Dynamic production-based relationships between activities for construction project planning

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Abstract

The schedule logic for construction projects is usually represented by a bar chart diagram that shows precedence dependencies between activities. However, in the construction project, many activities depend on each other during their execution. To simulate these execution dependencies, these classical precedence relationships permit the overlapping of activities by using lags with a fixed duration or with a percentage of completion. For these precedence point-to-point external relationships, the difficulty of representing interdependencies and overlapping has imposed, in the past, the study of the impact of the upstream activities over the downstream activities, the proposition of the temporal Interval-to-Interval format and the introduction of the Internal Division concept and its internal measurement as a function of production: we refer to this as the Temporal Function.

This paper reviews and analyses the roles, advantages and disadvantages of the Temporal Function as proposed by Chronographic Scheduling, and introduces production-based dynamic relations. The proposed production-based relations extend the Temporal Function role to a dynamic relationship between the interlinked activities. The internal dependencies between any two activities can be represented by a mathematical function. These temporal functions could also be probabilistic, which means that they permit a certain gap in the interdependence of activities. These proposed production-based dynamic functions contain the rules that manage these interdependencies.

The principal strength of this model is its relative ability to perform simulation studies based on the probabilistic aspect of the dynamic relationships, the streamlining of interactions between activities, the varying rates of production and the change of the internal margins of activities. These simulations include construction operations and overall schedule optimization, resource levelling simulations, cost minimization, compression of the project duration and the probability of the project's completion within the scheduled time frame.

Keywords: scheduling, simulation, chronographic, temporal logic, precedence

1 Introduction

The schedule logic for construction processes is usually modelled through precedence relationships and constraints between the project activities. Planners have diverging preferences for using the Arrow Diagram Method (ADM) or the Precedence Diagram Method (PDM). Some prefer PDM because it utilises four types of relationships: PDM allows overlapping by using lags that simulate partial start or finish dependencies, without the obligation of splitting activities. Moreover, the most commonly used scheduling software usually features a bar charts diagram that shows precedence
dependencies between activities. Others, however, prefer ADM, where the first activity is split into two independent activities and the successor activity cannot start until a sufficient quantity of work is completed within the predecessor activity. They also assert that the precedence relation types and lags are insufficient to ensure an accurate computation of the schedule. One example of this is the reverse critical path (Wiest, 1981; Badiru and Pulat, 1995), in which the project duration increases when one diminishes the duration of a critical activity. Another example is the production of incorrect erroneous results produced with some types of relations and delays when using multiple calendars (Kim and Garza, 2005).

However, the utilisation of ADM as a solution is limited by two major shortcomings. Firstly, this method is not modelled within common scheduling software, and secondly, by agreeing to split the project activities, managers consent to increasing their total number, making the schedule more complex to model. In addition, Francis and Miresco (2002; 2006a) show that the incorrect use of lags employed with precedence relationships is the basis of these anomalies. These lags should be replaced by realistic relationships between activities. We should also note that activities depend on each other during their execution. A relationship that limits only the start or the finish of the successor activity is considered insufficient for making an appropriate assessment of project progress. If some changes take place after the relationship’s effect, the successor activity will not be affected. The planner will be forced to make modifications manually.

The shortcomings of these precedence point-to-point external relationships for representing interdependencies and overlapping have, in the past, imposed the study of the impact of upstream activities upon downstream activities. Eppinger (1997) and Peña-Mora and Li (2001), have used the concepts of concurrent engineering to address this problem. They have proposed an overlapping framework based on the activity progress rate, upstream task reliability, downstream task sensitivity and task divisibility. Allen (1984) describes the logic based on temporal intervals rather than time points, defines thirteen possible temporal relationships and describes situations from either a static or dynamic perspective. Song and Chua (2007) present a temporal logic intermediate function relationship based on an interval-to-interval format. The temporal logics residing in intermediate functions from three perspectives: the construction life cycle of a single product component, functional interdependencies between two in-progress components, and availability conditions of an intermediate functionality provided by a group of product components. Many studies (Hendrickson, Martinelli and Rehak, 1987; Pultar, 1990; Chehayeb and AbouRisk, 1998)) have discussed the utilization of time as the only constraint required for the relationship between activities, and have used simulation models to provide production-based linking structures.

To address a practical solution, the Chronographic Model (Francis and Miresco, 2006b) introduces the internal division concept and internal measurement as a function of production: we refer to this as the Temporal Function. This paper reviews and analyses the roles, advantages and disadvantages of Temporal Functions and introduces production-based dynamic relations.

2 The Chronographic Method

The Chronographic Model defines the role of the production entities, the temporal function and their relationship as a function of quantities.

2.1 The production entities

The production entities are presented as a time-scaled quantifiable activity. These types of activities use time, such as time in a bar chart, as an external measurement, and the executed quantities as an internal progress measurement. Activities can have one or more internal divisions. These divisions are related to the quantity of work to be accomplished and can be adjusted automatically as a function of the production rate variation.
2.2 Temporal functions and relations as a function of quantities

The temporal functions specify the decisional and relational constraints between activities. Temporal functions are represented graphically through directional connections that connect activities on one or more points, called connection points. Each connection point can be at one of the two extremities of the activity or on one of its internal divisions.

Figures 1.a and 1.b represent the relation between two activities \( X_i \) (02.012 – Excavation) and \( X_j \) (03.008 – Foundation). The excavation activity is codified as follows:

\[
X_n(I, S_i, D_i, Q_i) \quad \text{or, more specifically} \quad X_i(02.01-Exc, 1, 15, 1600 \text{ m}^3)
\]

Where:
- \( X_n \) represents the activity number and has the value of 1,
- \( I \) represents the activity code and has the value of 02.01-Exc,
- \( S_i \) represents the activity start date and has the value of 1,
- \( D_i \) represents the activity duration and has the value of 15,
- \( Q_i \) represents the activity’s estimated quantity of work and has the value of 1600 m\(^3\).

These two activities are related through a temporal function that connects the first internal division \( Q_{iy} \) of the activity \( X_i \), which represents 400 m\(^3\) of excavation, to the start \( Q_{jy} \) of the activity \( X_j \). This temporal function is codified as follows:

\[
U_m(k; X_i; Q_{iy}; X_j; Q_{jy}) \quad \text{or, more specifically} \quad U_i(1; 02.012.\text{Exc}; 400; 03.008.\text{Foun}; 0)
\]

Where:
- \( k \) represents the branch number and has the value of 1,
- \( X_i \) represents the predecessor activity code and has the value of 02.01-Exc,
- \( Q_{iy} \) represents the quantity of work related to the first internal division \( Q_{iy} \) of the predecessor activity \( X_i \) and has the value of 400 m\(^3\).
- \( X_j \) represents the successor activity code and has the value of 03.008.\text{Foun},
- \( Q_{jy} \) represents the work related to the start \( Q_{jy} \) of the successor activity \( X_j \) and has the value of 0 m\(^3\).

2.3 Modelling interdependencies among activities

The use of multiple Temporal functions permits the tracking of interdependencies between two in-progress activities. Each section in the successor activity is related, through a predetermined Connection Point, to its correspondent predecessor section. Thus, any changes in predecessor productivity could affect the corresponding successor section. Figure 2 shows the internal production...
rate and the internal relations between two activities. In this figure we can observe that each section in
the successor activity depends on the advancement of the relative section in the predecessor activity.

Figure 2. The internal relations between two activities

3 Production-based dynamic relations

The proposed production-based relations extend the Temporal Functions role to a dynamic
relationship between the interlinked activities. The internal dependencies between any two activities
could be probabilistic, which means that they permit a certain gap in the interdependence of activities.
The amount of flexibility of these internal dependencies is reliant on the predefined activity category.
For example, the relation between electrical wiring, as a successor activity, allows certain flexibility
in the work to be accomplished for the erection of the framing division, as a predecessor activity. In
figure 3.a, the advancement of activity $X_j$ depends on its predecessor $X_i$. This temporal function
is codified as: $U_m(k; X_i; Q_{0i} - \Delta Q_{0i} ; X_j ; Q_{iy})$. The probabilistic gap $\Delta Q_{0i}$ is related to the first
internal division $Q_{iy}$ of the predecessor activity $X_i$ and it has only a negative value. This means that
the connection point $Q_{iy}$ on the successor activity can support a delay in the predecessor activity less
than or equal to this gap: $T(Q_{iy} - \Delta Q_{iy}) \leq T(Q_{iy})$. Otherwise, the successor activity should be
delayed or may be interrupted if it was already started.

Figure 3. Probabilistic dependencies between two activities

In figure 3.b these two activities $X_i$ and $X_j$ depend on each other throughout their execution. The
difference, with figure 3, is that any delay in the successor activity will also affect the predecessor
activity. The codification is as follows:

$U_m(k; X_i; Q_{iy} \pm \Delta Q_{iy} ; X_j ; Q_{jy} \pm \Delta Q_{jy})$

Knowing that:

$T(Q_{iy} - \Delta Q_{iy}) \leq T(Q_{jy} - \Delta Q_{jy})$
\[
T(Q_i y + \Delta Q_i y) \leq T(Q_j y + \Delta Q_j y) \\
T(Q_i y + DQ_i y) \geq T(Q_j y - \Delta Q_j y)
\]

In figure 4.a, the internal advancement of the activity \textit{Foundation} depends on its predecessor \textit{Excavation}. The \textit{Excavation} Activity is an independent activity while activity \textit{Foundation} is a dependent one. In figure 4.b the two activities \textit{Excavation} and \textit{Foundation} depend on each other throughout their execution. In these circumstances, these two activities are dependent activities. Any adjustment in the productivity of one affects the other.

![Figure 4. Probabilistic interdependencies between two in-progress activities](image)

The challenge with this approach is that it requires detailed preparation work, which is suitable for major activities such as building superstructure work. However, this method is less appropriate when several activities are interlinked together throughout their execution. Significant preparation work then imposes and compromises the visual aspects of the schedule by multiplying internal dependencies. One solution is the use of multiple layers, as CAD does. Data and constraints can be arranged on different layers in order to help the manager to improve the graphical visualizations of the schedule (Francis and Miresco, 2006c).
In order to address a practical solution, the internal interdependencies between any two activities can be represented by a mathematical function, associated with the first Temporal Function. This relation contains the rules that manage the interdependencies between the two in progress activities. The mathematical details for this solution will be presented in a future article.

4 Conclusion

The proposed production-based dynamic relations extend the Temporal functions role to a functional relationship between the interlinked activities. Relationships could also be probabilistic which means that they permit a certain gap in the inter-dependencies between activities. The internal relations between activities can also be replaced by a mathematically functional relationship, associated with the first Temporal Function.

The principal strength of this model is its relative ability to perform simulation studies based on the probabilistic aspect of dynamic relationships, variation in production rates, changes in internal margins, and the streamlining of interactions between activities. These simulations will permit performing several analyses, including the optimization of construction operations and the overall schedule, resource levelling, cost minimization, compression of the project duration and the probability of the project's completion within the schedule. The application of these proposed production-based dynamic relations and their simulations present many advantages: they facilitate the role of the planner to present a more realistically detailed schedule, they assist the manager in making adjustments during project monitoring, and finally, they enhance the visual aspects when several activities are interlinked together throughout their execution.

References