking technique will allow project teams to establish project schedule plans more realistically and efficiently by representing all kinds of relationships between activities with improved flexibility.

The schedule hierarchy in construction project is generally composed of three levels. The highest level is a milestone schedule and represented by Bar Chart format. The middle level is an integrated project schedule (IPS) and represented by CPM format. The lowest level is a detail working schedule and usually represented by Bar Chart. The traditional scheduling techniques such as ADM or PDM cannot represent all kinds of schedule within schedule hierarchy as identical schedule format. However, the BDM can represent all kinds of schedule within the schedule hierarchy as an identical CPM format. This paper presents an example of representing three level's schedules in schedule hierarchy by the BDM technique.

2. RESEARCH METHODS

This research is performed in the following steps. First, the major issues of the PDM with regard to overlapping networks are surveyed and the BDM is proposed as a new networking technique to overcome these limitations and inefficiencies. Second, the basic concept, principle, and characteristics of the BDM are defined, the organization and interpretation of relationships in the BDM are explained, and the schedule computation methods used in the BDM are described. Third, the applicability and rationality of the BDM is verified by performing schedule computations in the complete BDM network. Fourth, the three level's schedule hierarchy of a sample project is defined, and an example of representing three level's schedules within schedule hierarchy by the BDM technique is presented.

3. SURVEY OF THE PDM

The PDM expresses the overlapping relationships of two consecutive activities by utilizing the four link relationships. The first link relationship, Finish-to-Start (FS), does not show overlapping. It is considered an overlapping relationship, however, because the predecessor's finish determines the successor's start. The second link relationship is Start-to-Start (SS); this permits the start of the predecessor to set the start of the successor. The third relationship, Finish-to-Finish (FF), allows the finish of the predecessor to establish the finish of the successor. The fourth, Start-to-Finish (SF), permits the start of the predecessor to determine the finish of the successor.

The PDM represents the overlapping between the predecessor and successor by the four link relationships between their starting and finishing points; it thus is impossible to depict overlapping at any middle point. For instance, let us assume that there are two consecutive activities—the preceding activity A of 10 days and the succeeding activity B of 12 days. If the two activities are connected from the 70% completion of activity A to the 33% completion of activity B, as shown in Fig. 1, the PDM can depict their overlapping relationship as SS, FF, and SF according to their locations and linkage preferences.

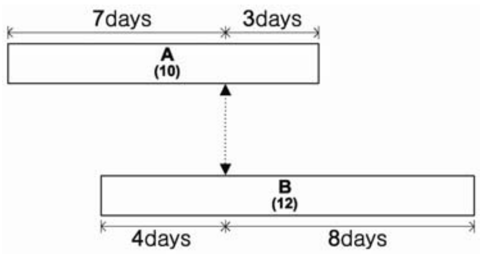


Fig. 1. Two Consecutive Activities

The first option is to select the SS link relationship with lead time 3 (SS3), shown in Fig. 2. The second is to choose the FF linkage with lead time 5 (FF5), illustrated in Fig. 3. The third is to pick the SF with lead time 15 (SF15), shown in Fig. 4. All three options represent the overlapping relationships between activities A and B identically. However, this circular depiction of the overlapping relationships through combinations of the starting and finishing points is not efficient or convenient; the two activities need to be positioned to align connection points. The overlapping linkage type then can be selected and the lead-time for the selected linkage calculated. Of course, overlapping relationships that depend solely on the starting and finishing points of two consecutive activities exist; it is more realistic and reasonable to expect two consecutive activities to interrelate directly at a middle point, however.

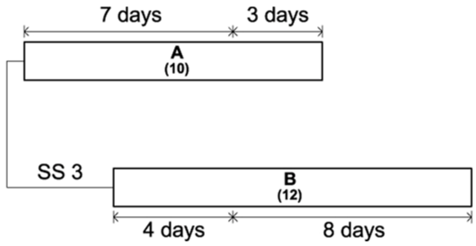


Fig. 2. SS3 Linkage

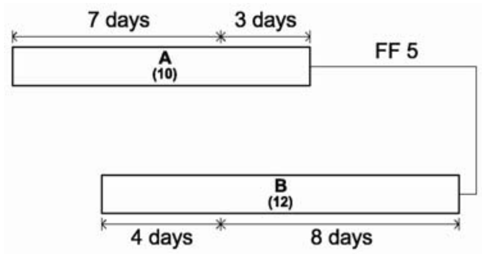


Fig. 3. FF5 Linkage

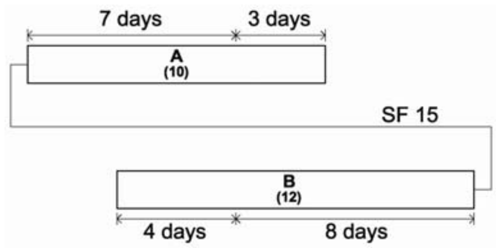


Fig. 4. SF15 Linkage

If two consecutive activities need multiple overlapping relationships in the PDM, it is best for them to be connected by the compound relationship that depicts only two overlapping linkages; this means that the start of the predecessor and the start of the successor are connected by SS and the finish of the predecessor and the finish of the successor are linked by FF. If the preceding activity A and the succeeding activity B have more than two milestones, they should be interrelated at more than two points. The PDM cannot represent multiple overlapping relationships properly with only two linkages, however. Since the predecessor and the successor should realistically be linked by multiple overlapping relationships, it is necessary to develop a new networking technique that can depict multiple overlapping linkages properly and correctly.

4. BEELINE DIAGRAMMING METHOD

4.1 Basic Concept, Principle, and Characteristics

This research proposes the Beeline Diagramming Method (BDM) as a new networking technique to overcome the inefficiencies and limitations of the PDM. The basic concept of the BDM is to represent the overlapping relationship of two consecutive activities by the shortest straight line; this has an arrow to represent the direction of work flow. The BDM connects any point of the predecessor to any point of the successor. This research defines the shortest straight line, which indicates a very direct or quick path or trip, as the "beeline" (Wiktionary 2009). Fig. 5 shows the basic concept of the BDM; a beeline connects the middle point of the preceding activity A to the middle point of the succeeding activity B. The BDM has only one principle: The BDM represents the single or multiple overlapping relationships of two consecutive activities in the network by a beeline or beelines in any circumstance. Building on the basic concept and principle of the BDM, its characteristics are as follows.

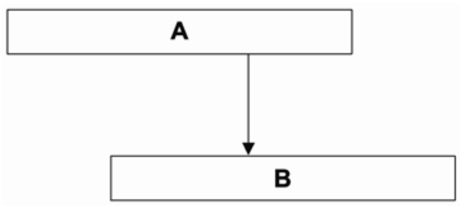


Fig. 5. Basic Concept of Beeline Diagramming Method

First, the BDM simplifies the PDM's overlapping relationships into one beeline. Thus, the complicated process of the PDM, which includes the positioning of activities, the selection of linkage types, and the calculation of the lead-time for the selected linkage, is eliminated.

Second, the BDM permits multiple overlapping relationships by means of multiple beelines between two consecutive activities. It therefore overcomes the limitations of the compound relationships found in the PDM, which has only two overlapping linkages.

4.2 Linkage Representation Types in the BDM

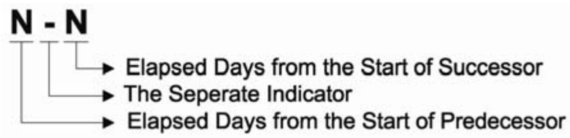
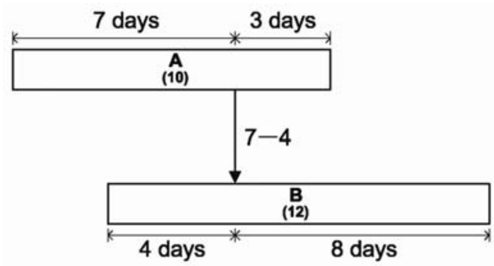


Fig. 6. Representation Type by the Elapsed Days

Linkage relationships between two consecutive activities in the BDM are represented differently from those in the PDM. Linkage relationships in the BDM can be represented at any middle point between two consecutive activities; the PDM, in contrast, represents linkage relationships only by FS, SS, FF, and SF relationships with lead-time between the starting and finishing points.

This research proposes three types of linkage representations in the BDM. The first is the "N-N" type shown in Fig. 6. This type represents two consecutive activities that are mutually connected at any point in days after their respective starts.

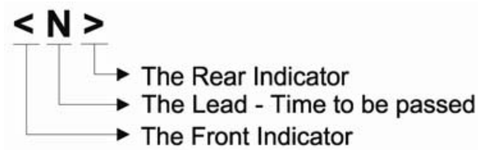
The initial "N" in Fig. 6 refers to the days that have elapsed from the start date of the preceding activity; the latter "N" refers to the days that have elapsed from the start date of the succeeding activity; the "-" is the separation indicator between the two Ns. An example of the first representation type is illustrated in Fig. 7. In this Figure, two consecutive activities in the BDM are connected by a "7-4" type—between a point of 7 days after the start date of the preceding activity A and a point



of 4 days after the start date of the succeeding activity B.

Fig. 7. An Example by the Elapsed Days

The second type is "<N>", shown in Fig. 8, wherein the successor starts some days after the completion of the



predecessor.

Fig. 8. Linkage Representation by Second Type

The "N" in Fig. 8 refers to the lead-time to be passed after the completion of the preceding activity. The initial "<" and latter ">" indicate the lead-time space indicators. An example of the second representation type is illustrated in Fig. 9.

Fig. 9. An Example by Second Type

Two consecutive activities in the BDM are connected by "<4>", wherein the succeeding activity B starts after the preceding activity A has been completed for 4 days.

The third type represents the multiple linkage relationships between two consecutive activities by the elapsed days or the second linkage type. Schedule computations will continue to be performed independently for each individual linkage. Fig. 10 shows an example of the multiple beeline relationships between two activities that have multiple milestones.

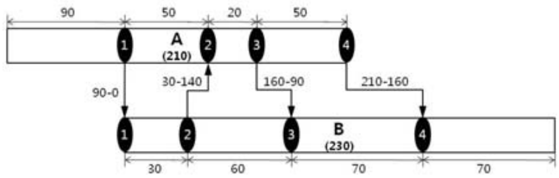


Fig. 10. An Example of the Multiple Beeline Relationships

4.3 Schedule Computation of the BDM

4.3.1 Forward Pass Computation

Forward pass computation determines both the early start date (ESD) and the early finish date (EFD) for the activities in the BDM network.

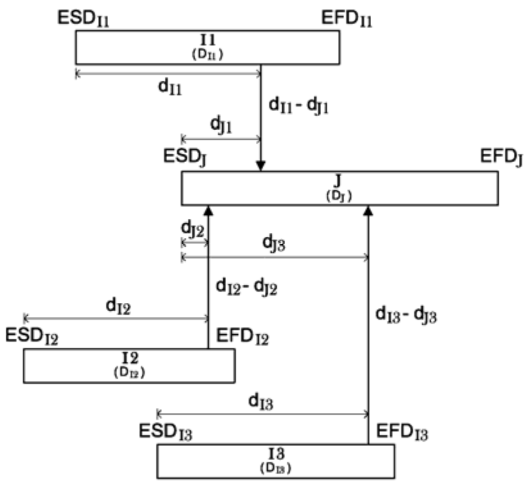


Fig. 11. Forward Pass Computation of BDM Merge Relationship

Fig. 11 illustrates the multiple versus single relationship of the BDM wherein activities I1, I2, and I3 are merged into activity J. Activities I1 and J have "d_{I1}-d_{J1}" of the BDM relationship, activities I2 and J have "d_{I2}-d_{J2}", and activities I3 and J have "d_{I3}-d_{J3}". In the multiple versus single BDM relationship, the ESD_J of the succeeding activity J is determined by the maximum early start date among the BDM relationships of activities I1, I2, I3, and J. Equation (1) expresses a formula to determine the ESD_J of the succeeding activity J through the forward pass computation in the multiple versus single BDM relationship.

$$ESD_J = \underset{\forall I}{Max}\ ESD_I + d_I - d_J \qquad (1)$$

$$EFD_J = ESD_J + D_J \qquad (2)$$

The symbol $\underset{\forall I}{Max}$ in equation (1) means that the maximization is to be over all the beelines IJ that are merged into activity J. This research verifies equation (1) through the simple example of the multiple versus single BDM relationship. Fig. 12 shows the multiple versus single relationship of the BDM wherein activities A, B, and C are merged into activity D. Thus activities A and D have a "7-3" BDM relationship, activities B and D have a "7-1" BDM relationship, and activities C and D have a "8-6" BDM relationship.

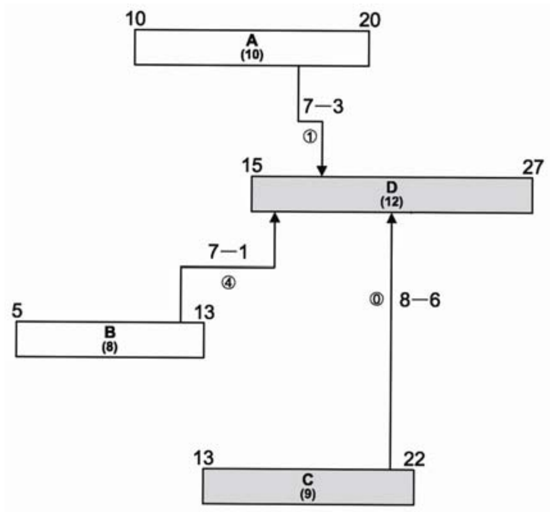


Fig. 12. An Example of BDM Forward Pass Computation

The ESD_D of the succeeding activity D in the BDM relationships with the preceding activities A, B, and C is calculated by applying equation (1) as follows: the first ESD_D of the succeeding activity D from the "7-3" relationship with activity A is calculated as $ESD_D = 10+7-3 = 14$; the second ESD_D from the "7-1" relationship with activity B is determined as $ESD_D = 5+7-1 = 11$; and the third ESD_D from the "8-6" relationship with activity C is computed as $ESD_D = 13+8-6 = 15$. The maximum value of "15" then is selected as the ESD_D of the succeeding activity D and the EFD_D is calculated as $EFD_D = 15+12 = 27$ by applying equation (2).

From the above, the forward pass computation of the BDM relationship proposed in this research is proved to be simple, obvious, and reasonable.

4.3.2 Backward Pass Computation

Backward pass computation determines the late start date (LSD) and the late finish date (LFD) of the activities in the BDM network. Backward pass computations in the CPM network calculate the LFD of the preceding activity first, and then determine the LSD by subtracting the duration of the preceding activity from the LFD. Due to the characteristics of the BDM network, the LSD of an activity is calculated first and the LFD is computed by adding its duration to the LSD.

Fig. 13 illustrates the single versus multiple relationship of the BDM wherein activity I bursts into activities J1, J2, and J3. Activities I and J1 have "d_{I1}-d_{J1}" of the BDM relationship, activities I and J2 have "d_{I2}-d_{J2}" of the BDM relationship, and activities I and J3 have "d_{I3}-d_{J3}" of the BDM relationship. In the single versus multiple BDM relationship, the LSD_I of the preceding activity I is determined by the minimum LSD among the BDM relationships of activities I, J1, J2, and J3. Equation (3) expresses a formula to determine the LSD_I of the preceding activity I through the backward pass computation in the single versus multiple BDM relationship.

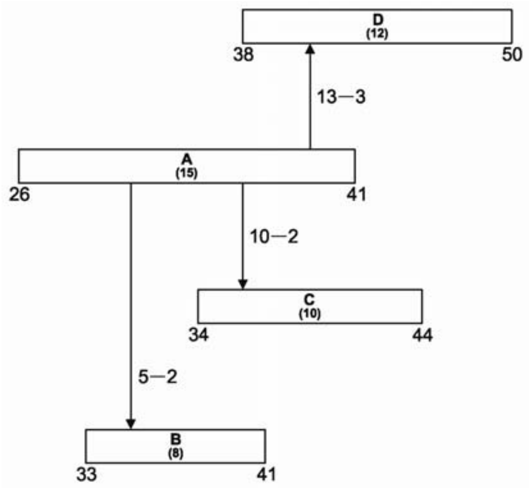


Fig. 13. Backward Pass Computation of BDM Burst Relationship

$$LSD_I = \underset{\forall I}{Min}\, LSD_J + d_J - d_I \quad (3)$$

$$LFD_I = LSD_I + D_I \quad (4)$$

The symbol $\underset{\forall I}{Min}$ in equation (3) means that the minimization is to be over all the beelines IJ that burst from activity I. This research verifies equation (3) through the simple example of the single versus multiple BDM relationship. Fig. 14 shows the single versus multiple relationship of the BDM wherein activity A bursts into activities B, C, and D. Activities A and B have a "5-2" BDM relationship, activities A and C have a "10-2" BDM relationship, and activities A and D have a "13-3" BDM relationship.

The LSD_A of the preceding activity A in the BDM relationships with the succeeding activities B, C, and D is calculated by applying equation (3) as follows: the first LSD_A of the preceding activity A from the "5-2" relationship with activity B is calculated as LSD_A = 33+2−5 = 30; the second LSD_A from the "10-2" relationship with activity C is determined as LSD_A = 34+2−10 = 26; and the third LSD_A from the "13-3" relationship with activity D is computed as LSD_A = 38+3−13 = 28. The minimum value of "26" then is selected as the LSD_A of the preceding activity A and the LFD_A is calculated as LFD_A = 26+15 = 41 by applying equation (4).

From the above, the backward pass computation of the BDM relationship proposed in this research is verified as simple, obvious, and reasonable, as was the forward pass computation.

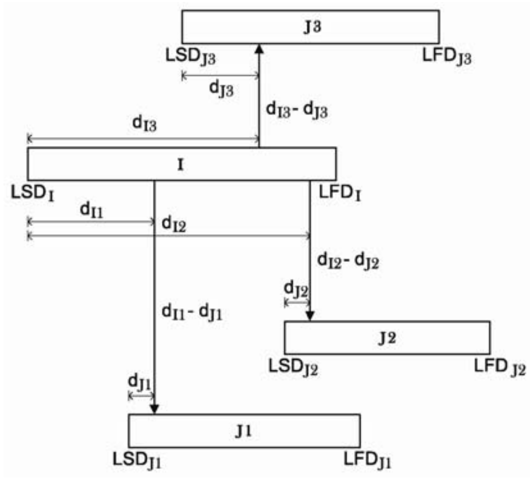


Fig. 14. An Example of BDM Backward Pass Computation

4.3.3 Computation of Free Float in the BDM

The free float (FF) is defined as the time span within which the completion of an activity may occur without delaying either the completion of the project or the start of any following activity [3]. During the forward pass computation, a difference between the early start date of an activity and the early finish date of the preceding activity may occur; this is called a link lag [3]. The link lag (LAG_{IJ}) between the preceding activity I and the succeeding activity J in the PDM is defined as equation (5).

$$LAG_{IJ} = ESD_J - EFD_I \quad (5)$$

A link lag (LAG_{IJ}) in the BDM can be defined as a difference between the connecting points of two successive activities; thus, it is stated as equation (6).

$$LAG_{IJ} = (ESD_J + d_J) - (ESD_I + d_I) \quad (6)$$

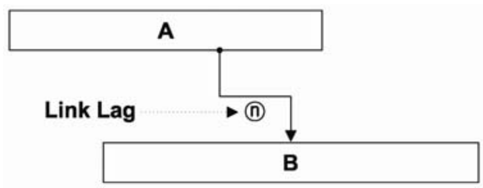


Fig. 15. Representation of Link Lag in BDM

When a link lag occurs in the BDM network, a beeline is modified into an offset-screwdriver shape with a horizontal line that matches the extent of the link lag's duration, as shown in Fig. 15. This unique representational method of a link lag in the BDM allows the time span between the early finish of the predecessor and the early start of the successor to be visually recognizable, something that is impossible in the PDM.

The free float also can be defined as the minimum value of the link lags [3]. If the single preceding activity I is connected to the multiple succeeding activity Js, the free float of activity I (FF_I) is the minimization of the LAG_{IJ} and can be expressed as equation (7).

$$FF_I = LAG_{IJ} = \underset{\forall J}{Min}\,(ESD_J + d_J) - (ESD_I + d_I) \quad (7)$$

The symbol $\underset{\forall J}{Min}$ in equation (7) means that the minimization is to be over all the beelines IJ that begin with activity I. Fig. 16 shows an example for computing the free float of activities in the BDM by applying equations (6) and (7).

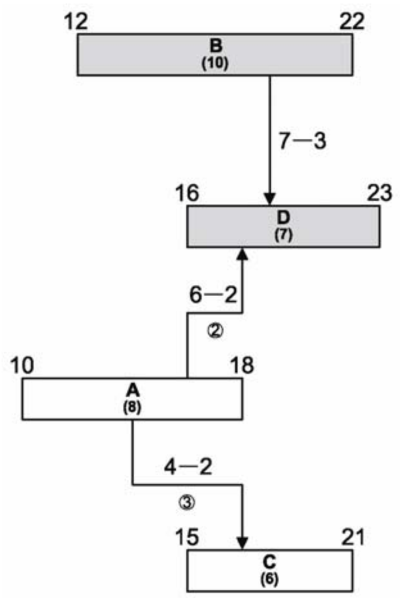


Fig. 16. An Example of Free Float Computation in BDM

In Fig. 16, activities A and C have a beeline relationship of “4-2”, activities A and D have a beeline relationship of “6-2”, and activities B and D have a beeline relationship of “7-3”. If the early start dates of activities A, B, and C already have been derived, then, through the application of equation (6), the LAG_{AC}, a link lag between activities A and C, is calculated as $LAG_{AC} = (15 + 2) - (10 + 4) = 3$, the LAG_{AD}, a link lag between activities A and D, is found as $LAG_{AD} = (16 + 2) - (10 + 6) = 2$, and the LAG_{BD}, a link lag between activities B and D, is computed as $LAG_{BD} = (16 + 3) - (12 + 7) = 0$. Through the application of equation (7), the FF_A, the free float of activity A, is derived as $FF_A = Min\,(LAG_{AC}, LAG_{AD}) = Min\,(3, 2) = 2$ and the FF_B, the free float of activity B, is derived as $FF_B = Min\,(LAG_{BD}) = Min\,(0) = 0$.

The basic concept for deriving the free float of an activity in the BDM is almost identical with the concept used in the PDM. In the BDM network, however, a free float is calculated based on the beeline connecting points between two consecutive activities.

4.3.4 Computation of Total Float in the BDM

The total float (TF) is defined as the time span in which the completion of an activity may occur and not delay the termination of the project [3], and it is the maximum float that an activity could possess. The total float of an activity can be derived from a difference between the forward and backward pass computations. Therefore, TF_I of activity I can be computed by a difference between LSD_I and ESD_I, or LFD_I and EFD_I, as expressed on the equation (8).

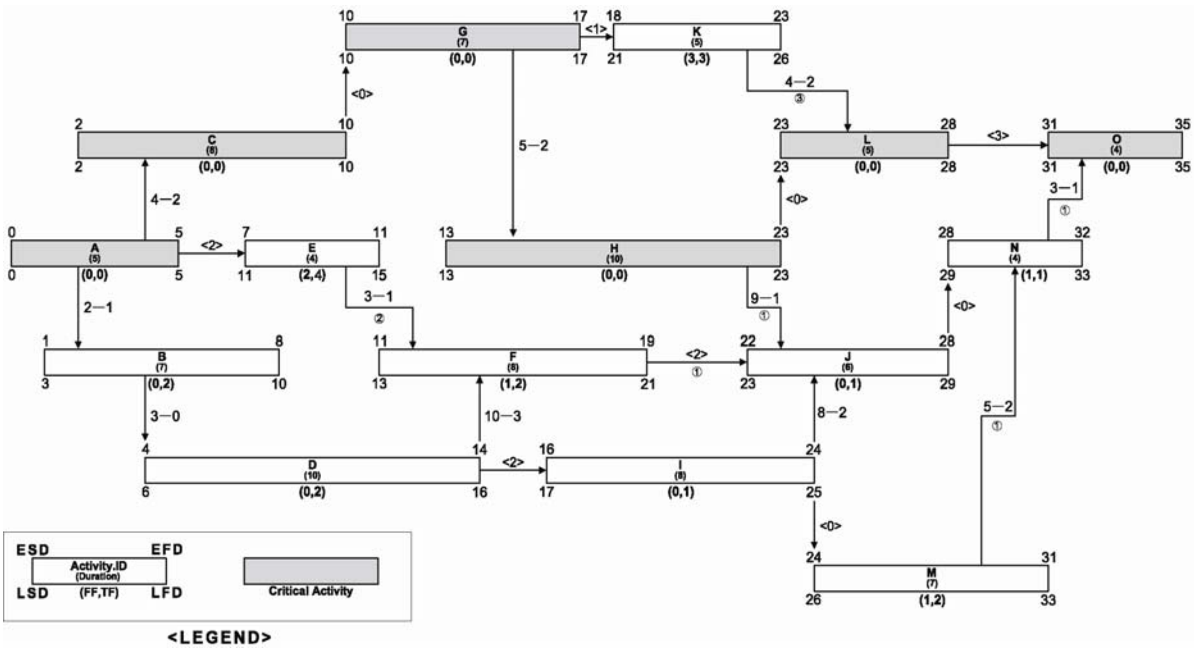


Fig. 17. Schedule Computation Result of the Complete BDM Network

$$TF_I = LSD_I - ESD_I = LFD_I - EFD_I \quad (8)$$

The concept for deriving the total float of an activity in the BDM is identical with the PDM because the BDM performs the forward and backward pass computations as the PDM does.

5. VERIFICATION OF THE BDM

This section verifies the basic concept, principle, and schedule computation methods of the BDM proposed in this research; further, it determines whether or not they are reasonable when they are applied to the complete BDM network for construction projects. The complete BDM network was constructed with 15 activities with various BDM relationships and the schedule computations were performed. The complete BDM network and its schedule computation results, with a critical path of A-C-G-H-L-O, are illustrated in Fig. 17.

The results of the complete schedule computations performed in the BDM network confirm that the basic concept and principle of the BDM have been applied reasonably. The BDM thus has all the key elements to evolve into a new networking technique that could replace the existing ADM and PDM.

6. AN EXAMPLE OF REPRESENTING THREE LEVEL'S SCHEDULES WITHIN SCHEDULE HIERARCHY BY THE BDM

6.1 Work Breakdown Structure and Schedule Hierarch of Interior Works

Fig. 18 shows a work breakdown structure (WBS) of interior works in an apartment unit of high-rise residential building project that is composed of three levels. Interior works begin with plastering work after building structure was completed, and will be completed with cleaning and final Inspection. The first level of WBS is a project itself, the second level shows the major works of a project, and the third level represents the detail work items to be included in a major work. The WBS generally provides the foundation of schedule hierarchy, thus the schedule hierarchy of interior works is composed with three levels as identical as WBS.

6.2 Three Level's Schedules by the BDM

The schedule formats within schedule hierarchy of construction project is generally represented by different scheduling techniques. Let's assume three level's schedule hierarchy. The first or highest level is a milestone schedule and represented by Bar Chart format. The second or middle level is an integrated project schedule (IPS) and represented by CPM format. The third or lowest level is a detail working schedule and usually represented by Bar Chart. The reason why these different scheduling techniques should be applied is because the traditional scheduling techniques such as ADM or PDM cannot represent all kinds of schedule within schedule hierarchy as identical schedule format. However, the BDM can represent all kinds of schedule within schedule hierarchy as an identical CPM format.

Fig. 19 presents an example of representing three level's schedules within schedule hierarchy by the BDM. The lowest level or detail schedule in Fig. 19 shows the relationships between work items of WBS level 3, and the middle level or summary schedule represents the multiple overlapping relationships between major works of WBS level 2 by BDM respectively. Further, the highest level or milestone schedule shows the summary of major milestones of a project by only one activity that has multiple milestones. Therefore, it is confirmed that all schedules within schedule hierarchy can be identically represented by the BDM.

The most distinctive characteristic of the BDM network in Fig. 19 is to express multiple relationships on intermediate milestones between door & window work and glass work, furniture work and flooring work in the middle schedule, which is impossible in the PDM. Further, it exactly represents the overlapping relationships between door & window work and ceiling & wall papering work, painting work and ceiling & wall papering work, ceiling & wall papering work and furniture work, furniture work and clean & inspection, on the time-scaled format. This unique feature that the BDM can represent all kinds of relationship between consecutive activities on the time-scaled format confirms that it could overcome the limitations and inefficiencies of the existing ADM and PDM.

7. CONCLUSIONS

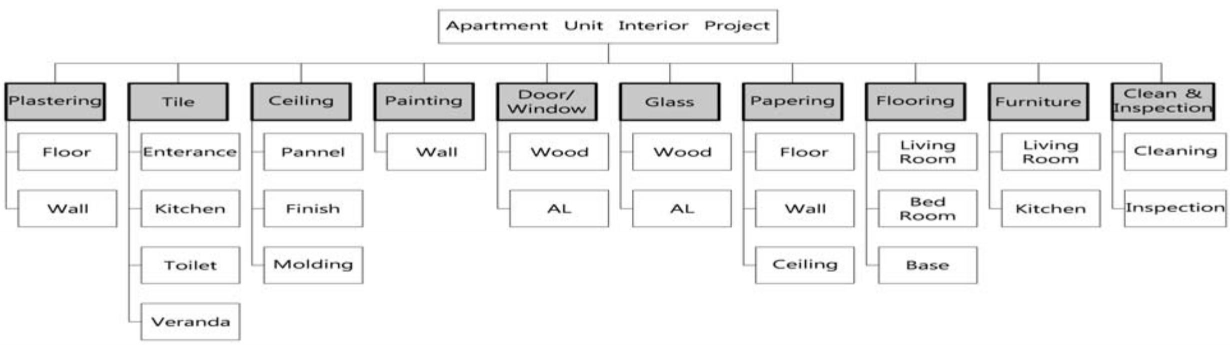


Fig. 18. Work Breakdown Structure of Interior Works

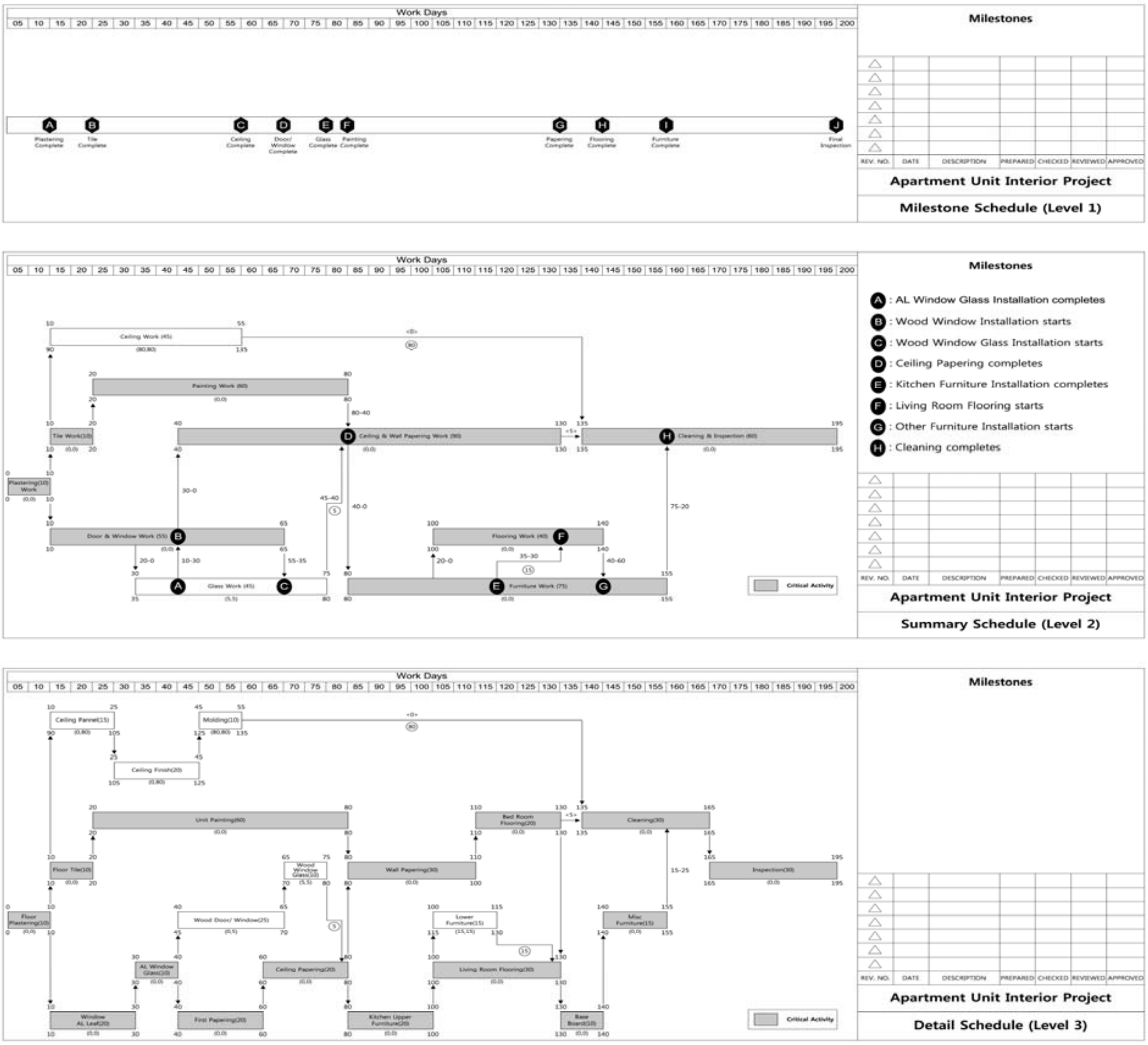


Fig. 19. An Example of Representing Three Level's Schedules within Schedule Hierarchy by the BDM

Construction projects are getting bigger and more complex. They need more flexible and innovative scheduling techniques that can be applied to all kinds of project management environments. This research therefore proposes the Beeline Diagramming Method (BDM) as a new networking technique that can represent all kinds of overlapping relationships between activities. This paper defines the basic concept, principle, interpretation methods, and schedule computation methods that the BDM requires to be an effective scheduling technique. To verify the BDM's adaptability and validity, the techniques proposed in this study have been applied to the complete BDM network. The verification results confirm that the BDM has all the key elements to evolve into a new networking technique.

The schedule formats within schedule hierarchy of construction project is generally represented by different scheduling techniques because the traditional scheduling techniques such as ADM or PDM cannot represent all kinds of schedule within schedule hierarchy as identical schedule format. However, the BDM technique can represent all kinds of schedule within the schedule hierarchy as an identical CPM format. This paper successfully presents an example of representing three level's schedules in schedule hierarchy by the BDM.

REFERENCES

[1] Callaham, Michael T. (1992). *Construction project scheduling*, McGraw-Hill.
[2] Fondahl, John W. (1961). *A non-computer approach to the critical path method for the construction industry: Technical report no. 9*, The Construction Institute, Department of Civil Engineering, Stanford University, Stanford, CA.
[3] Harris, Robert B. (1978). *Precedence and arrow networking techniques for construction*, Jon Wiley & Sons.
[4] Ponce-Campos, Guillermo (1972*). Extensions of the solutions of deterministic and probabilistic project network method*, Ph.D. Dissertation, The University of Michigan, Ann Arbor.
[5] Kim, Seon-Gyoo (2010). Advanced Networking Technique, Kimoondang, South Korea