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Conversion of Overlapping Relationships from PDM to BDM in CPM Network

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----------***ABSTRACT***----------
Most of the schedule management software currently applied in construction project uses the Precedence Diagramming Method (PDM) because overlapping relationship between activities is possible. However, the overlapping relationship between the activities of the PDM is expressed in the form of a bar chart in order to indicate the four combinations that connect the start and end points of the preceding and subsequent activities. In the bar chart format, overlapping connecting lines between activities occurs, making it difficult to visually judge the logic between activities. Therefore, the visual representation of the PDM schedule is very weak. This makes it difficult for construction professionals to communicate by lowering their understanding of the schedule. Also, the PDM has a limitation in that it cannot express a two-way multiple overlapping relationships. In order to overcome the problems of the PDM, the Beeline Diagramming Method (BDM) was proposed in 2010. The BDM is capable of expressing a two-way multiple overlapping relationships while horizontally expressing the connection relationships between activities from left to right. Therefore, the BDM has a very good visual expression and is very flexible in expressing overlapping relationships, so it is possible to establish an accurate schedule. In this study, we propose a method for converting the four overlapping relationships of the PDM into the overlapping relationships of the BDM. Through this, it is possible to convert the schedule prepared by the PDM to the schedule of the BDM, thereby maximizing the advantages of the BDM to improve the efficiency of schedule management, and ultimately contribute to the advancement of schedule management.

Keywords: *Overlapping, Conversion, CPM, PDM, BDM*

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I. Introduction

Awareness of the importance of scheduling in the construction business is widely spread and applied to various projects. However, from a practical point of view, it is also true that the utilization of scheduling is somewhat inferior compared to other industries.

The starting point of modern scheduling was Arrow Diagramming Method (ADM), the first Critical Path Method (CPM) proposed in 1956. However, most current scheduling software uses the Precedence Diagramming Method (PDM) proposed in 1972. The biggest reason for applying the PDM instead of the ADM is that the PDM allows for overlapping relationship between activities.

The overlapping relationship between activities can express the interrelationship between activities more realistically in the actual construction project, and reduce the number of activities in the network so that the project can be managed efficiently. The overlapping relationship between the activities of the PDM is indicated by four combinations that connect the start and end points of the preceding and following activities. However, in the actual construction project, the overlapping relationship between the preceding and following activities can have a mutual correlation at any point in the middle of the activity. Therefore, it cannot be concluded that the PDM accurately and efficiently expresses the overlapping relationship between activities.

In addition, the network of the PDM is not represented from left to right, but is arranged vertically from top to bottom. This is to prevent the overlapping relationships in the PDM from intersecting. However, if the activities are arranged in a vertical downward direction, the relationships between activities cannot be accurately grasped visually. Also, the PDM has a limitation in that it cannot express a two-way multiple overlapping

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relationships. As such, the schedule prepared by PDM weakens the efficiency of scheduling due to visual limitations, and thus does not fully satisfy construction professionals.

In this study, the Beeline Diagramming Method (BDM) proposed in 2010, a new scheduling technique that can link the interrelationships between activities at any point in the middle of the activity, as well as display two-way multiple overlapping relationships, is described. (Kim, 2010) And we propose a method of converting the four overlapping relationship expression methods of the PDM to the overlapping relationship of the BDM. Through this, it is possible to convert the schedule prepared by the PDM to the schedule of the BDM, thereby maximizing the advantages of the BDM to improve the efficiency of schedule management, and ultimately contribute to the advancement of schedule management.

Research Scope and Methods

This study is to transform the four overlapping relationship expression methods of the existing PDM into <N>, N-N types of the BDM, and proceeded as follows.

First, the basic concept and principle of the PDM and the representation method of overlapping relationships are investigated, and the basic concept and principle of the new scheduling technique, the BDM, and the method of interpretation and representation of overlapping relationships are investigated.

Second, we propose a method of converting the four expression methods of FS, SS, FF, and SF, which are the overlapping relationship display methods of the PDM, to the BDM method, respectively.

Third, the conversion method proposed in this study is verified through the sample network.

Theoretical Review of PDM and BDM

Theoretical Review of PDM

The PDM is currently the most widely used scheduling technique internationally. In addition, most of the internationally used project management software uses the PDM as a basis. The advantages of the PDM are as follows.

First, dummy activity is unnecessary. The basic concept of the PDM is that a node becomes an activity, and the lines connecting the activities indicates only the preceding and succeeding relationship of the activities.

Second, the schedule calculation is very simple and convenient. In the PDM, the node is the activity, so the node time and the activity time are the same. Therefore, it is possible to calculate the schedule at a time.

Third, it is possible to express the overlapping relationship between preceding and succeeding activities. The ADM could only express the FS (Finish-to-Start) relationship in which the succeeding activity starts after the preceding activity is finished. However, in the PDM, the overlapping relationship can be expressed in the form of SS (Start-to-Start), FF (Finish-to-Finish), and SF (Start-to-Start). Due to the various expressions of overlapping relationships in the PDM, it became possible to reduce the total number of network activities and to express the interrelationships between activities more realistically.

Fourth, multiple overlapping relationships between preceding and succeeding activities can be expressed. If there are two overlapping relationships, not just one, between the predecessor and the successor, it is possible to express SS and FF at the same time. This overlapping relationship is called a compound relationship. (Harris, 1972) However, the PDM cannot express two or more multiple overlapping relationships.

Expression of overlapping relationship in PDM

In the PDM, the method of expressing the overlapping relationship between the preceding and succeeding activities is divided into the following four types.

First, the Start-to-Start (SS) is a relationship in which the preceding activity starts and the succeeding activity starts after a certain period has elapsed. The overlapping relationship is indicated by linking the starting point between the predecessor and the succeeding activities. Figure 1 shows an example of an SS relationship.

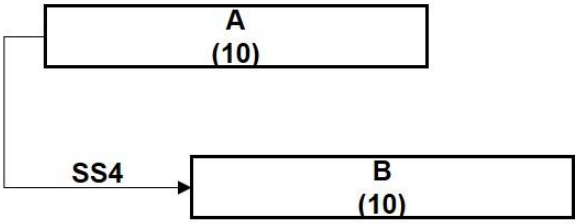

Figure 1. Example of Start to Start (SS)

Second, the Finish-to-Finish (FF) is a relationship in which the preceding activity is finished and the succeeding activity is finished after a certain period has elapsed. Figure 2 shows an example of an FF relationship.

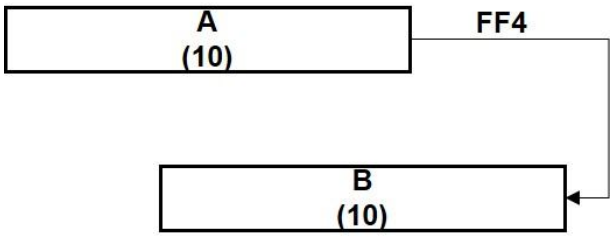

Figure 2. Example of Finish to Finish (FF)

Third, the Start-to-Finish (SF) is a relationship in which the preceding activity is started and the succeeding activity is finished after a certain period has elapsed. Figure 3 shows an example of an SF relationship.

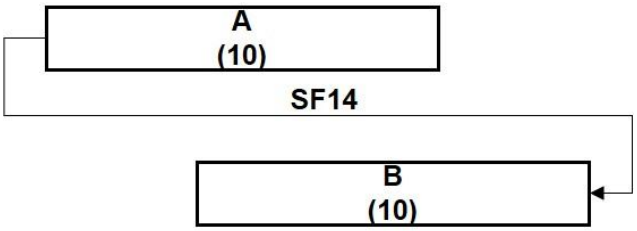

Figure 3. Example of Start to Finish (SF)

The fourth is a compound relationship. This relationship is a method of expressing two types of overlapping relationships between preceding and succeeding activities by linking the starting points of the preceding and succeeding activities with an SS relationship and linking them with an FF relationship between the completion points. Compound Relationship is very suitable when expressing a relationship in which the successor activity changes in the same way when the preceding activity changes. Figure 4 shows an example of a compound relationship.

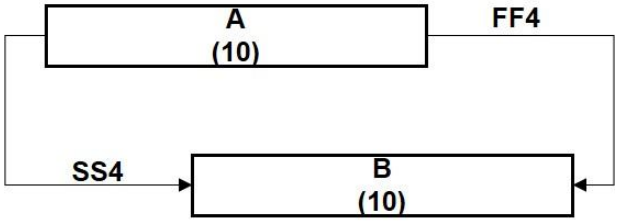

Figure 4. Compound Relationship

Basic Concept and Characteristics of BDM

The basic concept of the BDM is to express the connection relationship between the preceding and succeeding activities as the shortest straight line from any point in the middle of the preceding activity to any point in the middle of the succeeding activity. In other words, when interconnection is required at any intermediate point in the preceding and succeeding activity, the closest distance between those points is connected with a straight line having an arrow in the direction of work. It is defined as Beeline, which means the shortest distance between each other. Figure 5 expresses the basic concept of the BDM. (Kim, 2010)

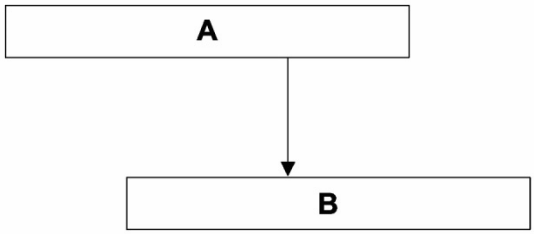

Figure 5. Basic Concept of BDM

The characteristics of BDM are as follows. First, since it is directly connected at any point in the middle of the preceding and succeeding activities, the expression of the overlapping relationship between the preceding and succeeding activities is simplified. Second, by enabling multiple linkages between preceding and succeeding activities, it is possible to express multiple linkages between preceding and succeeding activities with a long activity duration and multiple intermediate milestones.

Linkage Representation Types in the BDM

In the BDM, the preceding and succeeding representation types are divided into three types and are as follows. First, the overlapping relationship between preceding and succeeding activities is expressed as 'N-N' as shown in Figure 6 for the number of days elapsed since the start of each activity.

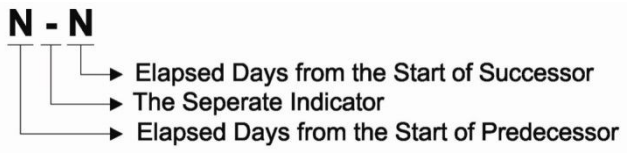

Figure 6. Representation Type by the Elapsed Days

In Figure 6, the front 'N' indicates the number of days elapsed after the preceding activity started, and the rear 'N' indicates the number of elapsed days after the succeeding activity started. The '-' in the middle is an indicator that separates the number of days 'N' of the preceding and succeeding activities.

Second, as shown in Figure 7, it is to express as a percentage after each of the preceding and succeeding activities started.

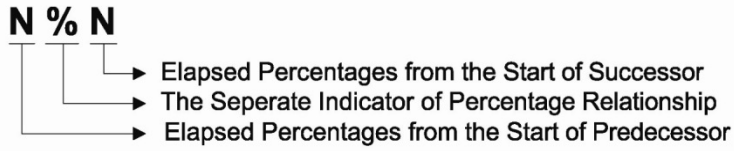

Figure 7 Representation Type by the Elapsed Percentage

In Figure 7, the 'N' in the front indicates the percentage rate after the initiation of the preceding activity, and the 'N' in the rear indicates the percentage rate after the start of the succeeding activity. The '%' in the middle is an indicator that separates the elapsed percentage 'N' of the preceding and succeeding activities, implying that the preceding and succeeding activities are linked after a certain percentage of time has elapsed.

Third, when a succeeding activity started after a certain period of time has elapsed after the completion of the preceding activity, it is displayed in the type of '<N>' as shown in Figure 8.

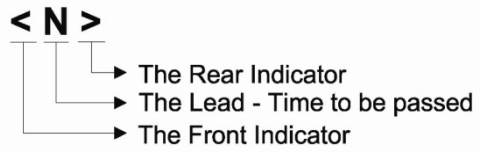

Figure 8. Representation by FS Type

In Figure 8, 'N' in the middle indicates the lead-time, which is a certain period of time after the completion of the preceding activity and before the start of the succeeding activity, and the '<' and '>' in front and rear of the number N are the space indicator for entering the lead-time.

If the preceding and succeeding activities have multiple completion points and have multiple beelines in both directions between them, they can be accurately expressed. As shown in Figure 9, when there are multiple completion points in both directions between the preceding and succeeding activities, it is possible to express two-way multiple beelines linking the connection points between the preceding and succeeding activities with the shortest distance.

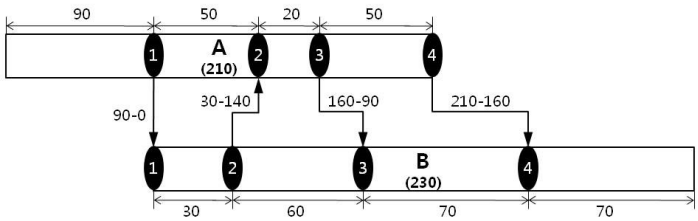

Figure 9. Two-way Multiple Relationship

This expression of two-way multiple overlapping relationships has the following expected effects. First, the overlapping relationships in the PDM is all about the two connection relationships between the preceding and succeeding activities, that is, the compound relationship that simultaneously expresses the SS and FF relationships. In other words, it is impossible to express more than three overlapping relationships between the preceding and succeeding activities. This is one of the factors that severely limit the flexibility of scheduling. Second, when summarizing the schedule, the summarized schedule can be expressed in the form of a network with two-way multiple overlapping relationships rather than a simple bar chart. Through this, it is possible to logically understand the overall construction flow even through the summary schedule.

Necessity to convert overlapping relationships from PDM to BDM

The schedules prepared by the PDM take the form of logical flow as the activities are arranged in the vertical and downward direction with the time axis. This form of expression of the schedule makes it very difficult to review the logical adequacy between the activities, and because a lot of unnecessary work logic occurs, it does not sufficiently satisfy the needs of the end-users of the schedule, including project management professionals.

However, the BDM schedule, like the ADM schedule, develops the logic of the activity from left to right parallel to the time axis, so that the overlapping relationship between activities can be expressed more efficiently and with wider flexibility than the PDM schedule. Therefore, if the BDM overlapping relationships can express all the overlapping relationships of PDM, it is necessary to find a way to convert the PDM schedule to the BDM schedule because users who are familiar with the PDM can easily understand and utilize the BDM.

Conversion Method of overlapping relationships from PDM to BDM

In order to convert the overlapping relationship expressed in the PDM to the BDM, a conversion method is required. In this study, we propose a method for converting the FS, SS, FF, and SF overlapping relationships of the PDM to the BDM as follows.

Conversion of Finish to Start (FS)

The FS relationship of the PDM can be expressed in the form of '<N>', which is the expression form when the subsequent work is started after a certain period of time has elapsed in the BDM. That is, in the PDM relationship, after a Lead Time (LT) has elapsed after the completion of the preceding activity, the succeeding activity is started, so the period 'LT' is converted to 'N' as it is. If expressed as a formula, it is the same as Equation (1).

$$N = LT \quad (1)$$

Figure 10 shows an example of converting 'FS3', which is a relationship where the preceding activity is completed with the PDM and the succeeding activity starts 3 days later, with the BDM, '<3>'.

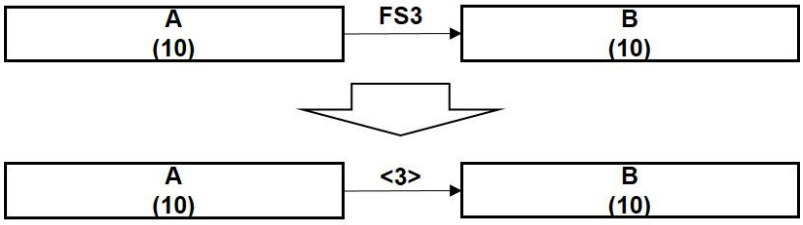

Figure 10. Example of converting 'FS3' relationship in PDM to '<3>' in BDM

Conversion of Start to Start (SS)

The SS relationship of PDM is a relationship in which the successor work starts after the preceding work is completed and a certain period (N) has elapsed, and it can be transformed into the 'N-0' relationship of BDM. Figure 11 shows the basic concept of converting the SS relationship of PDM to the 'N-N' relationship of BDM. In Figure 11, the difference between the start time of the preceding activity and the start time of the succeeding

activity can be expressed as d_I of BDM. If d_I is LT=3, it can be expressed in the form of 'LT-0' where d_J is 0. If this is expressed as a formula, it is as Equation (2). Therefore, 'SS3' of PDM becomes '3-0' of BDM.

$$d_I = LT,\ d_I = 0 \quad (2)$$

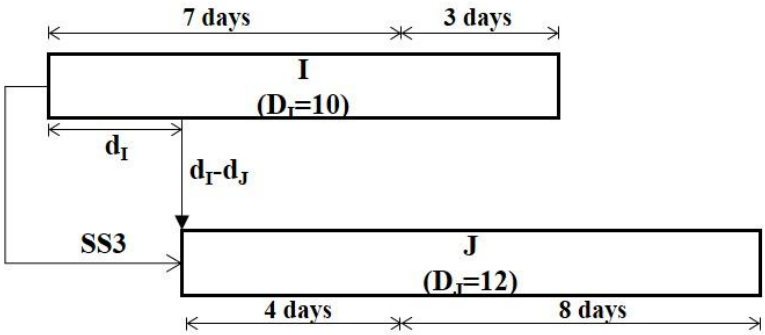

Figure 11. The concept of converting the SS relationship of PDM to BDM

Figure 12 shows the relationship in which the preceding activity starts with the PDM and the succeeding activity starts 4 days later as 'SS4'.

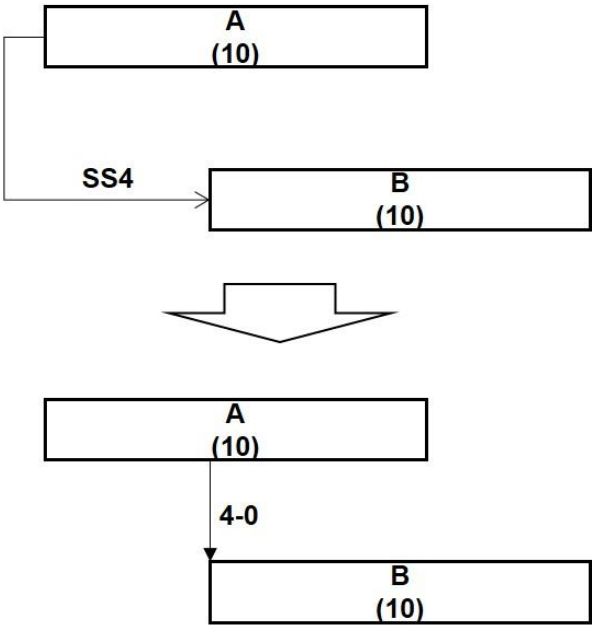

Figure 12. Example of converting 'SS4' relationship in PDM to '4-0' in BDM

Conversion of Finish to Finish (FF)

The FF relationship of PDM is a relationship in which the succeeding activity is completed after a certain period has elapsed after the preceding activity is completed, and it can be converted to the 'N-N' relationship of BDM. Figure 13 shows the basic concept of converting the FF relationship of PDM to the 'N-N' relationship of BDM.

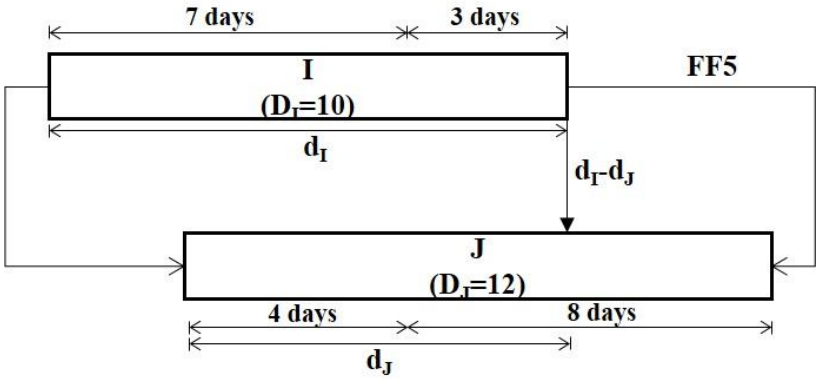

Figure 13. The concept of converting the FF relationship of PDM to BDM

In Figure 13, the entire working period (D_I) of the preceding activity becomes the d_I of the BDM, and d_J is the end time of the preceding activity minus the start time of the succeeding activity, and is expressed as 'D_I–(D_J – LT)'. If this is expressed as a formula, it is as Equation (3). Therefore, the 'FF5' relationship of PDM becomes '10–7' of BDM.

$$d_I = D_I \, , \, d_J = D_J - LT \tag{3}$$

Figure 14 shows an example of converting 'FF4' to '10-6' using the BDM as 'FF4', in which the preceding activity is completed with the PDM and the succeeding activity is completed 4 days after the completion of the PDM.

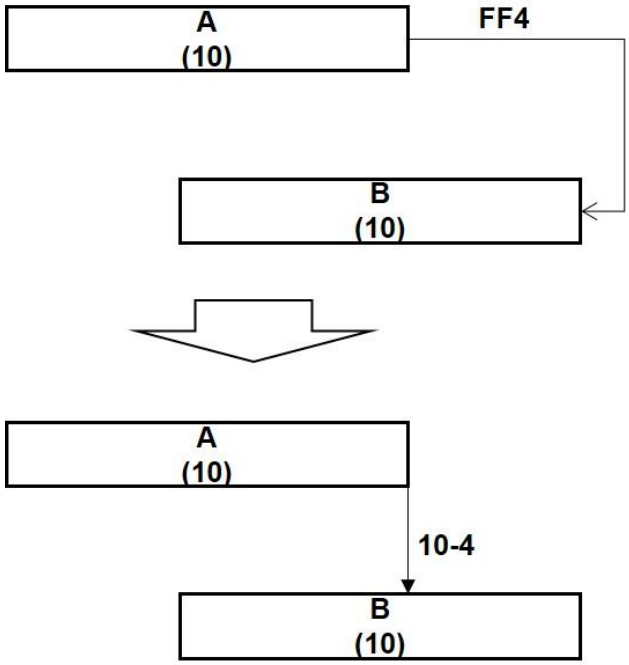

Figure 14. Example of converting 'FF4' relationship in PDM to '10-4' in BDM

Conversion of Start to Finish (SF)

The SF relationship of PDM is a relationship in which the preceding activity is started and the succeeding activity is completed after a certain period of time has elapsed, and it can be converted to the 'N-N' relationship of BDM. Figure 15 shows the basic concept of converting the SF relationship of PDM to the 'N-N' relationship of BDM.

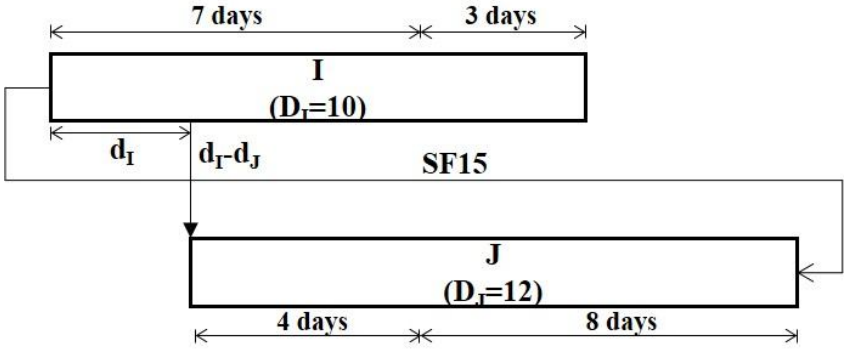

Figure 15. The concept of converting the SF relationship of PDM to BDM

In Figure 15, the difference between the start of the preceding activity and the start of the succeeding activity, (LT – D_J), becomes the d_I of the BDM relationship, and d_J becomes 0, so it can be expressed as '(LT – D_J)–0'. If this is expressed as a formula, it is as Equation (4). Therefore, 'SF15' of PDM calculates d_I of BDM as '15 – 12 = 3' and d_J is '0', so 'SF15' of PDM becomes '3–0' of BDM.

$$d_I = LT - D_J \text{ , } d_I = 0 \quad (4)$$

Figure 16 shows an example of converting the relationship 'SF14', in which the preceding activity starts and the succeeding activity is completed 14 days after the start of the PDM, into a '4-0' relationship with the BDM.

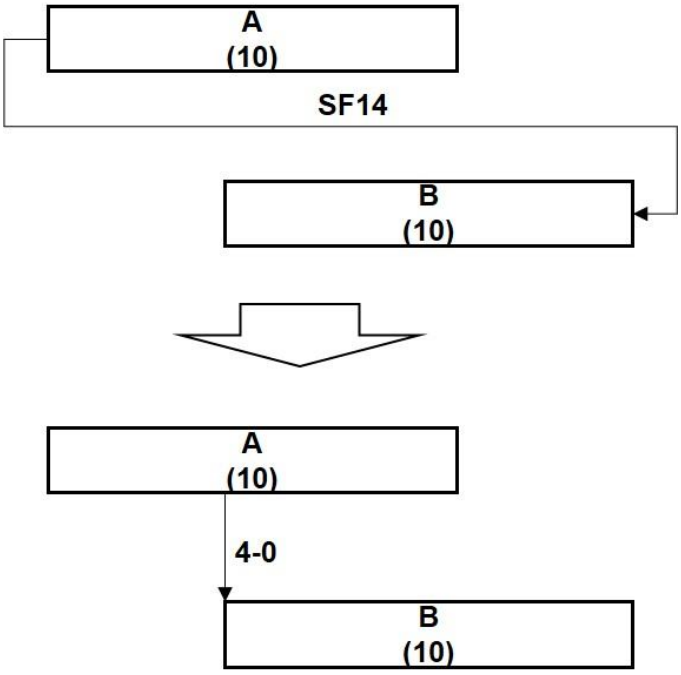

Figure 16. Example of converting 'SF14' relationship in PDM to '4-0' in BDM

Verification of Converting PDM to BDM

The legitimacy and usefulness of the result of converting the PDM to the BDM is verified by applying it to the CPM schedule prepared based on the PDM.

CPM Schedule based on PDM

Figure 17 is the CPM schedule of the 'City Center Building Addition Project' prepared using the PDM.[3] The CPM schedule in Figure 17 shows typical PDM overlapping relationships. The representation of the PDM schedule is listed in a bar chart format to avoid crossing PDM overlapping relationships. Therefore, as the number of activities increases, the schedules expands indefinitely in the vertical downward direction.

[3] Sample project uploaded to P6, Oracle's project management software

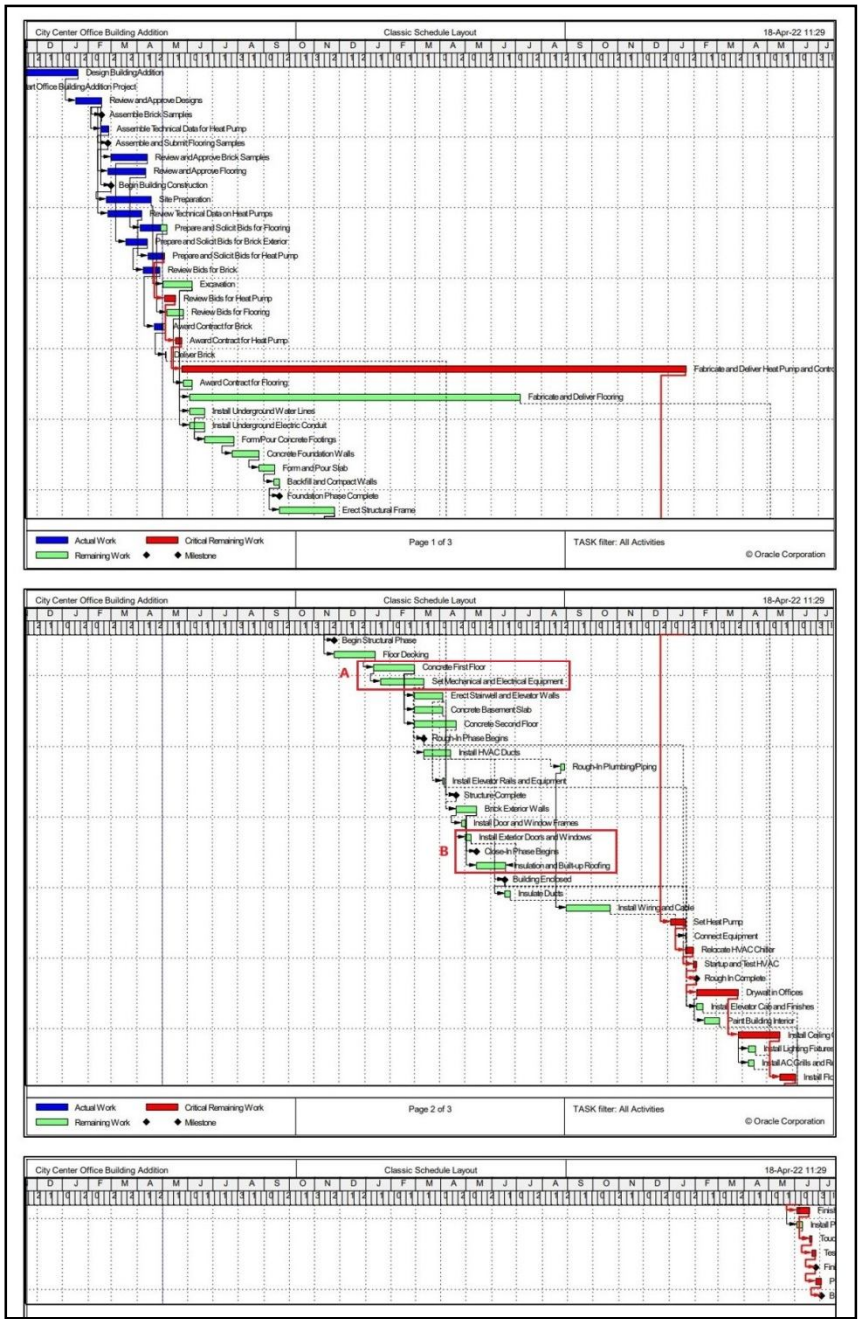

Figure 17. CPM schedule prepared by PDM

Although the total number of activities in the PDM schedule in Figure 17 is 56, it is expressed in excess of 2 pages of paper divided vertically. If the number of activities exceeds 500, more than 20 pages of paper in the vertical downward direction will be required. If each activity is arranged in a vertical downward direction on multiple independent papers, it is almost impossible to accurately identify the connection between the activities.

The key to the CPM schedule is to easily recognize logical connections between activities. If the connections between the activities cannot be identified in the schedule, it is no different from the bar chart schedule. It is difficult to expect efficient and systematic schedule management in the bar chart schedule. (Callahan and Michael, 1992)

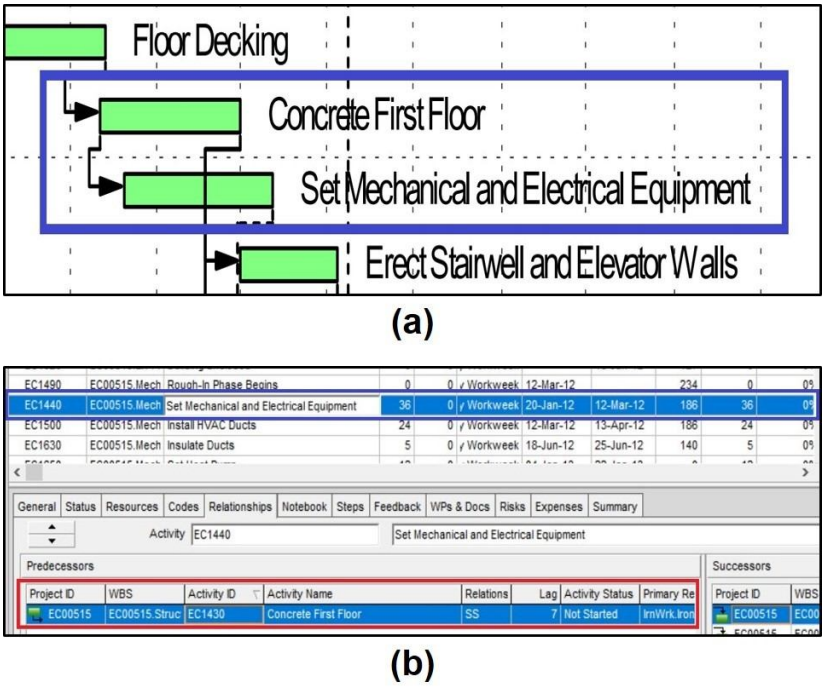

Figure 18. SS relationship in PDM Schedule

If the square box A in Figure 17 is enlarged, it is like Figure 18(a). In Figure 18(a), it can be recognized that the 'Concrete First Floor' activity and the 'Set Mechanical and Electrical Equipment' activity have an SS relationship, but the Lead Time (LT) cannot be confirmed. The LT of SS relationship can be confirmed in Lag of Fig. 18(b), which is a capture screen of P6. In Fig. 18(b), the Lag value is '7'. Therefore, the two activities are connected by the 'SS7' relationship.

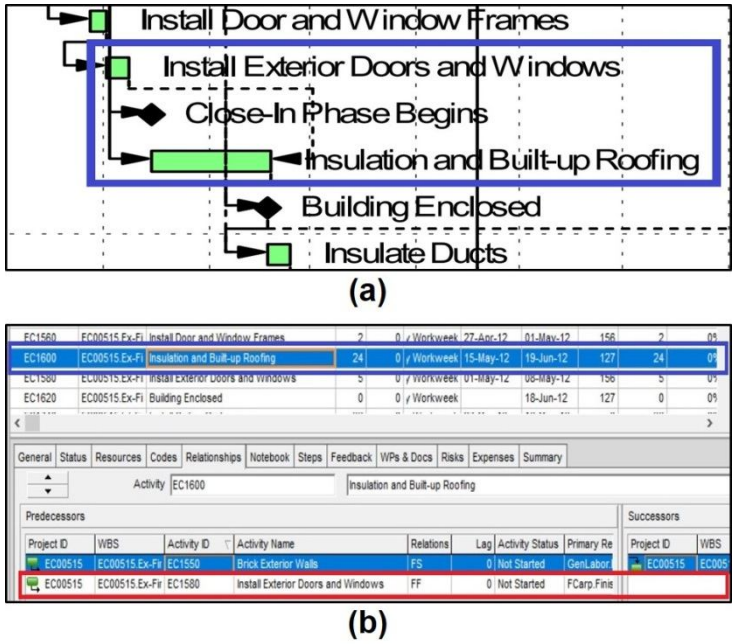

Figure 19. FF relationship in PDM Schedule

Also, if the square box B in Figure 17 is enlarged, it is like Figure 19(a). In Fig. 19(a), it can be recognized that the 'Install Exterior Doors and Windows' activity and the 'Insulation and Built-up Roofing' activity have an FF relationship, but the Lead Time (LT) cannot be confirmed. The LT of the FF relationship can be confirmed in the Lag of Fig. 19(b), which is a capture screen of P6. In Figure 19(b), the Lag value is '0'. Therefore, the two activities are connected in the 'FF0' relationship.

Most of the PDM scheduling software is designed to check the information on the preceding and succeeding

relationships between activities in an independent table. This is because if too much information is expressed in the bar chart, it is not easy to recognize the connection between activities. As described above, in the PDM schedule, as activities are arranged in a vertical downward direction, detailed information of the schedule is separated from the chart, so the readability and efficiency of the schedule are rapidly reduced. This is one of the biggest weaknesses of the PDM schedule.

CPM Schedule converted to BDM

Figure 20 is the result of converting the PDM schedule in Figure 17 into the BDM schedule using Beeliner[4], scheduling software developed based on the BDM.

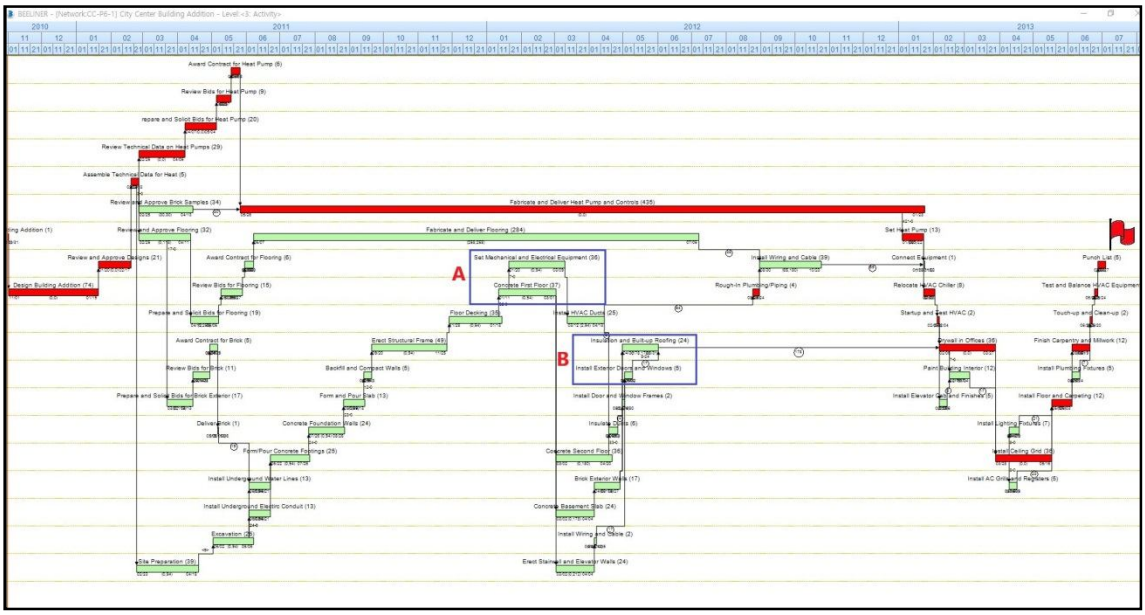

Figure 20. CPM schedule converted to BDM

Comparing the BDM schedule in Figure 20 with the PDM schedule in Figure 17, the following characteristics can be found.

First, even in the BDM schedule, the overlapping relationship between the activities of the PDM schedule is freely expressed. Figure 21 is an enlarged view of the square box A in Figure 20. The PDM relationship 'SS7' in Figure 18 was converted to the BDM relationship '7-0' according to Equation (2). Also, Figure 22 is an enlarged view of the square box B in Figure 20. The PDM relationship 'FF0' in Figure 19 has been converted to the BDM relationship '5-24' according to Equation (3). In other words, since the PDM overlapping relationship can be completely converted to the BDM overlapping relationship, the method of converting the PDM to the BDM proposed in this paper has been proven justified.

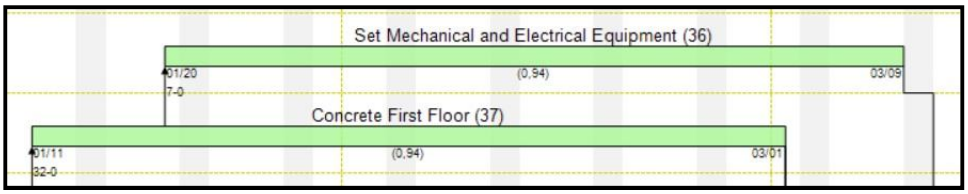

Figure 21. The result of the conversion of PDM's 'SS7' relationship to BDM's '7-0' relationship

[4] Schedule management software based on the BDM developed by Beeliner Ltd. Co.

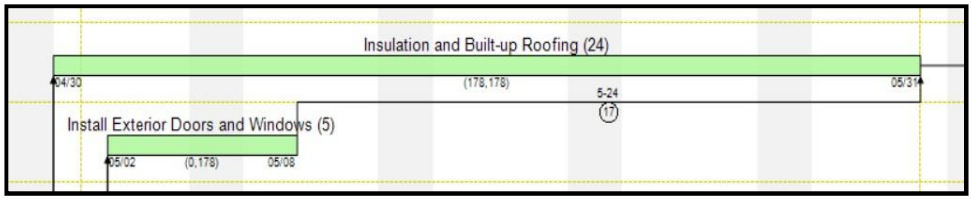

Figure 22. The result of the conversion of PDM's 'FF0' relationship to BDM's '5-24' relationship

Second, the activities of the PDM schedule are arranged in a vertical downward direction, whereas the activities of the BDM schedule are arranged from left to right along the time axis. Therefore, the BDM schedule can easily recognize the flow of work visually.

Third, the connections between activities in the PDM schedule overlap in the vertical downward direction, and the logic between activities cannot be accurately identified. However, in the BDM schedule, the logic between activities is connected without overlapping along the time axis, so the flow of work can be easily identified visually.

Fourth, as the number of activities increases, the PDM schedule is expressed separately on the multiple pages, whereas in the BDM schedule, all activities can be expressed on one page regardless of the number of activities. This characteristic of BDM schedule is to realize the advantages of the ADM schedule as it is. Although the ADM has the disadvantage of not being able to express the overlapping relationship between activities, the visual excellence of being able to express the entire schedule on one page is the greatest advantage that the PDM cannot overcome. In other words, the BDM not only expresses the entire schedule on one page so that the flow of work can be easily grasped visually, but also the percent progress curve (S-Curve), EVM, and resource profile can be expressed simultaneously with the schedule, so that project professionals can efficiently share and communicate schedule.

II. Conclusions

As the environment surrounding the construction project changes rapidly, the need for systematic project management for the success of the project is gradually increasing. In particular, high expectations are placed on the role of schedule management that integrates all functions of project management.

However, compared to the importance of schedule management, the scheduling technique applied to the project is still stuck in the PDM, a technology from 50 years ago. CPM schedule started with ADM in 1956, and entered the 2000s without major changes after the overlapping relationship of the PDM was announced in 1972. However, innumerable problems and inconveniences to the PDM were raised by schedule professionals, and various alternatives were suggested to overcome them. Among them, the LDM (Logical Diagramming Method) (Ponce de Leon, 2008) and the RDM (Relational Diagramming Method) (Plotnick, 2008) are representative. However, as these techniques are slightly modified versions of the ADM and PDM, they could not be an alternative to solving the fundamental problems of ADM and PDM.

The biggest problem with the ADM is that it cannot display overlapping relationship between activities because only the Finish-to-Start (FS) relationship between the preceding and succeeding activities is applied. However, in the ADM, the flow of work is arranged horizontally, so the visual expression is still preferred by field engineers. On the other hand, the PDM can display the overlapping relationship between the preceding and following activities. Therefore, the work logic can be accurately expressed. However, in the PDM schedule, it is difficult to visually recognize the flow of work because the activities are arranged in a vertical downward direction. This is the biggest drawback of the PDM and is the reason why field engineers ignore the PDM schedule.

In 2010, a BDM that can simultaneously satisfy the visual excellence of ADM and the overlapping relationship expression of PDM was proposed. The BDM has not been widely known since it has not been proposed for a long time. Therefore, in this paper, the core of the PDM is to prove the legitimacy and efficiency of the BDM by proposing a method of converting the expression of the PDM overlapping relationship to the BDM overlapping relationship.

The method of converting the PDM overlapping relationship to the BDM overlapping relationship proposed in this study was verified by applying it to the actual project. As a result, it was confirmed that the BDM has the following advantages over the PDM.

First, the PDM overlapping relationship can be completely converted into the BDM overlapping relationship.

Second, the activities of the PDM schedule are arranged in a vertical downward direction, but the activities of the BDM schedule are arranged from left to right along the time axis, so that the flow of work can be easily recognized visually.

Third, it is not possible to express that the connection between activities does not intersect in the PDM schedule, but it can be expressed so that the connection between activities does not intersect in the BDM schedule.

Fourth, since the PDM schedule is printed over several pages, information such as the network and progress rate cannot be displayed at the same time. However, in the BDM schedule, the network and S-Curve, EVM, and Resource Profile can be simultaneously expressed on one page.

These advantages of the BDM will be a key factor in overcoming the inconvenience felt in the PDM. In addition, it will help schedule experts who were familiar with the PDM to access the BDM more easily. In the rapidly changing construction project environment, it is expected that the BDM will improve the efficiency of schedule management and improve the success probability of the construction project by allowing the schedule to be shared and communicated smoothly.

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