CPM BAR CHART TECHNIQUE FOR CONSTRUCTION SCHEDULING

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ABSTRACT : This paper proposes the CPM bar chart (CBC), a hybrid of the bar chart and the critical path method (CPM). The CBC overcomes shortages of the fence bar chart, while still retaining its advantages. The fence with direction is applied instead of the broken fence, which triggers considerable problems to identify and apply in the fenced bar chart. In addition, the notorious task to find dummy activities is no longer required. Upon the benefits of simplicity in the bar chart and logical work sequence in the CPM network, the CBC provides a relatively easy way to create and understand a schedule, thus improving communication quality between project participants.

Key words : CPM, bar chart, scheduling

1. INTRODUCTION

Construction projects inherently engage a variety of specialized groups and stakeholders who include the owners, architects, engineers, supervisors, and contractors. The projects, depending on their conditions, also relate to construction managers (CMr), financial institutes and government offices. Harmonious and efficient communication among these participants is essential to accomplish these projects successful. The participants, however, reach to the different degree of understanding of using various techniques to plan, execute, and manage projects (Clough et al. 2000). Scheduling and managing construction projects is not free from the disagreement although Liberatore et al. (2001) proved that the critical path methods (CPM), one of the network scheduling techniques, is effective to a number of construction projects. As a result, the participants except CMr or scheduling specialists have been disclosed to difficulties comprehending and using the CPM (Clough et al. 2000).

In addition, these difficulties in association with the CPM increase especially in such areas as resource leveling, resource constrained scheduling, precedence diagramming methods (PDM). These methods are employed to organize complex relationships of activities and to schedule renewal with activity split that applies PDM. The techniques, therefore, are not effective in their utilities without specialists armed with the appropriate knowledge of scheduling.

On the other hand, bar chart is preferred by many construction companies due to that it provides not only more simplicity in drawing up the schedule, but also more flexibility in its management than the CPM. However, it also accompanies the shortcomings; the relations between activities are not as conspicuous as in the CPM and float time of each activity, which indicates the status of project managed, is invisible. When unexpected schedule delay occurs and legal issues arise, the analysis, adjustment, and settlement grounded on the bar chart schedule offer limited solutions to the claim because the precedence and succession among activities are unclear (Hinze 2004).

Melin (1981) presented the fenced bar chart (FBC) method to overcome these problems. It constructs the work schedule with ease as much like the CPM style by applying the fence and bar, which is the same used in the bar chart, to establish relations between activities. This advantage helps project participants communicate about the work schedule more smoothly. In addition, it, as one of the educational tools for scheduling, enables activities to explain the process of various work schedule improvements. The effectiveness of this method has been proved through time management classes at universities.

Here is introduced and discussed the FBC method of advantages and disadvantages. Besides, this paper proposes CPM bar chart (CBC) and examines its effectiveness by applying it to a set of examples.

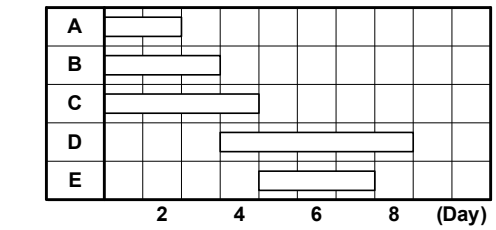
2. FENCED BAR CHART

2.1 Introduction

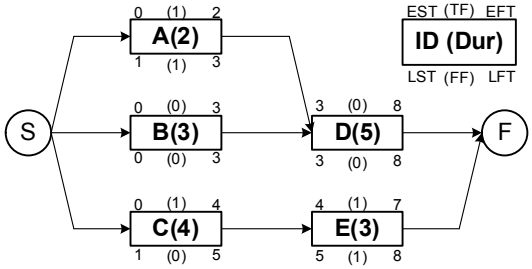
The FBC is the combined form taking advantages of the bar chart and the CPM. Figure 1 (a) shows the bar chart schedule of a work. The good of the FBC is that the time-

scaled bar presents the start and finish of each work and it accordingly reveals the uncomplicated work schedule to non-specialized project participants without knowledge of the scheduling. But the counterpart of the strong point is in the work flows not clarifying the predecessors and successors of activities. This triggers the problem that it is difficult to evaluate and estimate the impact from schedule changes from certain activities during the course of project work. For example, if activity A should end with two days extended from the finish date scheduled, the bar chart provides insufficient information of how the delay of activity A does affect not only the schedule of other activities but also the project as a whole.

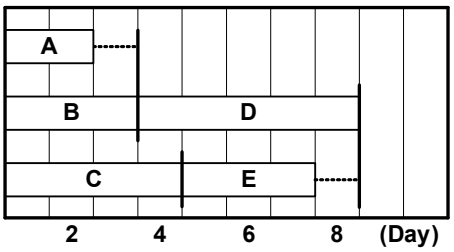
On the other hand, the identical work schedule constructed with the CPM becomes more obvious especially in activity relations than with the bar chart. It can also afford the estimated completion time and critical path over the whole project and the schedule information of each activity such as early start time (EST), early finish time (EFT), late start time (LST), late finish time (LFT), total float (TF) and free float (FF). If the work schedule of an activity is changed, the CPM enables to estimate its impact on the project and following activities with the information of the work schedule of other activities and their logical links among them. Its utility is exemplified with activity C that requires additional two days to finish it. Activity C has non-day of FF and one day of TF. If its finish time is delayed by two days, the start time of a following activity, which is activity E, is also delayed by two days and therefore the project ends with one day deferred compared with the expected finish time.



(a) Bar chart schedule



(b) CPM schedule



(c) Fenced bar chart schedule

Figure 1. Project Organization by Bar Chart, CPM, Fenced Bar Chart

Figure 1 (c) is the schedule by the FBC that utilizes the fence, which is the vertical line connecting to activities, and the network logic of the CPM to draw up the same project. Activity D in the figure, for instance, should begin after the activities A and B are finished and activity E is able to start when activity C is completed. The horizontal dotted line concatenates between activities and fences when the completion of a precedent activity does not directly connect to the beginning of a following activity. Although activity D is the successor of activity A, activity D should defer its beginning until activity B is finished because the earliest beginning of activity D should follow the completion of both activities A and B. The dotted lines thus act as concatenator to manifest relation between activities A and D.

The simplicity of the FBC based on the bar chart makes the work schedule readable without the specific and specialized knowledge of the CPM. It also serves such the information quality of work schedule as the floats and critical path as the CPM provides. Therefore, the characteristics and advantages from it are summarized as following;

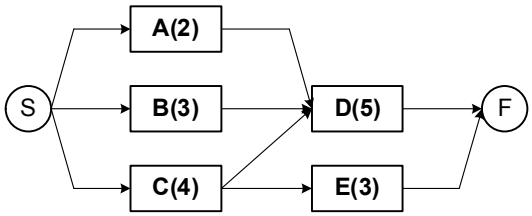
- The fence and dotted lines are the elements that connect to separate activities constructing the network logic of a project schedule.
- The visualized time-scaled bar makes it easier to compare and link the start and finish time of one activity with another or more.
- The dotted lines represent the free float of an activity. For example, both activities A and E have one day free floats from Figure 1 (c).
- Total float is attained by accumulating the free float of each activity on the paths from the end to the start point of a project. As a result, the total floats of activities A, C and E in Figure 1 (c) are one day each.
- The critical path is found on the path with no dotted lines between activities. Activities B and D in Figure 1 (c) are located on the critical path.
- The work schedule changes that occur from time to time during the course of project work and the impact from them become apparent. If activity A in Figure 1 (c) is delayed from the original schedule by two days, visualized work schedule allows to grasp activity D one day delayed and the project one day deferred as well.
- Resource constrained scheduling and resource leveling can be embodied in the FBC with no difficult because it enables required resources corresponding to an activity to be arranged on the time unit of the horizontal axis.
- When compared with the bar chart, the FBC allows more work schedules to be presented on a smaller area. The bar chart in Figure 1 (a) requires as many rows as activities, in which one row is dedicated to one activity. The FBC, on the other hand, arranges as many activities in a row as required, thus saves the space for the scheduling.

2.2 Split of Fence

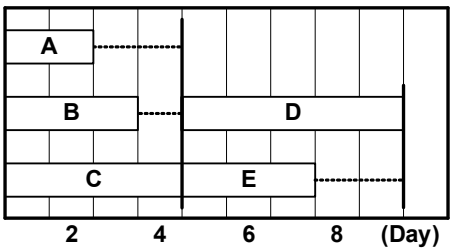
The FBC, as above mentioned, has many advantages. However, the fence that is split on occasion makes its users confused, which has been proven through the schedule classes at universities.

The example of the fence split corresponds to Figure 2. With the logic of the FBC applied, Figure 2 (a) is frequently drawn wrong as seen in Figure 2 (b). The error in it is that the fence connects between activities A and E and extends itself linking activities B to E. Following this logic of schedule, the start time of activity E should be delayed by one day or more if activity A is not finished until three days after the original plan or the end time of activity B is shifted more than one day as scheduled. Activity E, however, has nothing to do with activities A and B.

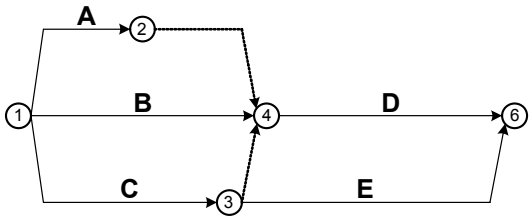
To cope with this problem, Melin (1981) proposed that the fence should be separated if activities link each other with the logical dummy activity applied in the activity on arrow (AOA). Figure 2 (c) is the construction of the identical schedule using the AOA. It retains the two kinds of dummy activities. One of these dummies is naming dummy that allocates each activity to a unique identification (ID). The naming dummy in Figure 2 (c) corresponds to dummy 2-4 that assigns different IDs to activities 1-2 and 2-4. Another type of dummy is to express the logic between activities. This kind of dummy should be required to set up the activity relations right. Activity 3-4 comes into this category. The existence of the logical dummy triggers the split of fence. In the example, part of the precedent activities (activities 1-2, 1-4 and 1-3) of the following activity (activity 4-6) accompanies the fence split depending on the activity relations. To complement the discontinuity of activities caused by the divided fence, the following activity labeled with an ID indicates the succession of precedent activities.



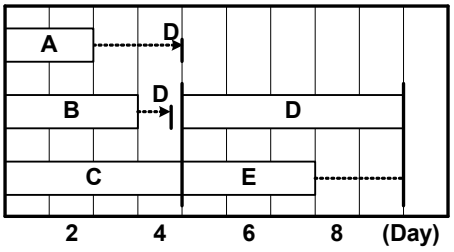
(a) CPM



(b) Incorrect fenced bar chart schedule



(c) AOA network



(d) Fenced bar chart with fence split

Figure 2. Fence Split

Figure 2 (d) is the reorganization of Figure 2 (a) with the FBC. A logical dummy is followed by activity D, which is preceded by activities A, B and C. The fence connected to activity D is separated from activities A and B except C that directly affects the beginning of activity D. The dotted lines, free floats to activity D, attaches to the split fence that establish the activity relations.

Finally, the FBC becomes complicated as the fence splits and the labels are generated to set up work relations. It also needs an additional work to make the AOA network to identify the fence where to be split. Considered the difficulty with the AOA that uses the dummies to organize the activity relations (Callahan et al. 1992), the separation of fence should produce the complexity of scheduling. The following of this paper, therefore, presents the CPM bar chat that improves the disadvantage from the FBC.

3. CPM BAR CHART

The CBC retains two characteristics different from the FBC. First, it uses the activity on node (AON) instead of the AOA to pinpoint the separation of fence. Figure 2 (a) is the example that employs the AON to identify the fence split. With the AON applied, if there is a condition that a working activity has more than one precedent activity, one or more of which have another following activity or more, then the precedent activity of the activity triggers the separation of fence from the activity. For example, activity D in Figure 2 (a) relates to three precedent activities, which are activities A, B and C. Activity C among these activities has another following activity that is activity E besides D; therefore, activity C generates the fence split from activity D.

Second, the activity relation between activities after the fence split should be organized with a direction. The separation itself without a controller might cause confusion. An arrow from the fence split originator towards the following activity provides the logic of activity relations. The fence split between activities C and D from Figure 2 (a) is enabled to hold the logic of activity flow retained in Figure 3 with an arrow added from activity C towards D. The arrow connects activity C to D, while averting activities A and B being linked to E. It requires no more fence split

and accordingly neither the labeling work.

The use of an arrow indicates that any activity relation is allowed within the fence including an arrow regardless of the direction imposed by the arrow. For example, Figure 4, another version of Figure 3, retains the activity relation that activity C points to E as its successor within the fence.

Another use of an arrow is found in Figure 5; the fence implies single and reciprocal directions at the same time. Figure 5 (a) shows the work schedule added to Figure 2 (a) with an activity relation between activities B and E. When activity A is neglected, Figure 5 (b) needs no two arrows, each of which represents one direction. Figure 5 (b) can then replace those arrows with just a fence that expresses the logic of activity flow. But the original work schedule considering activity A should include the activity relations from activities A, B and C towards D. Activities B and C need an arrow directing from B and C towards D, therefore it finally appears as in Figure 5 (d) where the fence retains both single and reciprocal directions.

The label after the fence is split in the FBC, on the other hand, is of no necessity in the CBC. But an appropriate separation of the fence and the use of label should also be considered when the fences cross each other depending on a work schedule. In Figure 6, the relation between activities AE and E needs the fence to be split because another activity relation between activities D and F crosses it in its expression.

As examined with the examples, the CBC requires no more dummies that could trigger a considerable amount of time and confusion to extract the fence split while working on it. In addition, without the fence split and label unless the activity relations cross one another, the direction imposed by an arrow generates enough information of the activity relation while promoting its simplicity.

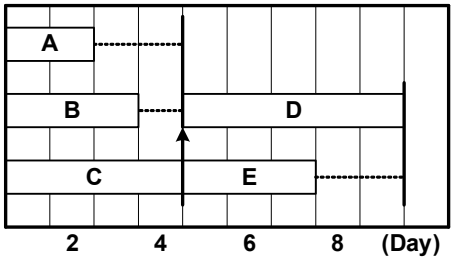


Figure 3. CPM Bar Chart

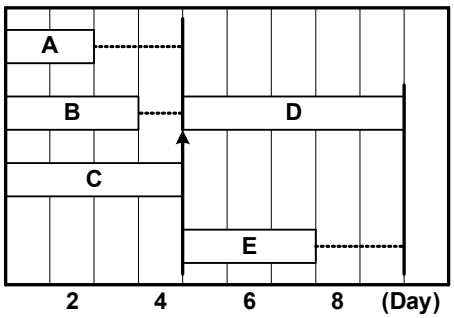
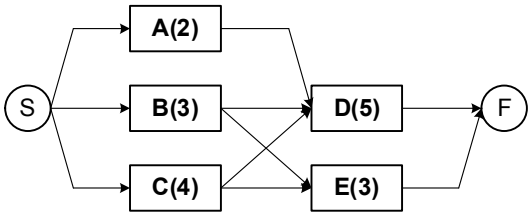


Figure 4. Work flow within a fence with an arrow in CPM bar chart

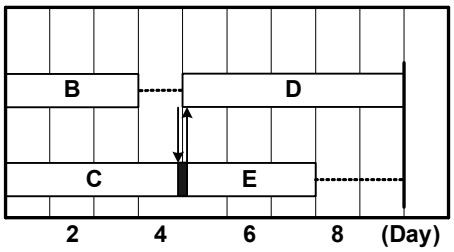
4. COMPARISION WITH FENCED BAR CHART

This chapter verifies the effectiveness of the CBC with an example work schedule comprising 24 activities that is visualized by the three different kinds of organizing methods, the CPM, FBC and CBC.

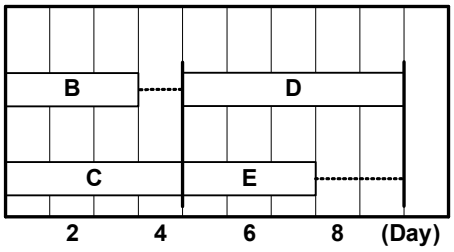
Figure 7 compares the FBC with the CBC. The CPM schedule in Figure 7 (a) exposes the EST, EFT, LST and LFT of each activity, and provides the critical path based on them. Prior to organizing by the FBC, the AOA network logic is used to furnish the information of fence split in Figure 7 (c). The total six logical dummies produce six splits on the fences corresponding activity relations in Figure 7 (c) including six labels of each. For example, activity 14 in Figure 7 (b) has the three precedent activities: the one



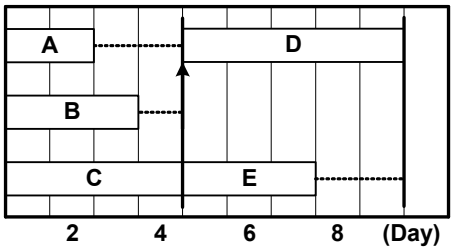
(a) CPM



(b) Dual direction Fence

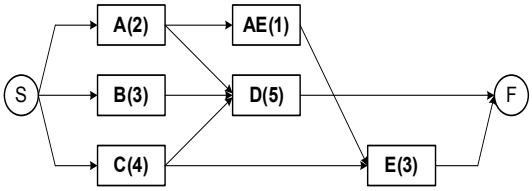


(c) Dual direction fence in CPM bar chart

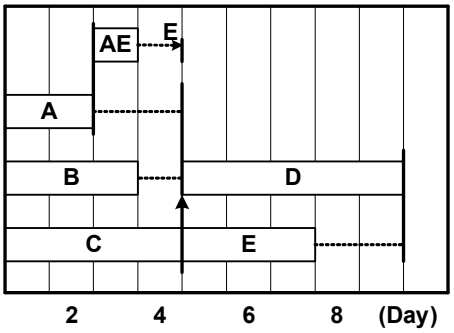


(d) Single and dual direction fence

Figure 5. Dual Direction in Fence



(a) CPM



(b) Fence split between activity AE and E

Figure 6. Fence Split in CPM Bar Chart

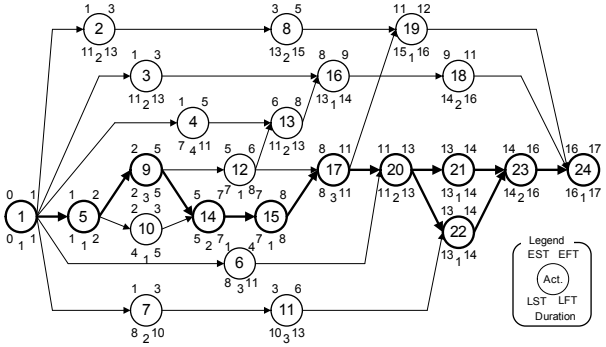
logical dummy d1 and the activities 9 and 10. Figure 7 (c), as a result, separates the fence from activity 10 that retains the free float towards activity 14.

The CBC, on the other hand, uses Figure 7 (a) to obtain the existence of fence split. With regard to the direction of an arrow from the network logic of activities 13, 14, 17, 19, 20 and 22, each of them has more than one precedent activity that is followed by another activity besides it. Activity 14 in Figure 7 (a) relates to activities 9 and 10 as the precedent work and activity 9 engages in activity 12 besides activity 14 as its successor. The direction from the fence split condition is from activity 9 to 14. It consequently needs no label due to the direction, but the continuity of its logical activity flow crossing over the activity relation between activities 8 and 19 generates the labeling work in addition to the fence split. As above examined, the CBC – see Figure 7 (d) - demands no confusion from the AOA network and the direction produced by the fence split condition within it creates no labeling work except specialized cases.

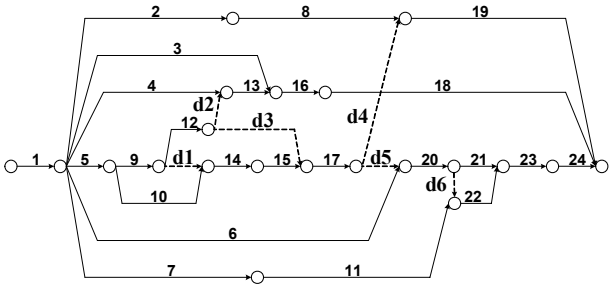
5. CONCLUSION

This paper proposes the CPM bar chart method that extracts and unites the advantages of the bar chart and the CPM network. It, with the benefit from the FBC retained, does not require the process of constructing the logical dummy, but avoids the confusion from the fence split. The fence endowed with the direction instead of the fence split and label from it enables the logic of activities to be sustained. The CBC as exemplified with a virtual project is easy to understand and apply its principle, thus is expected to contribute to the effective communication of projects and the scheduling education program as well.

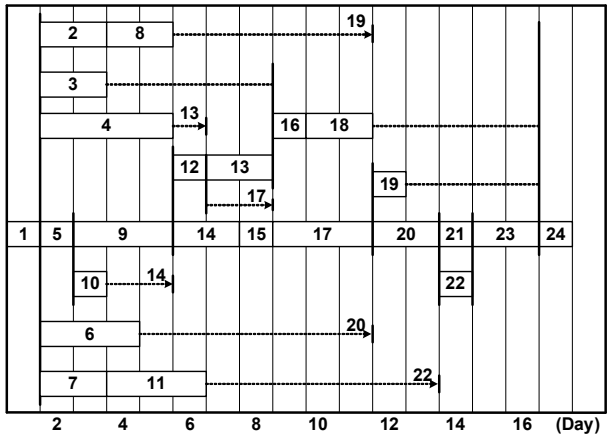
The use of CBC, however, is limited to the finish-to-start



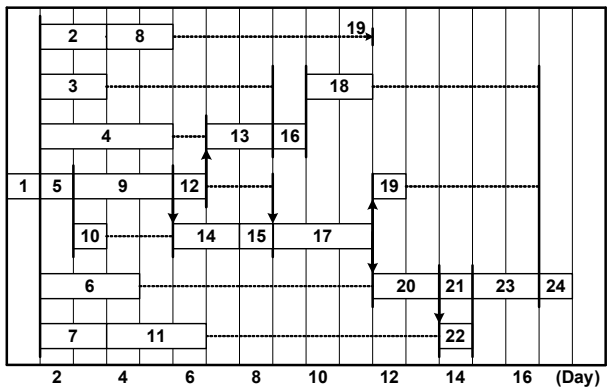
(a) CPM



(b) AOA network



(c) Fenced bar chart



(d) CPM bar chart

Figure 7. Comparison of CPM Bar Chart with Fenced Bar Chart

activity relation with zero lag time between the predecessor and its successor. In future research to organize more various activity relations, it needs to expand its use to precedence diagram method (PDM) that accompanies the diverse non-lag times between activities expressed with such as start-to-start, start-to-finish, finish-to-start and finish-to-finish. These relations are enabled in most commercial scheduling programs in which one activity relates to another appearing as the bar chart. But those programs become complicated to grasp overall activity relations in case that the number of activities increases. This provides the reason that the further research is made of the CBC in conjunction with the PDM.

Besides the improved CBC, computer-based programming application is required to construct the CBC automatically with the activity information to increase the work productivity. This computer program should be integrated into the established scheduling system. It therefore reduces the dual inputs of the same data with additional time wasted and the task to record incorrect information by repetition.

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