Extended model-based master scheduling for building projects using advanced line of balance

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ABSTRACT: This study addresses a two-step approach to model-based scheduling using the Advanced Line of Balance (ALoB) technique. In the first step, a master schedule is developed by using a product model, a resource and cost model, and public databases such as Ratu files. In the second step, this model-based master schedule is refined by a project manager who injects additional project specific information into it.

The objective of this paper is a methodology that can be used to set up a model-based master schedule of a residential building project and then to refine this master schedule to satisfy the conditions in a particular project. The paper introduces building construction information modeling, advanced line of balance before describing the process and structure of model-based master schedule. After a discussion about extending a master schedule into a usable schedule, the findings of a case study are presented. It is concluded that a two-step methodology to create an extended master schedule is feasible.

1 INTRODUCTION

Even in simple projects of repetitive nature, work schedules are never based on a standard master schedule. They are made by schedulers from scratch. The quality of these schedules is greatly dependent on schedulers' accumulated tacit knowledge. Project managers exert only limited control over the quality of these work schedules. However, a semi-automated model-based master schedule that is adjusted by project manager input can be a viable alternative to existing practice. Human and computer model interaction can be used to form a scheduling culture that makes use of a master schedule adjusted later by a project manager.

"Model-based" scheduling is a computer aided scheduling technique that automatically processes information retrieved from information models and creates a dynamic scheduling platform.

Since formulating a work schedule is a complex and challenging activity, an intelligent approach would involve a two-step approach, first a novice scheduler generating a model-based master schedule, and then a project manager testing and calibrating the master schedule iteratively based on project conditions. When calibrating the model, a project manager can adjust the contents, precedence relationships, resource-related assumptions, and activity durations in the schedule. The proposed methodology involves setting up a "model-based" schedule by using Advanced Line of Balance (ALoB) and using historical company-specific data to adjust it.

The model-based master schedule is built first by dividing the project into different sections such as building 1, building 2 and building 3, and then into different phases such as earthwork/foundation, superstructure/roof, and interior works if this is a building project. The next step is to create a list of activities for each phase. The durations of these activities are estimated using historical data obtained from company archives. Some of the activities are then combined into sets of "combined activities" that are easier to manage and control. Combined activities are balanced (synchronized) in such a way as to achieve a reliable, risk free and balanced schedule. Finally, a master schedule is created by Vico Software's Control application using this basic information. This master schedule is then used as a template to create a more realistic schedule for the project at hand.

The objective of this paper is to introduce a methodology that can be used to set up the master schedule of a residential building project based on a building construction information model and to refine this master schedule such that it satisfies the conditions in a particular project. The model-based master schedule can be built in a short period of time by using minimum input from a scheduler but represents a realistic picture of the content, logic, and duration of a typical building project undertaken by the company. This model-based schedule is then calibrated by project managers interacting with the software package, hence adjusting and refining the schedule to fit the specific conditions of the project at hand. The paper consists of two parts: (1) the proposed model is introduced with its theoretical background, and (2) the preliminary findings of a case study relative to scheduling a residential building project are presented and discussed.

2 BACKGROUND

2.1 *Literature Review*

A knowledge-based system is not a new idea and has been researched in the literature (e.g., Kähkönen, 1993). However, it uses subjective data preventing it from being an efficient problem solving system. Also, knowledge-based systems can lead to non-systematic, ad-hoc solutions. Model-based systems have evolved from knowledge-based systems but can overcome these shortcomings by embedding knowledge into decisions and by using IT tools to operate the process, creating project management tools that are systematic and non-arbitrary.

Firat et al. (2008a) reviewed some of the earlier literature about knowledge-based systems (e.g., Kähkönen, 1993), detected a slow transition to model-based systems, identified some fundamental problems with this transition, and proposed possible viable solutions. As a transition to model-based systems, Akbas (2004) proposed a geometry-based process model (GPM) where he split the construction project into limited workplace sections and then generated discrete simulations. Kataoka (2008) proposed a method of processing simple 3D geometries to generate construction components for automatic takeoff and scheduling using construction planning knowledge.

Many contractors (e.g., Skanska CS Finland), especially those that repeatedly build similar facilities, have been reusing past project schedules to generate new schedules. In fact, Firat et al. (2007) and Chevallier and Russell (2001) suggested using template schedules to semi-automate the making of draft schedules. Dzeng and Tommelein (1997) reviewed the academic efforts in automated planning systems and applied case-based reasoning to generate new schedules (Dzeng and Tommelein, 2004). After thorough literature review, Waly (2001) categorized automated planning in three stages, namely, through the use of knowledge-based systems, through 4D models, and through virtual environment planning models.

4D models were introduced in the early 1990s (e.g., Skolnick et al., 1990; Matsuzawa et al. 1994), were further developed in subsequent years (e.g., McKinney and Fischer, 1998; Dawood et al., 2005), and their area of application was widened (Akinci and Fischer, 1998; Doulis et al., 2007). 4D models combine product models (i.e., 3D CAD models) with process models (i.e., schedule information) to represent a schedule graphically and visualize construction. The visualization feature of 4D models helps to identify potential problems and errors that could have serious consequences if discovered later (Koo and Fischer, 2000). However simply adding time to 3D models is not producing effective project plans, even though there were some attempts (e.g., Aalami, 1998; Fischer and Aalami, 1996) to automatically generate activities and eventually 4D models using the relationships among objects in the product model. Currently, commercially available 4D software use schedule information simply to visualize construction, except for a GIS-based system developed by Poku and Arditi (2006) that can also be useful in the day-to-day management of a project.

The rapid development of 4D technology opens promising future paths to model-based scheduling such as integrating product and process models. The Tekla Structures Construction Management tool (with its Task Manager add on) (Tekla, 2009) allows scheduling starting from a 3D model by assigning durations to tasks and by assigning tasks to building components. Firat et al. (2009a) further discuss the integration of model-based scheduling and 4D scheduling. Even though the majority of commercial 4D modeling tools use activities created by CPM, there has also been recent efforts to combine 4D CAD and LoB (e.g., Björnfort and Jongeling, 2007), because location-based scheduling provides a promising alternative to activity-based planning approaches in 4D CAD (Jongeling and Olofsson, 2007).

Some researchers have studied model-based scheduling, but no attempt was ever made to organize the scheduling process in a rational manner. Hence there is a need to generate model-based schedules and use them to generate project schedules.

2.2 *Theoretical Background*

According to Firat et al. (2008b), model-based scheduling can be performed by integrating Building Information Modeling (BIM) and Advanced Line of Balance (ALoB) with the input of an interactive planner.

2.2.1 *Building Construction Information Modeling*

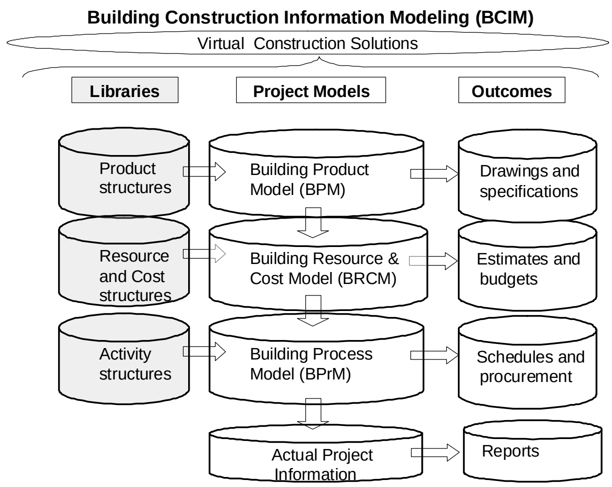

Figure 1. Building Construction Information Modeling (BCIM).

Building Construction Information Modeling is presented in Figure 1. It emphasizes the critical production phase and processes. BCIM is a dynamic, library-based information model that automatically generates design and production information such as drawings, reports, specifications, estimates, bills of quantities, budgets, schedules, simulations, and procurement plans. Actual project processes information can be fed back into the model. BCIM is dynamic because there is a constant flow of information through the model and because the model is capable of handling change orders during construction.

As shown in Figure 1, BCIM consists of three models: (i) a building product model (BPM) that contains information about building elements and products (Alsakini et al., 2007), (ii) a building resource and cost model (BRCM) that contains information about the quantities and the costs of building products to be used in construction, and (iii) a building process model (BPrM) that calculates activity durations. The BPM produces the technical sequences, and dependencies of activities, BRCM complements them with man-hours, and BPrM makes use of all this information to proceed with the duration calculations of activities.

2.2.2 *Advanced Line of Balance*

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 use different algorithms to solve the scheduling problem. Construction projects vary in their main constraints; time, cost, resource, space, etc. Activity-based scheduling methods such as the Critical Path Method (CPM) are suitable for time-driven project schedules, but they are not suitable when there are spatial limitations, whereas location-based scheduling methods such as Line of Balance (LoB) are well suited for spatial planning and are more effective in resource planning and hence a better solution to resource-driven projects. Whereas a time-driven project is governed by a hard deadline, a resource-driven project depends a great deal on the availability of resources. Activity-based scheduling emphasizes completion of a project in minimum duration, but is not able to achieve a continuous flow of resources in resource-driven projects. Location-based scheduling methods such as LoB are indicated in these circumstances.

Line of Balance (LoB) is a graphical scheduling technique that is designed to plan and manage continuous workflows in specified locations with balanced resources (Firat et al., 2008c). In LoB, only one activity can take place in a work space at a time. This activity sets the pace, and all other activities are scheduled to continue from one location to another without any interruptions to ensure the workflow. Soini et al. (2004) define this as a Location Breakdown Structure (LBS). Building projects are repetitive in nature and are well suited for LoB applications.

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., 2001), CHRISS (Computerized High Rise Integrated Scheduling System) (Arditi et al., 2002) and ALISS (Advanced Linear Scheduling System) (Tokdemir et al., 2006). LoB was modified and further developed into Advanced Line of Balance (ALoB) at Helsinki University of Technology in efforts that started back in 1985 (Kiiras, 1989). These efforts lead to a commercial software package, originally named DynaProject™ and later called VicoControl™ (Vico, 2009). VicoControl™ has become a popular planning software among large contractors in Finland (Kankainen and Seppänen 2003) e.g., Skanska CS Finland, because it is the most advanced commercial software package with a location-based scheduling algorithm.

In ALoB, a project is divided into sections. The most effective order of the consecutive implementation of each section is planned. A section is defined as a physical part of the project, like a detached wing or the floors of a building, in which activities are completed in their entirety. Sectioning is performed according to construction methods, design, location or number of floors (Firat et al., 2009b). Sectioning enhances early consecutive start ups, constructability and work performance.

Advanced Line of Balance (ALoB) differs from the traditional LoB in that the sections (e.g., floors of a building) need not to be equal in size or in their activity content. In a time-location diagram, the workflow of each activity is shown through the sections of a project (Firat et al., 2008c, Firat et al, 2009b). Every activity is represented by a line in a diagram where the x-axis shows time information and the y-axis the location of the activity. The slope of the line represents the production rate of the activity. Balancing is the synchronization of activities such that preceding and succeeding activities do not conflict with each other, hence, balanced activities are represented by parallel lines in an ALoB diagram that show a constant time-space buffer between different tasks (Firat et al., 2007). In the Finnish construction practice the production is often synchronized according to the superstructure. Firat et al. (2009b) discuss the use of ALoB in model-based scheduling thoroughly.

3 PROPOSED METHODOLOGY

The proposed two-step methodology is presented in Figure 2. VicoControl™ is used as the scheduling software in both steps. In Step 1, a semi-automated process takes place to generate a master schedule. In this process, resource and cost information are transferred to VicoControl™ automatically. In Step 2, once the model-based master schedule is developed, the project manager modifies it in VicoControl™ according to the project specific conditions.

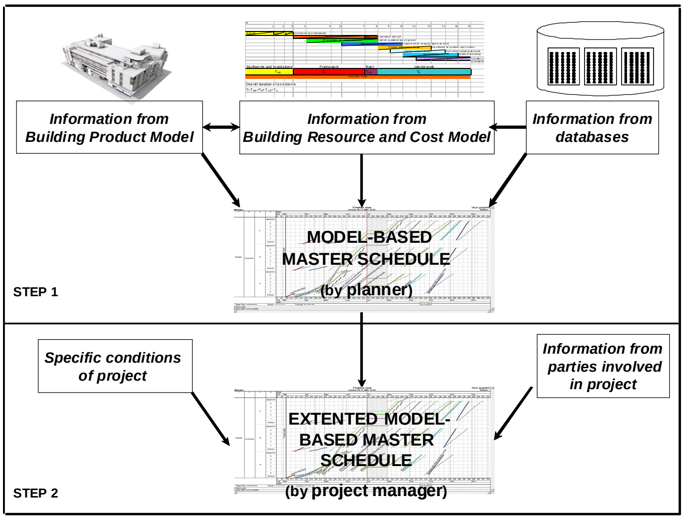

Figure 2. The proposed two-step methodology of extended model-based master scheduling.

The details of this methodology are discussed in the following sections.

3.1 *Process of generating model-based master schedule*

Figure 3 shows the information flow in the process of generating a model-based master schedule. The quantity information is retrieved from the Building Product Model (BPM) and is coupled in the Building Resource and Cost Model (BRCM) with company-specific databases (including productivity information, unit cost, etc.) to form a spreadsheet based on an activity list and phases. A phase is the combination of activities that are dependent on each other. Activity sequencing is done by using ALoB in the Building Process Model (BPrM) as seen at the bottom part of Figure 3.

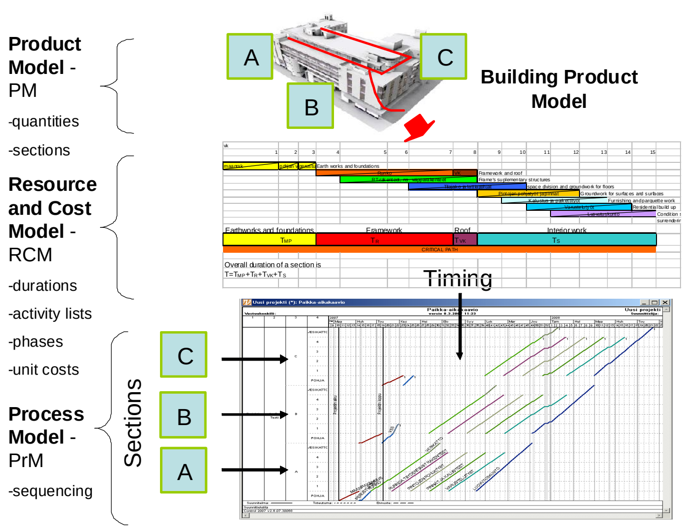

Figure 3. Process flow in generating model-based master schedule.

For the purpose of this paper, the terms "activity" and "task" are used interchangeably, because activity is defined by Callahan et al. (1992), as a single discrete work step in the project, and task is defined by Clough et al. (2000) as a part of a project that needs to be completed within a defined period of time.

The proposed model is developed following lean thinking and Koskela's (2000) "Transformation Flow Value" (TFV) concept. Moreover Ballard's (2000) last planner is also used as a complement even though last planner is a micro management tool.

The first two models involved in Building Construction Information Modeling (BCIM) (i.e., the Building Product Model (BPM) and the Building Resource and Cost Model (BRCM)) have been thoroughly investigated in the literature and have found practical use in industry. However, the Building Process Model (BPrM) is not fully adopted by the construction industry. Hence, the focus of this paper is in process models i.e., construction schedules. More specifically, the scope of this research is narrowed to the development of an extended model-based master schedule. A master schedule is planned by making use of the outcomes of BPM and BRCM, whereas an extended schedule is obtained after the master schedule is refined by a project manager to comply with the realities of the project being undertaken.

3.2 *Structure of the model*

The model-based master schedule is created first by establishing a location breakdown structure (LBS) by sectioning a project into working spaces that are small enough to allow effective control of the work (for more information, see Firat et al., 2009b). The objective is to create a schedule for each section. Each section is represented by phases (e.g., substructure, interior works, etc.) each of which is composed of activities. Phases are sequenced using finish to start interdependencies (Figure 4), but can make use of other types of interdependencies such as start to start, finish to finish, etc. The duration of a phase is governed by the durations of the activities that define that phase. These activities follow the same pace and are created automatically by the ALoB algorithm. The duration of a section is based on the durations of the activities on the critical path. In the model schedule, to model, the term "combined activities" is used to simplify the list of the activities.

The durations of the activities in the phases are calculated by using empirical rules and information provided by RATU (Construction Productivity Information), a database for construction related information in the Finnish construction industry (Ratu, 2009). The Ratu file contains information about work methods with respect to good building practice, work and material requirements as well as information about planning and quality assurance. The information contained in the Ratu file concerns both building and renovation work, and is based on observations and studies at actual work sites (Ratu, 2009).

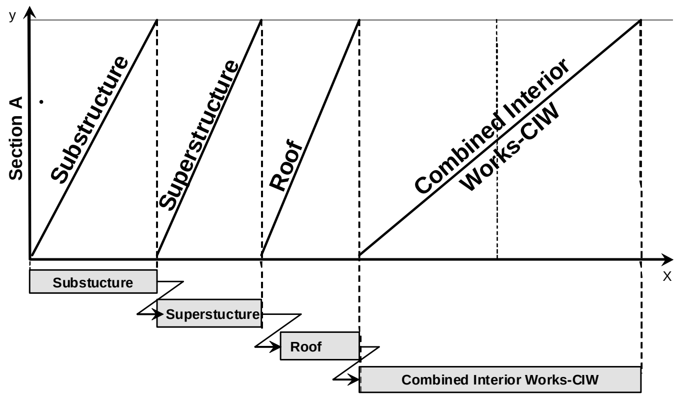

Figure 4 Phasing of a section of a building.

The phasing of an example building is shown in Figure 4. Activities that are dependent on each other are combined in phases. For example, the two activities earthworks and foundations (including base floor slab) are combined into the substructure phase. Quantity information about these activities such as gross area of the site, volume of excavated material, building area, number of piles, area of foundation formwork, quantity of reinforcing bars, volume of foundation concrete, etc. are filled in manually into a spreadsheet. The spreadsheet calculates activity durations based on these quantities and the unit rate retrieved from Ratu files.

After forming the spreadsheet, this information is imported to Vico Software Control™ (Vico, 2009). The second step in developing a project schedule involves manipulating the template file imported to VicoControl™. The template schedule includes the same list of activities with the same codes used in the spreadsheet. Firat et al. (2007) described thoroughly the steps in the creation and use of a template schedule feature of VicoControl™ in model-based scheduling.

3.3 *Extension of the model-based master schedule*

The project manager's contribution to scheduling occurs after the project manager receives the model-based master schedule from the planner. Using the template file feature of VicoControl™ (Vico, 2009), the project manager updates the sequencing information along with other data such as durations and lags. With the development of a semi-automated model-based master schedule, the project manager's efforts to generate a working schedule are expected to be easier. Model schedules have systematic development procedures, providing project managers a non-arbitrary kick off in the project. With the help of the planner, a project manager can feed in project-specific requirements into the schedule and can refine the schedule by adjusting the activity contents, durations, precedence relationships, etc. after discussing the issues with the parties involved in the project. A model-based master schedule can help a project manager to make better decisions relative to a usable schedule, because model-based master schedules can serve as a decision support tool for project managers. However, this needs a new mindset requiring that project managers adopt model-based scheduling as a project management tool. Indeed, since model-based master schedules are generated by using company-specific data, they can provide a systematic planning culture throughout the company.

3.4 *Case study to test the model*

The first step of the proposed methodology was tested on a real project undertaken by a major international contractor (Skanska CS-Finland). This case project was a residential building project built in Finland of 60 units. The project consists of three buildings with 5 floors each, and one bomb shelter. Pile foundations are used in the substructure of the buildings. Project construction area is 4612 m2, where the total building area is 883 m2. An illustration of the case project is presented in Figure 5.

Figure 5. An illustration showing the general site view of the case project.

In Figure 6, the original schedule prepared and used by the project manager is compared with the model-based master schedule developed by the authors by using the first step of the methodology described in this paper. In the original schedule, the information for most of the activities was retrieved from the in-house databases, estimators, and project managers, whereas the information for few came from Ratu.

The project is divided into three sections as there are three detached buildings. Dashed lines show the original schedule ("actual" in the legend in Figure 6), and the solid lines show model-based master schedule ("target" in the legend in Figure 6). Testing similarities between the two schedules yielded some initial results. The correlation between the model-based master schedule and the original schedule turned out to be reasonable. The actual time of completion of "superstructure" phase was 2% shorter than the time in the model-based master schedule, and the actual time to complete the remaining part of the project was 7% larger than the time in the model-based master schedule. The differences in durations showed that there is a need to calibrate the model. For example, soil conditions are very project specific and hard to model. Hence, an updating system is needed for the model.

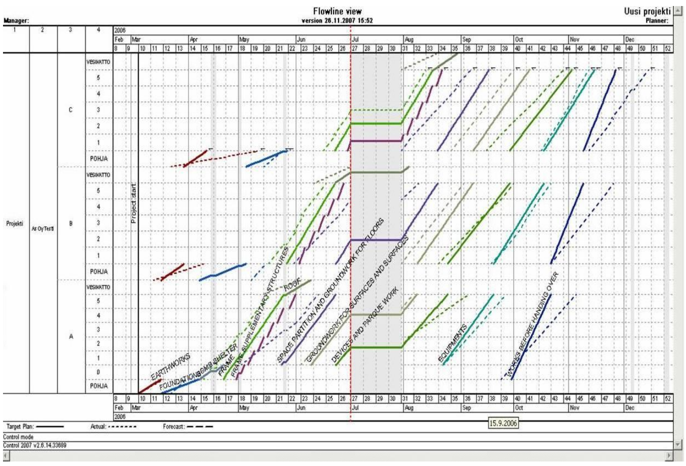

Figure 6. Comparison of original vs. model-based master schedule for a case project.

When Figure 6 is examined closely, it is found that activity durations in the model-based master schedule are generally shorter than the durations in the original schedule. The fact that a difference exists between the model-based master and the original schedules requires that a planner rethink the assumptions made in the development of the model-based master schedule. Hence this comparison signals that in all likelihood, a model-based master schedule needs to be refined.

The preliminary results of using a model-based master schedule in a case project were promising. This case study showed that it is possible to develop a model-based master schedule that can be of use to a project manager, who is expected to refine the schedule to get it in line with actual project conditions. The satisfactory performance of the proposed methodology encouraged the parties involved to continue with the research. The proposed model needs to be further developed and then tested in more case projects. A larger number of test cases is likely to generate a larger amount of data and a more credible environment to validate the model.

4 CONCLUDING REMARKS

This study addresses a two-step approach to model-based scheduling using the Advanced Line of Balance (ALoB) technique (See Figure 2). In the first step, a master schedule is developed by using a product model, a resource and cost model, and public databases such as Ratu files. In the second step, this model-based master schedule is refined by a project manager who injects additional project specific information into it.

A literature review about model-based scheduling reveals that there is a slow transition from knowledge-based scheduling to model-based scheduling, but that model-based scheduling requires a solid and rational structure. An attempt was made in this study to combine Building Construction Information Modeling (BCIM) (See Figure 1) alongside Advanced Line of Balance (ALoB) to produce an easy-to-use scheduling method. The only limitation of the proposed methodology is that it has been tested only on building projects so far.

The first step of the proposed methodology was tested in a case study, which showed that the correlation between the model-based master schedule and the original schedule prepared and used by the project manager was reasonable, but that a better calibrated master schedule could yield better results.

Further research directed towards increasing the number of test cases and developing automated calibration systems is expected to improve the proposed methodology. It is believed that model-based master schedules can serve as decision support tools for effective project management.

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