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Should Time be the Only Scale Required for Relationship and Margin Calculations?

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Abstract

Precedence logic's four types of relationships, four types of margins and by simulating the work production through lags present several shortcomings that affect the accuracy of the schedule and margin calculations, as is well documented in the literature. To overcome these gaps, the Chronographic Method has proposed many developments over several years, including allowing for split activities with internal divisions according to quantities. Internal divisions extend the relationships between activities to deterministic and probabilistic point-to-point, by-section or continuous relations, generating realistic dependencies and new types of floats (Complete, Start, Finish and Partial floats). Activities and divisions may also have external and internal scales. External horizontal scales may designate the measuring unit of the x-axis for an orthogonal system and should be unique for the entire project (e.g. time that defines the external horizontal scale unit of the bar chart diagram). Internal horizontal scales can be distinct for each activity or section. External and internal scales may be based on time, cost, work progress, quantity, risk or performance. For the purposes of calculation, this paper uses time as the external scale and the amount of work as the internal scale. Relations and margins can then be calculated according to the external scale (time) or the internal scale (quantity). The calculation constraints and project tracking can then be based on either time or quantity. This paper explains this concept and the calculation equations for these new types of margins; discusses the limitations of the traditional margins and the use of time as the only scale required for relationship and margin calculations; and demonstrates the relevance of using other measures, including the amount of work, Site occupations for scheduling calculations. The proposed chronographic logic and margin calculations can then be used to simulate the project's real conditions.

Chronographic method, construction, margin, Precedence diagram, project by [1]

1. Scheduling Logic

The Precedence Diagram Method (PDM) is currently the most widely used scheduling method for construction projects. PDM was originally published by [1] as the Potential Tasks Method and disclosed by [2] under the acronym "PDM". Common scheduling software plans projects using a method that combines the bar chart diagram and precedence logic. The Precedence Method proposes four types of relationships (Finish-to-Start, Start-to-Start, Finish-to-Finish, and Start-to-Finish). However, by using external constraints and lags to simulate production, precedence logic lacks precision: i) via the reverse critical path [3]; ii) when using certain types of relations and delays with multiple calendars [4]; iii) when using lags with Start-to-Start or Finish-to-Finish relations [5]; and iv) when two or more activities depend on each other during the execution process [6].

The shortcomings of using these external precedence relationships to represent interdependencies and overlaps have, in the past, generated studies on the impact of upstream activities on downstream activities. Allen [7] describes the logic based on temporal intervals rather than time points and defines thirteen possible temporal relationships that describe situations from either a static or dynamic perspective. The concept of concurrent engineering has been used to address this problem [8, 9] by proposing an overlapping framework based on activity progress rates, upstream task reliability, downstream task sensitivity and task divisibility. Francis and Miresco [5, 10] have proposed chronographic logic, providing for internal divisions of activities according to quantities while extending the relationships between activities to point-to-point relations and generating realistic dependencies and new types of floats. The Chronographic Model also makes a distinction between two types of lags, that is, the technical lag, such as concrete curing, and the production lag, which imposes partial dependencies in order to simulate production. Song and Chua [11] have presented a temporal logic intermediate function relationship based on an interval-to-interval format. The temporal logic resides within intermediate functions from three perspectives: the construction life cycle of a single product component, the functional interdependencies between two in-progress components, and the availability conditions of an intermediate functionality provided by a group of product components. Lu and Lam [12] have proposed a method that automatically transforms schemes in a PDM network, such as Non-Finish-to-Start (FS) relationships, into their equivalent. A graphical representation bee-line diagram (BDM) using a bee-line relation, has been developed by [13]. The chronographic production-based relation allows probabilistic dependencies between activities, while the production-based dynamic function allows one to follow the interdependencies between the two in-progress activities using sectional mathematical functions [6]. Hajdu [14] has proposed a mathematical model of PDM with point-to-point relations, along with continuous precedence relations for Better Modelling Overlapping Activities [15].

2. Constraints and Internal Float Concept

The Precedence Method proposes four types of relationships (Finish-to-Start, Start-to-Start, Finish-to-Finish, and Start-to-Finish) and defines four types of floats (Total Floats, Free Floats, Interfering Floats and Independent Floats), two of which, the Total and Free Floats, are frequently used. These floats are based on the premise that every activity is a single integral entity. However, each activity also represents an execution process in which different sections are affected differently. To overcome these gaps, the Chronographic Method has led to many developments over the years, including split activities with internal divisions according to quantities. Internal divisions extend the relationship between activities to include deterministic and probabilistic point-to-point relations, along with by-section and continuous relations, while generating realistic dependencies and new types of floats [10]. This new calculation logic, combined with the existing floats, has resulted in the creation of a new margin calculation logic that can simulate actual project conditions.

Figure 1 illustrates the constraints between activities using four examples. Figures 1.a and 1.b have a Start-to-Start link with a lag of 5 days. Figure 1.b shows the internal production rates of these two activities and demonstrates how Sections A1 and A2 are predecessors of Sections B1 and B2, respectively. This type of link presents certain flaws:

- It simulates the work production through lags. The lag stimulates the production under Section A1. Thus, Section B1 is presumed to start after the completion of Section A1. If the production rate of this predecessor section changes (by increasing or decreasing), the duration of the lag will remain unchanged, forcing planners to adjust the duration manually. This is difficult to perceive for larger projects.
- It fails to follow the progress between two activities with an inter-connected execution. In real-life situations, many activities depend on each other during their execution. A relationship that limits only the start or finish of the successor activity is considered insufficient when properly assessing progress. If some changes take place after the relationship's effect, the successor activity will not be affected and the planner will be forced to make modifications manually.

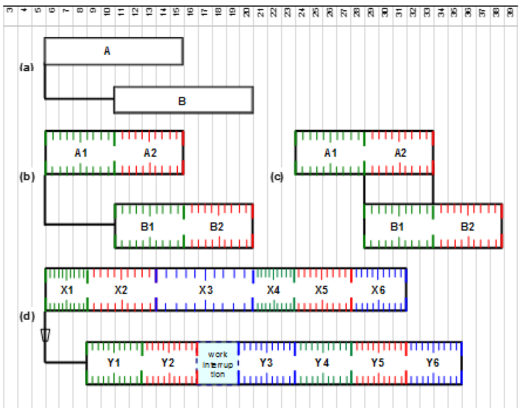

Figure 1: Constraints between Activities

- Margin calculations: Floats will be calculated on the basis of this unique link between Start-to-Start and lag, and may accidentally limit the extension of the predecessor duration. This is clearly explained under Figure 3.a.

The limitations are usually caused by a failure to add resource links and the existence of phantom floats. This is due to the difficulty of retracing these links and their instabilities. Any change in the availability of resources, or even in the production rates, can affect these links. Limitations can also arise through the strict use of external constraints and by neglecting every internal execution process. Finally, by using time as the only scale required for relationships and networks, along with critical paths and margin calculations, the schedule fails to consider other measurements, including workloads and site occupation when scheduling calculations. The proposed chronographic logic and their margin calculations can then be used to simulate the project's actual conditions.

Figure 1.c shows the same example using the chronographic point-to-point logic that permits multiple internal interdependencies between activities. In this figure, the ends of Sections A1 and A2 as predecessors are linked with the start of Sections B1 and B2, respectively. The production-based dynamic function concept [6] suggests replacing the multiple internal interdependencies between activities with a mathematical function associated with a single temporal function, Figure 1.d. This function contains the rules that manage the interdependencies between

the two in-progress activities by tracking the internal variation during production. The internal production of each activity can vary from one period to another, affecting the relative period of the dependent activity, which may be interrupted.

We must differentiate between work interruptions and internal floats. Floats are expected from the planning phase and during scheduling updates. As mentioned above, floats are used to level the resources and optimize the project. Work interruptions are considered as execution constraints. In Figure 1.d, the work is interrupted between Sections Y2 and Y3 in order to comply with the technical constraints caused by slower-than-expected progress in the predecessor Sections X2 and X3. This interruption will not prevent Team Y from performing other work, if possible.

2.1. *Internal Floats*

The Chronographic Method identifies three (3) new external float types: the Complete Float, the Start Float and the Finish Float. These three floats could be partial if applied to a particular activity section. Table 1 illustrates the combination of Chronographic Floats with the two most popular and traditional floats, the Total Float and the Free Float. Note that the Chronographic Floats could also be combined with the Independent and Interference Floats.

Table 1: Combination of Existing and New Floats

	Total Float	**Free Float**
Complete	Complete Total Float	Complete Free Float
Start	Start Total Float	Start Free Float
Finish	Finish Total Float	Finish Free Float
Partial Complete	Complete Total Float	Complete Free Float
Partial Start	Start Total Float	Start Free Float
Partial Finish	Finish Total Float	Finish Free Float

The Complete Float considers the entire activity as a single integral entity. No constraints affect its beginning, end or internal sections differently. The Start Float and the Finish Float are created when the beginning and end of the activity are affected differently. Partial Floats concern every section of the activity and could be Partial Complete Floats, Partial Start Floats or Partial Finish Floats. The comprehensive results of this study can be found in [16]. The Start and Finish Floats are created when one of the two extremities of an activity (or a section) is fixed (or semi-fixed). This means that the end has at least one predecessor and one successor constraint. These relational constraints limit the earliest and latest dates of this extremity, which could be more restricted than the other extremity.

Figure 2 shows examples involving the Start and Finish Free Floats. In Figure 2.a, Activity X has two relationships with its end. The first is a predecessor relationship with Activity B and the second is a successor related to Activity C. These two relationships limit the movement of this end. Thus, the early finish becomes equal to the late finish date of this activity. The start of Activity X possesses different constraints, which leaves greater float at its start. If the duration of Activity X is flexible, it can benefit from this Start Float by starting earlier and decreasing productivity, if necessary.

Figure 2.b shows an example in which Activity Y has a Free Finish Float of 4 days and a Free Start Float of zero days. This activity has two relationships that constrain its start. The first is a predecessor relationship with Activity E and the second is a successor relationship with Activity F. Thus, the early start date becomes equal to the latest start date. The end of Activity Y possesses different constraints, which leaves more floats. If the duration of Activity Y is flexible, it can benefit from this Finish Float by decreasing productivity, if necessary.

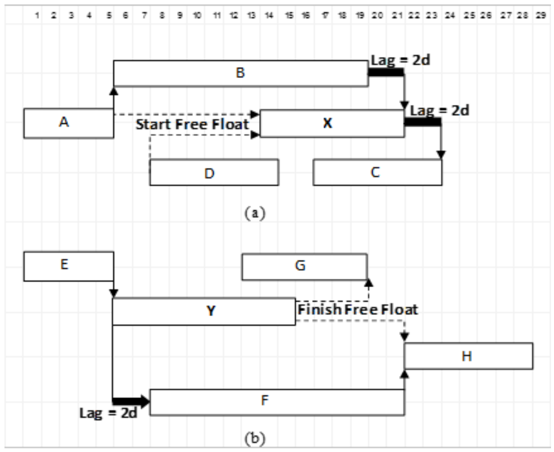

Figure 2: Start and Finish Free Floats

The Start Free Float (SFF) for Activity X is calculated as follows:

$$\text{SFF} = \min\begin{cases} \text{FS} \rightarrow ES_{Activity} - \left(EF_{predecessor} + Lag - 1\right) \\ \text{SS} \rightarrow ES_{Activity} - \left(ES_{predccessr} + Lag\right) \end{cases} = \min\begin{cases} 14 - (5+0-1) = 8 \\ 14 - (8+0) = 6 \end{cases} = 6\text{d} \qquad (1)$$

The Finish Free Float (FFF) of Activity Y is calculated as follows:

$$\text{FFF} = \min\begin{cases} \text{FS} \rightarrow ES_{successor} - \left(EF_{Activity} + Lag - 1\right) \\ \text{FF} \rightarrow EF_{successor} - \left(EF_{Activity} + Lag\right) \end{cases} = \min\begin{cases} 22 - (15+0-1) = 6 \\ 19 - (15+0) = 4 \end{cases} = 4\text{d} \qquad (2)$$

3. External and Internal Scales

With the Chronographic Method, activities may have external and internal scales. In this paper, external horizontal scales designate time and internal horizontal scales designate quantities.

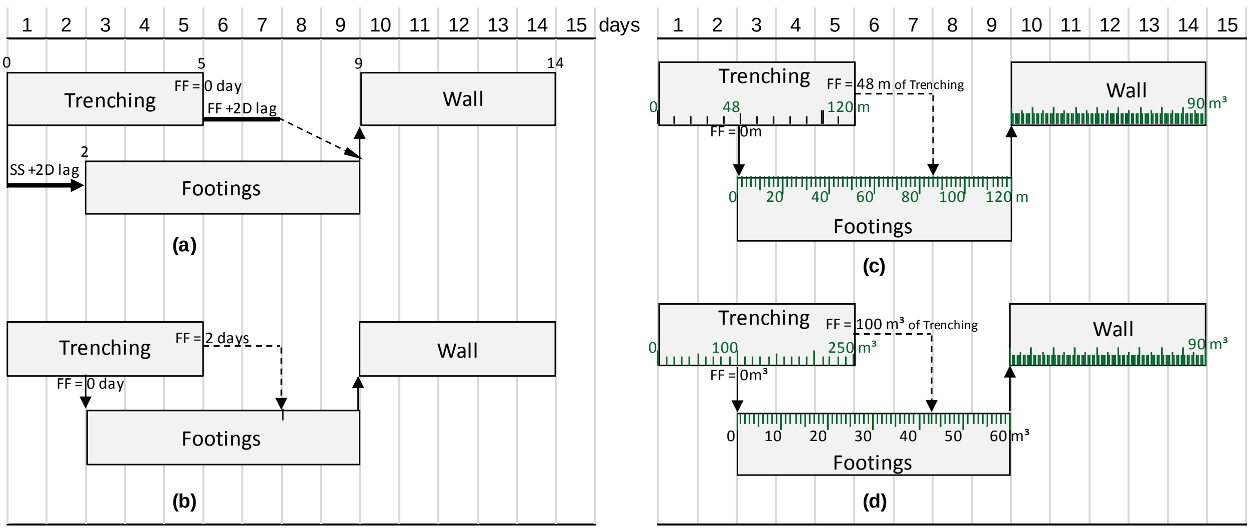

Figure 3: Calculating the Free Float Using the External and the Internal Scales

Activities may also have one or more internal divisions. These divisions could be related to the external scale (time), or the internal scale. They may also be related to the targeted workload and adjusted automatically as a function of production variation rates. Calculation constraints and project tracking can then be based on either time or quantity.

The example presented in Figure 3 schedules the construction of a wall that consists of three activities: Trenching, Footing and Wall. This example illustrates the graphical modeling and calculation of the Free Complete and Partial Floats for the Trenching activity. Figure 3.a illustrates the calculation of the Free Float (FF) with the Precedence Method. In this example, both the Trenching and Footing activities have two links: Start-to-Start with a lag of two days, and Finish-to-Finish with lag of two days. The FF is the smallest float calculated with all links between activities. Thus, the FF of the Trenching activity is equal to zero.

$$FF_{\text{Trenching}} = \min \left\{ \begin{array}{l} \text{1 – Start-to-Start with a lag of two days:} \\ ES_{\text{Footing}}\text{ (Day 2)} - Lag_{SS}\text{ (2 days)} - ES_{\text{Trenching}}\text{ (Day 0)} = 0 \text{ day} \\ \text{2 – Finish-to-Finish with a lag of two days:} \\ EF_{\text{Footing}}\text{ (Day 9)} - Lag_{FF}\text{ (2 days)} - EF_{\text{Trenching}}\text{ (Day 5)} = 2 \text{ days} \end{array} \right\} = 0 \text{ day} \quad (3)$$

However, if the method accepts flexible durations for the activities, a Free Finish Float could be created for the Trenching activity. If the activity duration became flexible, the manager could use the available float of each section in order to optimize the project [10]. In this case, the activity possesses three Free Margins: A Start Free Float (of 0 Day), a Finish Free Float (of 2 days), and a Complete Free Float for the whole activity that is equal to the smallest Free Float, or zero day.

The other three Figures (3.b, 3.c and 3.d) illustrate the links between activities and the float calculations using Chronographic logic with internal divisions and internal and external scales.

When using external scale (Figure 3.b), both the Footing and Trenching activities are linked with to links (Internal-to-Start and Finish-to-Internal). A minimum lead of two days between both activities is required at all times. This means that the Footing activity can only start if a minimum of two days has elapsed from the Trenching activity and must remain at least two days to finalize the Footing activity after the end of the Trenching activity. In addition, there must be a maximum duration of four days between the executions of both activities at all times. This means that the Trenching activity must stop if this duration is exceeded. Thus, floats may differ from one section to another or on every day for a continuous link. For example, the Free Float for the Trenching activity is zero days at the end of the first relationship (Internal-to-Start). Any implementation delay during these initial two days will delay the start of the Footing activity.

$$FF_{\text{1st sec Trench}} = \min \left\{ ES_{\text{Footing}}\text{(Day 2)} - ES_{\text{Trenching}}\text{(2 days)} \right\} = 0 \text{ days} \quad (4)$$

There is a two-day Free Float at the end of the Trenching activity.

$$FF_{\text{end Trench}} = \min \left\{ EF_{\text{1st sec Footing}}\text{(Day 7)} - EF_{\text{Trenching}}\text{(Day 5)} \right\} = 2 \text{ days} \quad (5)$$

or

$$FF_{\text{end Trench}} = \min \left\{ EF_{\text{Footing}}\text{ (Day 9)} - Lead_{\text{Min remain dur. finalize Foot.}}\text{ (2 days)} - EF_{\text{Trenching}}\text{ (Day 5)} \right\} = 2 \text{ days} \quad (6)$$

With the internal scale (Figures 3.c and 3.d), both Footing and Trenching activities are linked in two ways (Internal-to-Start and Finish-to-Internal). There must be a minimum lead of 48 linear meters, or 100 m³ according to the scale, between both activities at all times. This means that the Footing activity can only start if at least 48 linear meters (or 100 m³) have elapsed from the Trenching activity and must remain at least 48 linear meters (or 100 m³) to finalize the Footing activity after the end of the Trenching activity. In addition, there must be a maximum of 96 linear meters (or 200 m³) between the executions of both activities at all times. This means that the Trenching activity must stop if this quantity is exceeded. The Free Float at the end of the first section of the Trenching activity (Start-to-Start relation with a lag of 48 linear meters or 100 m³) is as follows:

$$FF_{\text{1st sec Trench}} = \min \left\{ ES_{\text{Footing}}\text{(48 ml of Trenching)} - ES_{\text{Trenching}}\text{(48 ml of Trenching)} \right\} = 0 \text{ ml}_{\text{ of Trenching}} \quad (7)$$

or

$$FF_{\text{1st sec Trench}} = \min\left\{ ES_{\text{Footing}}(100\text{m}^3 \text{ of Trenching}) - ES_{\text{Trenching}}(100\text{m}^3 \text{ of Trenching}) \right\} = 0\ \text{m}^3{}_{\text{of Trenching}} \quad (8)$$

The Free Float at the end of the first section of the Trenching activity is as follows:

$$FF_{\text{end Trench}} = \min\left\{ EF_{\text{Footing}}(216 \text{ ml of Trenching}) - Lead_{\text{Min remain finalize Foot.}}(48\text{ml of Trenching}) - EF_{\text{Trenching}}(120\text{ml of Trenching}) \right\} = 48\ \text{ml}_{\text{of Trenching}} \quad (9)$$

or

$$FF_{\text{end Trench}} = \min\left\{ EF_{\text{Footing}}(450\text{m}^3 - Lead_{\text{Min remain finalize Foot.}}(100\text{m}^3 - EF_{\text{Trenching}}(250\text{m}^3 \right\} = 100\ \text{m}^3{}_{\text{of Trenching}} \quad 10)$$

4. Conclusion

The calculation of margins using the external and internal scales may better simulate the project's actual conditions. External and internal scales may be based on time, cost, work progress, quantity, risk or performance. For calculation purposes, this paper uses time as the external scale and workload as the internal scale. This illustrates the calculation of internal and external margins and tracks the interdependencies between the two in-progress activities. This paper presents the impact of the application of chronographic logic and internal and external scales on the critical path and margin calculations. Thus, this paper does not propose a methodology that would optimize the logic, but rather one that would simulate actual on-site conditions as closely as possible in order to yield a more realistic result. In conclusion, the application of the proposed logic permits the tracking of interdependencies between two in-progress activities and yields more realistic results when tracking internal dependencies and margins. These advantages allow the planner to present a more realistic and detailed schedule and to make adjustments when monitoring the project.

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