Finance-based scheduling using integer programming method for building construction project in Jakarta

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Abstract. Construction project management consists of planning, scheduling, and controlling. Planning is important because it’s set down the target of project to achieve successfulness. Successfulness of a project consists of several aspects, including: cost, quality, time, and HSE (Health, Safety, and Environment). In many cases, scheduling is optimized with minimum costs for achieving a project’s goal. This doesn't necessarily guarantee that contractors can provide the budget according to the scheduling. This paper will focus on optimizing scheduling by considering financial capabilities. The method used to optimize scheduling by considering financial capabilities is called Finance-based Scheduling Method. The stages to do finance-based scheduling method, are: arranging initial scheme, arranging extension scheme, and formulating an integer programming model. This study have purpose to obtain optimal scheduling by considering contractor’s financial capabilities. Analysis of this study uses integer programming to find the most optimal solution. However, integer programming requires different modeling for each case and result from it must be simplifying become a bar chart so it’s make easier to understand.

1. Introduction
Construction project is a series of activities which carried out in achieving certain goal. However, the implementation is limited by time and resources needed. In order to achieve this goal, project planning is one of the important stages. It is important to determine the stage of activities and specified criteria.

Scheduling is one of the implementation of project planning, which is ideally carried out before construction begin. This process is important to do considering, because we need to determine relationship between the activities to achieve project’s goal. The relationship between activities can be described in a network diagram which is can used to calculate duration of delivering project until finish and determine critical path. Determination of critical paths is also important to do because the activities located on this path will receive more attention during construction. If there is activity on critical path that is late for completion, it will affect overall duration and cost of the project. There are several ways to manage project scheduling, including: s-curves, bar charts, linear programming, and integer programming.
After completing scheduling, cash flow analysis can be done to get an estimated cost. Cashflow analysis is important for construction project, because we can calculate the maximum costs needed in each period. Maximum cost need to be adjusted to the budget that company can provide for the project. Furthermore, the budget that company provide called by credit limits. In most cases, scheduling only focus on optimizing duration with minimum costs, without considering credit limits (financial capabilities). In fact, it is important to adjust the maximum cost needed each period with credit limits. This research present a scheduling method that considers financial capabilities, referred as finance-based scheduling method.

2. Literature review

2.1. Project scheduling

Project scheduling can be seen as a science compared with art of planning, it defines as logic, sequence and the calculation of critical path, float, start and finish dates of individual activities, and thus determines the feasibility of delivering the project within desired completion dates and budget [1]. Scheduling on construction projects consists of time, labor, equipment, materials, and finance. Accuracy of scheduling in project implementation greatly influences the avoidance of many losses, such as swelling construction costs, late project submission, and disputes or claims [2].

Some of the most commonly used scheduling methods are as follows: gantt or bar charts, milestone charts, line of balance, networks, program evaluation and review techniques, arrow diagram network, precedence diagram network, graphical evaluation and review technique [3]. PERT was originally developed in 1958 and 1959 to meet the needs of “age of massive engineering” where the techniques of Taylor and Gantt were inapplicable. Around the same time a company introduced a similar method known as the Critical Path Method (CPM) which also spread widely and was mainly concentrated in the construction industry [4]. The critical path is the longest path through the network and determines the duration of the project, as well as the shortest amount of time needed to complete the project.

2.2. Project financial management

Construction finance management is a high risk business with historically low profit margins. Control over costs, cash flow, and adequate project funding is very important for the success of each construction business [5]. An early estimate is also important to the project team because it becomes one of the key project parameters. It helps formulate execution strategies and provides a basis plan engineering and construction. [6]

Contractor's cash inflows and outflows are not always same each period throughout duration of project are generally caused by retention. Retention is a number of payments held by the project owner as a guarantee that the building built by the contractor is performing properly. Therefore, the contractor will experience a deficit and can experience financial problems. Contractors need to use their capital or borrow a certain amount of money to finance the implementation of the project. However, there are additional costs caused by borrowed need to be prepared which must be taken into account in the preparation stage for bidding [7].

Scheduling process is useful for determining the time starting from activities to complete the project in minimum time. For some project schedules, there are cash requirements specified. The schedule must be designed in such a way that the project's cash requirements for each period do not exceed the allocated credit limits. Small credit limits lead to an extension of the duration of the project and result in excess indirect costs [8].

Many of scheduling method focuses on finding the optimum duration with minimum costs, or what is known as a time-cost trade-off. Many research has been done to develop mathematical modeling to solve this time-cost trade-off problem, among others: the use of mixed-integer programming, linear/integer programming hybrid method [9], genetic algorithm [10]. However, scheduling with the time-cost trade-off method does not consider scheduling aspects that have budget constraints (credit limits).
2.3. *Finance-based scheduling Method*

Finance-Based Scheduling is used to carry out projects combines with financing, project duration, and budget (credit) needed [11]. To achieve profitable businesses, contractors must focus on minimizing three things. First, reducing financing definitely increases profits, but requires an increase in budgets that need to be prepared to shorten the duration. Second, minimizing budget to increase likelihood of being approved by a third party (bank) and giving effect being able to negotiate better interest rates. It can also be used to determine time of loan repayment, but it certainly results in an increase in duration and interest of the loan. Third, shortening the duration increases profits by reducing overhead costs and borrowing costs but requires a high amount of budget. Therefore, the cost of loan, duration of project, and the amount of budget needed are a set of contractor problems.

Elazouni and Gab-Allah in their study proposed a method for optimized scheduling with a critical path method that could be financially adequate (credit limits fulfilled). So that the schedule generated by critical path method can be executed financially [12].

3. *Methodology*

In this research, the main problem is to arrange scheduling of multi-storey building project in Jakarta using the finance-based scheduling method. By using this method, it allows scheduling to adjusted the financial capabilities of contractor when delivering a construction project. The stages in this study are summarized in the form of a diagram that can be seen in Figure 1.

![Figure 1. Research flow chart](image-url)
3.1. Determining the network
Initial network that has been arrange using critical path method (CPM) is presented in form of bar chart, this diagram describes time information of each activities during project as in Figure 2. The Critical Path Method is carried out analysis of advanced calculations and countdown calculations, which are useful to find out the total float (TF) and free float (FF) of each activities. Total float represents maximum shift in an activity without affecting duration of the project (T). Critical activity is sign with TF = FF = 0, by using Critical Path Method, it can be seen the fastest duration to complete the project’s activities.

![Figure 2. Initial network bar chart](image)

3.2. Critical Path Method (CPM)
Critical path method is the sequence of activities that determines duration of the project. Critical path method offers countless benefits such as reduce delays, optimize efficiency, float calculation, visualize dependencies, and improve organization.

The purpose of analyzing network is to predict the total duration needed until the construction is completed. This method provides a graphical display of the network (activity on node network) through precedence diagram network. Critical path shows which activities are important to received more attention in maintaining the project completion on time and which activities that can still shift without affecting total duration of project.

3.3. Cash flow analysis
Network diagram that has been created will convert into a bar chart to make it easier for other users to read schedule. Based on bar chart, an analysis of project cash flow is carried out. So, the amount of expenses in each period can be predicted.

3.4. Project duration extension scheme
Basic objective of finance-based scheduling method is to minimize the extension of duration. Network extension such as Figure 3 is a modification of initial network that allows an increase the extension of duration (M). The results is increasing project duration by (T + M), and increasing total float value for each activities by Jk.
Total float that adjusts to duration extension is the time space for an activity can shift without affecting the duration of the project that has been extended. Total float adjustment can be seen in Equation 1.

$$J_k = TF_k + M$$  \hspace{1cm} (1)

Cash flow analysis is carried out from point of view of the construction company, starting at the beginning of project and running over time, modeling cash flow sequentially adds income and expense [5]. The following are the equations used for cash flow analysis in the period can be seen in Equations 2 to 4.

$$Et = \sum_{t=1}^{m} Y_t$$  \hspace{1cm} (2)

$$P_t = KE_t$$  \hspace{1cm} (3)

$$F_t = N_{t-1} + E_t$$  \hspace{1cm} (4)

Information:

- $m$ = extension of duration (in units of time)
- $K$ = multiplier to determine the amount of payment
- $F_t$ = cumulative cash flow at the end of the period $t$
- $P_t$ = value of receipt at the end of period $t$
- $E_t$ = expense in period $t$

**Figure 3.** Network bar chart with extension

3.5. **Integer programming modelling**

In this study, integer programming use to find optimal solution from existing case. By using integer programming, we have to compose a mathematical models according to the case of research objects to be input in linear programming. Of course, the solution will be produced is very dependent on the inputted model.
3.6. **Integer programming analysis**

Integer programming uses mathematical models to describe problems as a constraint. The word programming does not refer to computer programming, but is a basic naming for planning so that this tool can be used in planning to get optimal results. All equations are input as linear mathematical functions, and the variables are given integer commands. Giving this command is used to ensure that the solution provided by integer programming is an integer value. The models that must be fulfilled when using integer programming, among others.

3.6.1. **Objective function.**

As mentioned above, the purpose of this model is to minimize the total extension of schedule through minimizing the shift from the last critical activity \( n \). Thus the objective function can be formulated as can be seen in Equation 5 below.

\[
\text{minimize } z = x_n
\]  

Information:

- \( x \) = shift in an activity
- \( z \) = destination function

3.6.2. **Activity shifting constraints.**

This constraint ensures that shifts in activities \((x_k)\) with \( k = 1, 2, \ldots, n \). \( N \) is the sum of all activities, in the form of integers in each extended total float. Constraint of shifting activities can be represented by Equation 6 and Equation 7 below. Through this equation also ensures that it only produces one value at the same time.

\[
X_k = \sum_{j=1}^{J_k} S_{kj}
\]

\[
\sum_{j=1}^{J_k} S_{kj} \leq 1
\]

Information:

- \( J_k \) = total float adjustment in activities \( k \)
- \( S_{kj} \) = integer variable \( S_{kj} \in \{0,1\} \)
- \( k = 1, 2, \ldots, n \) for all \( q \in Q_k \)

3.6.3. **Activity sequence constraints.**

This shifting constraint between activities are needed because the earliest completion of each activity \( Q \) must be equal to or more than the completion of the earliest activity \( K \) plus duration of the activity \( Q \), which can be represented mathematically like Equation 8 below.

\[
\text{EF}_q \geq (\text{EF}_k + D_q)
\]

Information:

- \( \text{EF}_q \) = the earliest completion time of activity \( Q \)
- \( \text{EF}_k \) = the earliest completion time of activity \( K \)
- \( D_q \) = duration of activity \( Q \)
- \( k = 1, 2, \ldots, n \) for all \( q \in Q_k \)
3.6.4. Specify credit limits constraints.
Negative cash flows for each period (t) including accumulated interest on loans may not exceed the specified credit limits. These constraint can be formulated like Equation 9 below.

\[
F_t \leq W
\]  

(9)

Information:
W = specified credit limits value

The term \(F_t\) can be formulated for each project period in the search for expenses for each activity. Furthermore, integer programming modeling for expense formulations can be seen in Equations 10 through equation 12.

\[
Y_{ki} = (1 - \sum_{j=1}^{Ik} S_{kj}) R_k; \ ES_k \leq i \leq EF_k
\]  

(10)

\[
Y_{ki} = S_{kj} \cdot R_k; \ ES_k + j \leq i \leq EF_k + j; j = 1, 2, ..., J_k
\]  

(11)

\[
Y_{ki} = 0 \text{ otherwise}
\]  

(12)

Expenses for K activities (\(R_k\)) will be considered from the start time until the completion of activity K. Based on integer programming modeling, the result will be an integer variable that shows a shift, for example: \(S_{k3} = 1\) shows a shift of K activities for 3 days.

4. Analysis and Result
In determining the duration of each job, it takes different productivity of workers and tools for each company. Table 1 shows the activity’s code, activity name, duration and cost for each activity and relationship for each activity.

| Code | Scope of work                  | Duration | Predecessors | Cost      |
|------|--------------------------------|----------|--------------|-----------|
| A    | Scattered                      | 21 d     |              | -Rp143,362,832 |
| C    | Foundation                     | 58 d     | Afs+2 d      | Rp891,623,788    |
| D    | Dewatering                     | 185 d    | aSS+15 d, jFF| Rp225,710,442    |
| E    | Basement (Digging)             | 45 d     | cSS+27 d     | Rp990,200,696    |
| F    | Cutting pile                   | 45 d     | eFF+19 d     | Rp64,222,088     |
| G    | Structure (Basement)           | 65 d     | fSS+14 d     | Rp4,769,600,943  |
| H    | Structure (GF)                 | 52 d     | gFF+26 d     | Rp691,836,066    |
| I    | Structure (1st floor)          | 30 d     | hFF+14 d     | Rp3,435,104,148  |
| J    | Structure (2nd floor)          | 30 d     | iFF+14 d     | Rp3,703,451,280  |
| K    | Structure (3rd floor)          | 30 d     | jFF+14 d     | Rp3,018,319,139  |
| L    | Structure (4th floor)          | 30 d     | kFF+14 d     | Rp2,801,573,585  |
| M    | Structure (Roof)               | 30 d     | lFF+14 d; pSS-12d | Rp2,457,464,922 |
| N    | Structure (LMR)                | 25 d     | mSS+15 d     | Rp23,003,994     |
| O    | Structure (Steel roof)         | 20 d     | m; Nff+10 d  | Rp152,178,576    |
| P    | Architecture (Basement)        | 35 d     | jSS+54 d     | Rp2,314,297,885  |
| Q    | Architecture (GF)              | 35 d     | kSS+54 d     | Rp5,069,234,120  |
| R    | Architecture (1st floor)       | 35 d     | lSS+130 d    | Rp5,069,234,120  |
| S    | Architecture (2nd floor)       | 34 d     | rSS+14 d     | Rp5,069,234,120  |
| T    | Architecture (3rd floor)       | 34 d     | sSS+14 d     | Rp5,069,234,120  |
| U    | Architecture (4th floor)       | 36 d     | tSS+14 d; nSS+149d | Rp5,069,234,120 |
| V    | Exterior façade & canopy       | 37 d     | sSS+22 d; tFF+6 d | Rp232,390,610 |
| B    | Scattered (Ex – Building)      | 15 d     | pSS+24 d     | -Rp143,362,832   |
| W    | External works                 | 120 d    | vFF+14 d; l; bFS-1d | Rp3,787,025,815  |
Based on the results of the analysis on some values of credit limits, there is a relationship curve between the extension duration of project and credit limits, as can be seen in Figure 4. On the curve it can be seen that graph tends to descending to right. This indicates that smaller credit limits value, cause longer the overall duration of project. However, the smaller credit value does not always cause the overall duration of the project extended, because each credit limits has its own extension duration range.

Maximum credit value is Rp. 10,653.98 (in millions), but based on Figure 4, up to a credit limits of Rp. 10,000.00 (in millions) has not caused an increase in overall project duration. This is because integer programming only shifts the start time of activities that are not included in the critical path, so it does not cause an extension in overall project duration.

Maximum value of duration extension which input on integer programming modelling is quite important. Therefore, this is related to limitations value of credit limits that can be analyzed. In this study, the maximum extension of the duration project used in this research is 5 weeks, thus causing the credit limits that could be analyzed only up to Rp. 3,800 (in millions). Based on the results of the analysis, minimum value of funds needed for each extension of duration range is obtained. This can help contractor to provide sufficient funds for execute project.

Figure 4. The relationship curve between extension of duration and credit limits

Finance-based scheduling method is not user-friendly because it needs to make a model that is suitable for each problem. If the limit is changed, a new model must be made before input to program. The results of integer programming analysis also need to convert into bar chart to make it easier for other users to read the results of scheduling using the finance-based scheduling method, as can be seen in Figure 5.
5. Conclusion
The result of the study shows that the lower credit limits, overall project duration will become longer. However, lowering credit limits does not always lead to an extend the duration of the project, because for each value of duration has credit limits range. Optimizing the scheduling of construction projects with finance-based scheduling method using integer programming is also useful in tender process and during construction, because it produces a duration for project that fulfilled the financial capabilities of the contractor. However, it is necessary to make a mathematical model that fits each problem to find the optimum solution using a linear programming software which are available in the market. The generated optimum scheduling as the solution needs to be convert into a bar chart for make it easy to understand.

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