Advanced Line of Balance Method (ALoB) in Partly-Repetitive Model-Based Scheduling

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Abstract

Model-based scheduling is defined as the semi-automated or iterative processing of project information that is retrieved from building information models, i.e., product models and resource and cost models. Model-based scheduling is becoming the new generation of scheduling. As a transition into the new mindset, it would be appropriate for model-based scheduling to evolve from basic scheduling methods such as activity-based (CPM – Critical Path Method) and location-based (LoB – Line of Balance Method) scheduling methods. The advantages of location-based scheduling methods over activity-based scheduling methods in repetitive construction projects have been thoroughly confirmed in the past by many researchers. Location-based scheduling methods such as Line of Balance (LoB) are particularly suited for use in building projects because of the repetitive nature of building construction**.** However, even though building projects are basically composed of repetitive serial activities, they also involve unique, complex, and non-repetitive activities; in many cases, locations differ (e.g., in size) and so do activity contents. A location-time diagram called Advanced Line of Balance (ALoB) was developed to extend the application area of this method into partly-repetitive projects and is presented in this paper. Hence the aim of this paper is to investigate the use of ALoB in partly-repetitive environments. The paper contains three parts: (1) the LoB literature is discussed, (2) the methodology of ALoB is discussed, and (3) the use of ALoB in model-based scheduling in partly-repetitive environments is discussed.

Keywords

Location based scheduling, Line of balance, Information system, Building information model

1. Introduction

A project schedule is currently created on the basis of a scheduler's accumulated experience in past projects and is the product of an individual and independent effort rather than an effort based on a

company specific planning system. The transition from individual knowledge-based scheduling systems to model-based scheduling has been slow (Firat *et al*., 2008a).

A repetitive project consists of a number of similar or identical units (Moselhi and El Rayes, 1993). Since residential projects contain repetitive processes and involve linear production, some parts of the production can be modelled into master schedules and these model schedules can be reused by schedulers who can modify them according to project-specific characteristics. Hence model-based scheduling is expected to become a serious alternative to existing scheduling practices. However, as all new challenges, model-based scheduling needs a different mindset. As a transition into the new mindset, it would be appropriate for model-based scheduling to evolve from basic scheduling methods such as activity-based (CPM – Critical Path Method) and location-based (LoB – Line of Balance Method) scheduling methods. This paper focuses on current research about Advanced Line of Balance (ALoB) that was developed for semi serial production like building construction, where activities are performed at different locations and where the scope and duration of activities in different locations may also differ.

The aim of this paper is to explore and to understand the use of ALoB in partly repetitive environments. The paper includes: (1) a brief literature survey of LoB, (2) the methodology of ALoB, and (3) a discussion of the use of ALoB in model-based scheduling in partly-repetitive environments.

2. Line-of-Balance (LoB) in the Literature

LoB is a technique for assembling, selecting, interpreting and presenting in graphic form the essential factors involved in a production process from raw materials to completion of the end product, against a background of time (Line of Balance Technology, 1962). As a scheduling tool, LoB has its origins in the manufacturing industry where it has been successfully used for a long time to plan and control repetitive one-off projects (Heinrich *et al*., 2005).

There are two main methodologies for scheduling: activity-based scheduling and location-based scheduling (resource-based scheduling in the U.S. context). These two methodologies are represented by different methods, often designed to achieve the same purposes in different ways. Activity-based scheduling methods are not suitable to represent the spatial dimension of construction work. These methods are based on a Work Breakdown Structure. In other words, their focus is on activities, whereas location-based scheduling methods such as LoB are well suited for spatial planning and are more effective in resource planning. Location-based scheduling methods use a Location Breakdown Structure. In other words, their focus is on locations (Norberg, 2008). Moreover, location-based scheduling supports the link between a work schedule and lean thinking, i.e., the "flow" concept (Koskela, 1999), since it enables continuous work flows with the use of balanced resources (Firat *et al*., 2007).

Harris and Ioannou (1998) list the various names given to variations of these methods, including "construction planning technique", "time-location matrix model", "time-space scheduling method", "disturbance scheduling", "horizontal and vertical logic scheduling for multistory projects", most of them associated with lean thinking "flowline" (Kenley, 2004). In their work, Huang and Sun (2006) tabulated many linear or repetitive scheduling methods alongside their authors, unique functions and/or applications. Furthermore, there have been several attempts to compare and to reconcile linear and network scheduling (Arditi *et al*., 2002a, Russell *et al*., 2006), Satisfactory results were reported by Jongeling *et al*., (2007) and Staub-French *et al*., (2008) who used 4D models and LoB together.

Four tools based on LoB principles were created at Illinois Institute of Technology over the last twenty years, namely SYRUS (System for Repetitive Unit Scheduling) (Arditi and Psarros, 1987), RUSS (Repetitive Unit Scheduling System) (Arditi *et al*., 2001a), CHRISS (Computerized High Rise Integrated Scheduling System) (Arditi *et al*., 2002b) and ALISS (Advanced Linear Scheduling System) (Tokdemir

et al., 2006). Even though there have been numerous academic efforts to develop and promote location-based scheduling methods, LoB has often been disregarded in favor of the activity-oriented critical path method (CPM) developed as an extension of the Gantt chart (Heinrich, 2005). However, LoB has been used as the principal scheduling tool in Finland since the 1980s (Soini *et al*., 2004).

3. Advanced LoB (ALoB)

LoB is based on the assumption that the rate of output will be uniform (Sarraj, 1990). In other words, the production rate of an activity is linear where the buffer time between activities is plotted on the x-axis, and the location of an activity on the y-axis. The y-axis also shows progress in terms of the degree of completion. The production rate of an activity is the slope of the production line and is expressed in terms of units per time. In Finland, a common productivity database that was developed by a joint effort of construction companies is available to potential users (Firat *et al*., 2007).

The scheduling and estimating process of LoB is quite similar the process in activity-based scheduling methods such as CPM (Norberg, 2008). The mathematics behind the various calculations involved in LoB and the process of the formal development of an LoB schedule are discussed by Sarraj (1990). This method has been modified and further developed in Finland starting in the 1980s. Research on LoB has taken place at Helsinki University of Technology (TKK) (e.g. Kiiras, 1989). Modified LoB has been the dominant scheduling method in Finland since then (Kankainen and Seppänen, 2003). Firat *et al*., (2007) discuss thoroughly the further developed version of the method called Advanced Line-of-Balance (ALoB). This paper initiates the research focused on the relation between ALoB and model-based scheduling. ALoB is further discussed in the following sections.

To start scheduling by ALoB, the construction project is broken into work spaces; this segmentation process is called sectioning. Location-based scheduling is based on sections. A section is defined as a physical part of the project, like a detached building, in which activities are completed in their entirety. These sections are further divided into smaller work spaces (Figure 1). In a work space, only one critical activity can take place at a time; it sets the pace. All activities are scheduled to continue from one location to another without any interruptions. Soini *et al*., (2004) define this as a Location Breakdown Structure (LBS). Through sectioning and LBS, all dependencies can be planned on a finish-to-start basis. Figure 1 shows an example of dividing a construction project into sections and work spaces. Figure 1 also shows Section A of the example project with its phasing process. T1 is the time of completion of earthwork and foundation works, and T2 is the time after earthwork and foundations until the completion of the section.
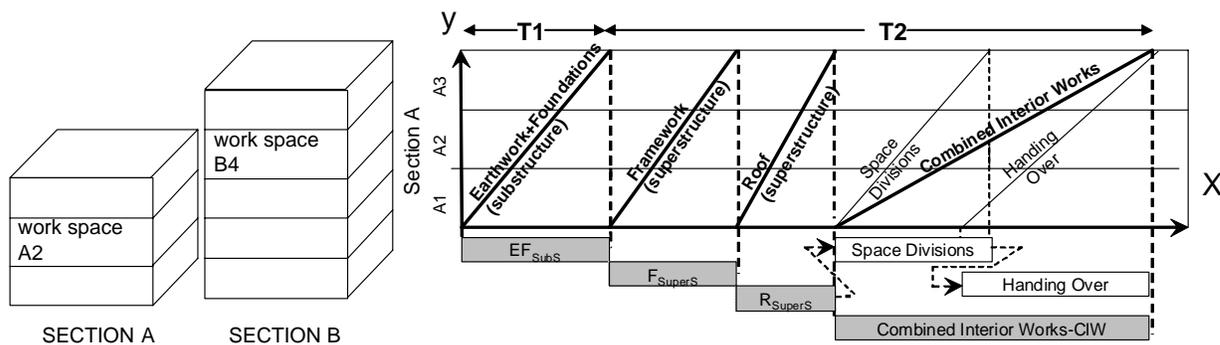

Figure 1: Sectioning and Work Spaces of a Project and Phasing of a Section of the Project

Sectioning is performed according to construction methods, design, location or number of floors. Each section is a whole from the bottom to the top floor and each section is designed and built as an

independent, detached building. Sections are selected such that activities form a non overlapping chain. The sectioning function of ALoB enables controlling various projects (Firat *et al.*, 2008a). The order in which the sections will be built is chosen according to size: the smallest section is built first, the largest the last. The order in which the sections will be built can also be chosen on the basis of the schedule or according to the Hoss' rules (Kolhonen *et al.*, 2003): a) the section that takes least time for the foundation works or the superstructure should be started first; b) among the sections that are left, the one that takes the least time for interior works should be started last. If the same section takes least time for the foundation, superstructure, and interior works, the order is chosen according to the foundation and the superstructure. Hoss' extended rules are based on total work relative to different phases of production: a) the section that takes the biggest ratio (total duration of interior works divided by total duration of foundation and superstructure) should be started first; b) the section that takes the smallest ratio should be started last. If the sections are not similar, more detailed attention has to be paid to the order.

The second step in ALoB, is the phasing of the activities that are dependent on each other (see Firat *et al.*, 2007 for further information). Activities are categorized as follows: substructure phase (earthwork, piling, excavation, and foundations), superstructure phase (load bearing frame, structural system, and facades), roof structure phase, combined interior works phase (completion works such as partition walls, space separators, tiling works, windows and doors; and project close-out activities such as completion works and tests).

Further phasing is done by decreasing the number of activities by combining the sub-activities into work packages. Synchronization and/or balancing, which means that preceding and succeeding tasks proceed at a similar pace, ensure similar production rates within activities, i.e., as parallel lines in a diagram that shows a constant time-space buffer between different activities. Work packages are synchronized by changing their contents or sub-activities. Sub-activities are not synchronized at the master schedule level. Instead, a work order is assigned to each of them (Firat *et al.*, 2007). The sequencing of activities is performed similar to the process in activity-based scheduling methods. Sequencing is the process of linking the activities created in the LBS to each other by assigning dependencies. Arditi *et al.*, (2001b) state that location-based scheduling can be more efficiently performed by combining the method with precedence diagram technology. While sequencing is done, the activities are paced such that activities proceed without interference from one location to another even if quantities are divergent. Only pace setting activities are drawn on a schedule. Properly phasing the activities and properly assigning dependencies between them allow developers to form a list of generic model activities. This list opens the way to model-based scheduling (Firat *et al.*, 2007).

Activity content is established by using a Location Breakdown Structure (LBS), a bill of quantities, and cost estimates if necessary. Hence the location of and the resources (i.e., crews and equipment) assigned to an activity are determined. The duration of each activity is calculated by a phase-specific duration model or rule. In model-based scheduling, activity content is established electronically and semi-automatically by the information flow coming from the Building Information Model (BIM). Firat *et al.*, (2008b) state that model-based scheduling can be performed by the integrated use of BIM technology and ALoB alongside the input of an interactive planner. A Building Construction Information Model (BCIM) is offered by Firat *et al.*, 2008b) as an environment, where data are stored, updated, and reused via the evolving project libraries of a building contractor. The three sub-models of BCIM include a building product model that produces the dependencies between activities, a resource model that provides man-hour information used to calculate activity durations, and a process model that contains dimensioning rules for activities. Using template schedules can also help to generate sequence and duration models (Firat *et al.*, 2007).

4. The Use of ALoB in Partly-Repetitive Model-Based Scheduling

The initial test results of model-based scheduling in a partly-repetitive building project are summarized in Firat *et al*., (2008a). Following the principles of ALoB and using the Building Construction Information Model (BCIM), the model first creates an LBS with proper sections. The activity durations are calculated for one section. The dimensioning in the activities in other sections is then performed automatically by the scheduling software VicoControl^{TM} (Vico, 2009). In the BIM environment, project-specific dimensioning information is retrieved from a contractor's resource model in order to find a company-specific planning system. Sequence models including all needed dependencies and start delays are retrieved from the company-specific template file and hence the model is created. Non-repeating and/or special activities are manually fed into the model schedule by an interactive planner. The non-repetitive part of the building is modeled in a different section.
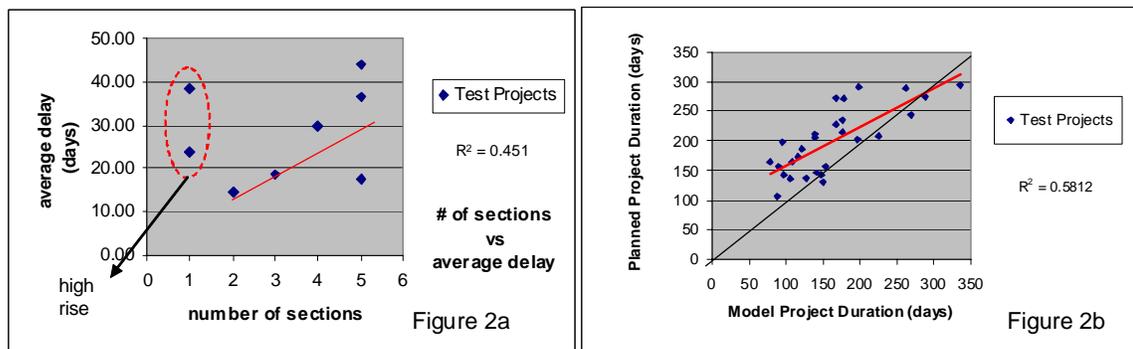

Figure 2: a) Number of Sections versus Average Delay in First 8 Test Cases b) Total Project Duration (T1+T2 in Figure 1) of Planned Schedules versus Total Project Duration of Model-Based Schedules in 28 Test Cases

Test results of model-based scheduling are shown in Figure 2. The correlation between the number of sections and average delay in the first 8 test results is given in Figure 2a. The partly-repetitive model-based scheduling was further tested in 20 additional projects. Model-based schedules were compared with planned schedules but not to executed schedules. Figure 2b shows the relationship between project durations generated by model-based schedules and planned schedules for the 28 test projects. The trend line in Figure 2b does not correspond to the diagonal that would have been the ideal match. It looks like the trend line needs some correction in order to reduce the variance from the perfect match.

The important results of these 28 test projects are that (1) there is no company-specific planning system, (2) projects are not recorded in databases, preventing organizational learning from happening, and (3). "control" is missing in projects. Using model-based schedules can make the scheduling process more efficient by generating company-specific planning systems, and tighten the schedules by reducing the completion time with more accurate, more reliable, more usable schedules. The iterative process of updating a model-based schedule can diminish the variance observed in Figure 2b.

5. Concluding Remarks

A literature survey revealed that LoB is becoming more popular as an effective alternative scheduling method especially in repetitive projects as it enables the easy and effective management of activities and of the resources needed at the locations where they take place. Even though building projects are basically composed of repetitive serial activities, they also involve unique, complex, and non-repetitive activities; in many cases, locations differ (e.g., in size, as observed in Figure 1) and so do activity contents. ALoB, with its sectioning feature offers new and effective solutions even to partly-repetitive projects.

Sections are the core of ALoB and they must be built so small that activities form a chain without overlapping. The sectioning feature increases the controllability of construction projects. The difference of ALoB from basic LoB is that the sections need not be equal in size or even in their activity content. Another key point in ALoB is reserving one location for one work at a time. It is suggested that the variations in activity contents are handled in the model-based environment by updating the information through the Building Construction Information Model (BCIM). Test results have shown that ALoB is an effective method for partly-repetitive model-based scheduling. However, an interactive relationship between the model-based schedule and a planner is important in developing a company-specific scheduling system.

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