Fundamental problems vis-à-vis viable solutions in the model based scheduling of building projects

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Abstract

The main aim of the paper is to explore and to understand fundamental problems in the model based scheduling of building projects and to suggest viable solutions for those problems. There have been attempts to overcome severe problems of not producing optimal project plans and master schedules among researchers and software vendors. PM/CM staff is still relying on their own experience. Herein, a focus is on planning master schedules. It is proposed that combined product and process modeling is a right way of solving problems. Fundamental problems are addressed through seven questions: (i) How to handle size variety? (ii) How to handle activity scope variety? (iii) How to manage work order, dependencies, and overlapping? (iv) How to dimension activities or to calculate their durations? (v) How to integrate a product model and a resource model with a process model to get enough data? (vi) How to take into account project specific conditions? and (vii) How to calibrate and to update models in order to correspond to real, changing building world? The location based Advanced Line of Balance (ALoB) is herein used as a means for demonstrating and solving fundamental problems. A building construction information model (BCIM) is suggested to provide enough data for developing viable solutions. Finally, the validity is discussed in terms of recognizing and solving the problems as well as using the ALoB method in the future.

Keywords: advanced line of balance, building information models, master schedule, model based scheduling, model based knowledge

1. Introduction

Knowledge management entails leveraging collective wisdom to accelerate responsiveness and innovation. Information has replaced physical products and inventories as one of the driving forces of competitive advantage [1]. New planning tools based on information and communications technology (ICT) are being adopted among construction project managers and planners. Nevertheless, most PM/CM planners are still relying much on their **cumulative**

experience. The copying of the plans of executed previous projects is still very common but this is not resulting in optimal project plans and master schedules.

Among researchers and software vendors, there have been attempts to overcome major project planning problems, i.e. model based scheduling systems are being adopted to optimize plans. However, it is herein argued that there are **many fundamental problems** in model based project scheduling, too. It is proposed that **integrated product and process modeling** is a viable way of dealing with such fundamental problems in model based scheduling and transferring knowledge inside organizations.

The aim is to explore and to understand fundamental problems in model based scheduling and to suggest viable solutions for such recognized problems in the primary context of building projects. The paper includes (i) a short literature review about scientific model based scheduling and available commercial software as well as (ii) a recognition of fundamental problems through seven research questions. In Finland, **the Advanced Line of Balance (ALoB)** or a slope line method has been largely used since the late 1980s. The ALoB was developed for semi serial production like building construction, where locations can be different as well as a scope of activities and durations in locations (sections) may differ. Herein, the idea is to use the ALoB for gaining root understanding of modeling construction production (and not to use the ALoB only as a scheduling method). **A building construction information model (BCIM)** is suggested to provide enough data for developing viable solutions to these problems. A working hypothesis is that **library models are a right way to transfer project knowledge.** Finally, (iii) the validity is discussed in terms of recognizing and solving fundamental problems as well as using the ALoB in the future.

2. Scientific models and commercial software for the scheduling of building projects

A slow but continuing movement has shifted **an emphasis from knowledge based planning systems to the model based ones** in building. For example, in the sequencing of activities there has been a migration from knowledge based scheduling (e.g. [2], [3]) to the model based one (e.g. [4]). The Professional Intelligent Project Planning Assistant (PIPPA) was one of the first model based planning systems that also has been evaluated in an industrial context, although a definition of an activity as an intersection of objects, actions, and resources was derived in part from the MOLGEN [2] concept of object and action abstraction [5]. Darwiche et al. [4] developed the OARPLAN as a computer software tool to generate project plans through reasoning about objects, actions, and resources. Sequenced activities are generated based on project objects through constraint satisfaction [6] and planning knowledge is represented as constraints based on activity constituents and their interrelationships. In turn, the Object Model Based Project Information System (OPIS) is an example of connecting model based planning and building information models (BIM) and combining several project planning applications around a shared object-oriented project database [7]. Some researchers are focusing on sub-elements like sequencing with different aspects [8] and combining time with other sub-elements, e.g. geometry [9].

Some researchers have suggested **improvements** [10] in terms of advanced visualization techniques such as 4D [11] and virtual reality [12] for the more effective evaluation and communication of schedule information. Others have reviewed and analyzed commercial 4D applications, e.g. Kähkönen and Leinonen [13] and Heesom and Mahdjoubi [14]. Jongeling [15] combines workflows and location based scheduling. He reports upon the satisfactory results when 4D models and a line of balance technique were used together to plan workflows. Recently, Porkka and Kähkönen [16] compiled the best known 4D applications and addressed challenges and future trends in 4D applications.

It seems that the first effective model based solutions, i.e. virtual, integrated PM/CM solutions, have been supplied by **some pioneering commercial software vendors**, based on a scheduling theory, coupling human interaction with models. Some well-known commercial software for scheduling of (construction) PM include Microsoft Project™ and Primavera Project Planner™. The latter is based on Critical Path Method (CPM), i.e. activity based scheduling methods. There are also some computer tools using linear scheduling methods and in particular **a location based scheduling methodology**, the repetitive Line of Balance (LoB) method, such as VicoControl™ (formerly Graphisoft Control™). In addition, software vendors have been developing 4D modeling tools and 4D models such as Virtual Product Chronology (VPS), Navisworks™ (Jet Stream), and CommonPoint™ with Project 4D. The fifth dimension is being added to come up with 5D technology, e.g. cost as part of Vico Software's Virtual Construction™ software. Typical software about scheduling and 4D is given in Commercial Software Links [17]. So far, commercialized software is based on a bottom-up principle of planning schedules, which requires all information of every activity before a complete schedule is at hand.

This literature review revealed that there are many product models and systems as well as many project planning models and control systems. However, **fundamental problems** inherent in model based scheduling have not been addressed adequately (or at all) in the reviewed portions of the scientific literature. Some templates of commercial software can be used in model based scheduling on a condition that we solve first the recognized fundamental problems (see the next section).

3. Recognized problems vis-à-vis viable solutions in model based scheduling in the context of building

Seven fundamental problems in model based project scheduling have been recognized. Herein, each of these problems is initially addressed and being solved by applying the principles of model based, semi-automated scheduling. The fundamental problems are addressed through seven investigative questions: (i) How to handle size variety? (ii) How to handle activity scope variety? (iii) How to manage work order, dependencies, and overlapping? (iv) How to dimension activities or to calculate their durations? (v) How to integrate a product model and a resource model with a process model to get enough data? (vi) How to take into account project specific conditions? (vii) How to calibrate and to update models in order to correspond to real, changing building world? Each fundamental question is being explored and initially solved as follows.

3.1 How to handle size variety?

An optional approach to this problem is to form a location breakdown structure (LBS) with a proper sectioning. **Sectioning in a ALoB** enables the effective management of different project sizes. The sections (locations) of a project should be **so small that a process model in every section is a chain model**. In Figure 1, an example of the sectioning of a case building is illustrated. In an exemplary place-time diagram, a breakdown (Arrow 1), a balanced and synchronized workflow (Arrow 2), and a non-continuous workflow (Arrow 3) are shown. The time between the activity lines (buffer) is shown on the x axis and the locations of each activity are shown on the y axis (Arrow 1). A slope of the line gives a production rate.

In the example, the case building is divided into three sections A, B, and C. **An idea is to start dealing with one section** at a time and then apply this procedure to the total project. Hence, when the sectioning is planned in a proper way so that activities form a chain without overlapping, a rule of balancing can be applied. When the first section is balanced, the same applied rule can be applied to the other locations of the building. In each location, all activities

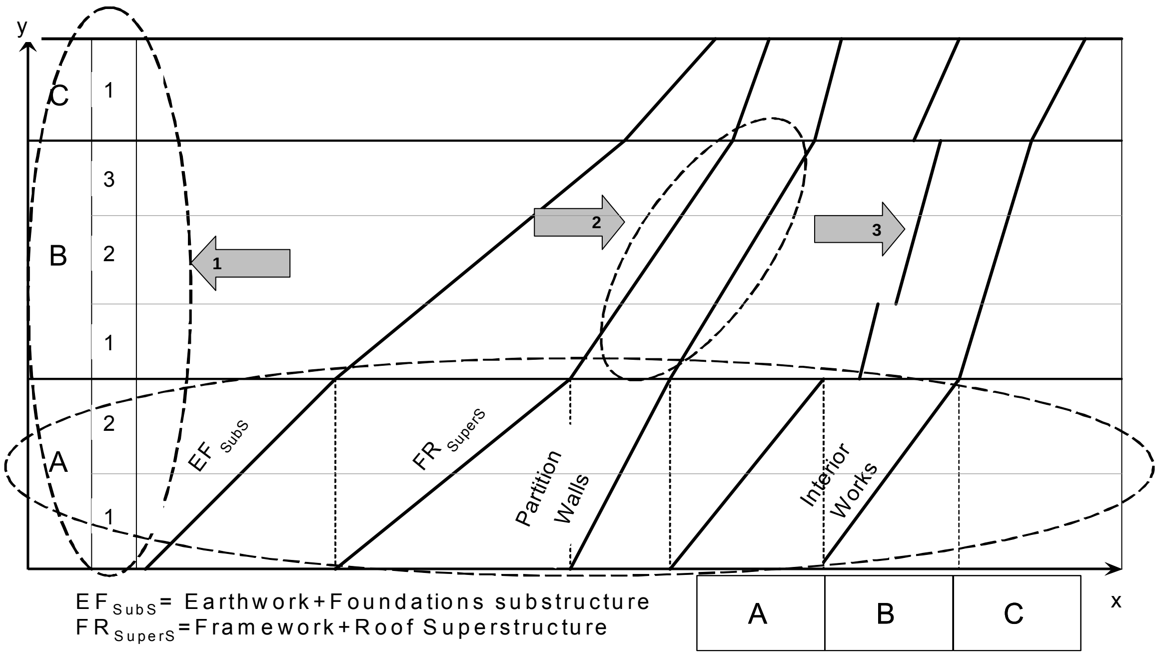

Figure 1. *Sectioning of a case building and a flow-line view as a sample ALoB: (1) The segmentation of a LBS and hierarchy levels, 2) a balanced workflow, and (3) a deviation, a non-continuous workflow.*

are completed entirely. In a workspace, only one critical activity is allowed to take place at a time, and all activities are scheduled to continue from one location to another without interruptions. Through the sectioning and the LBSs, all dependencies in one section can be planned on a finish-to-start (FS) basis. A list of the activities is compiled for deciding upon **a work breakdown structure** (WBS). The list of the activities is retrieved from the libraries of the sub-models of the Building Construction Information Model (BCIM), i.e. the product, resource, and cost models and also the library of the process model (see also section 3.5) and this WBS is then used in the next steps to form phases and work packages.

3.2 How to handle activity scope variety?

As a rule, scheduling activities are based on work groups or trades. Work scope is very project specific. **By using phases, i.e. the logical combinations of building elements,** generic schedules can be created. The phasing is corresponding, for example, to the Uniformat II's [18] building elements and related site work (site elements) classification.

In advanced product models, building elements and building products as their constituents contain also **activity information.** Phases are formed aligning with the Uniformat II classification (and e.g. in the context of Finland, with the national classification, BUILDING 2000 [19]). Earthwork (E) and foundation (F) as substructures can be complied in the first phase, while framework (F) and roof (R) as superstructures can be put in the second one (in single section). An interior phase can be divided into two phases: partitioning (space division D) and interior (I). This joint phasing corresponds to a combination of Level 1 (major group elements) and Level 2 (group elements) in the Uniformat II [18]. The modeled dependencies between these phases in one exemplary section are given in Figure 2. The phases are broken further into activities or work packages. Activities are then synchronized by changing their work contents or work groups. Phases have different inner structures and different rules for calculating durations.

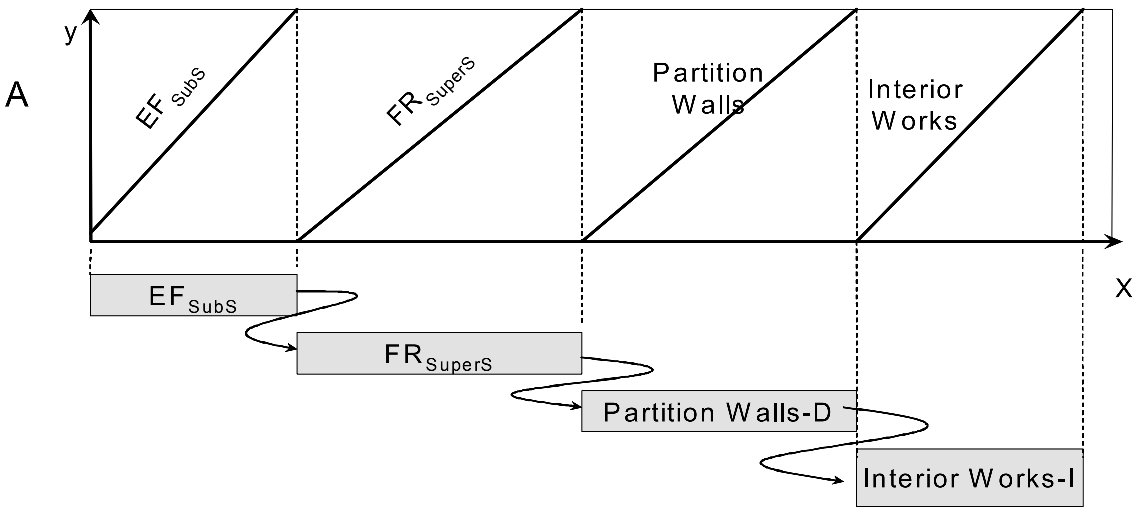

Figure 2. *Joint phasing of a typical building project (see the same abbreviations in Figure 1).*

The novelty of this scheduling logic lies in a breakdown which is planned by **a top-down rationale**, not the bottom-up one used in conventional scheduling systems. Joint phasing is planned, phases are balanced, and from a top downwards activities are balanced within respective phases.

3.3 How to manage work order, dependencies, and overlapping?

A technical sequence of activities is herein retrieved from a product model. No overlapping is needed in the basic section model. A work order can be checked by a project model with a 4D animation. Proper phasing and the assignment of dependencies between them enable to create a list of generic model activities that brings along viability in model based scheduling. All this sequencing of activities can be modeled without involving a temporal dimension (too early).

3.4 How to dimension activities or to calculate their durations?

The top-down dimensioning of activities proceeds as follows. A total duration of a project is divided between phases and each of phase durations are divided further between activities. A duration of each activity is calculated by a phase specific duration model or rule. A process model produces dimensioning rules for activities. As Kanoglu [20] states, duration estimating models should take into consideration construction phase parameters (i.e. labor productivity, weather conditions) and design phase characteristics (i.e. a number of floors, constructability) for more accurate estimation in design phases. The advanced determination of the durations of activities is herein based on a dynamic integration (interfaces) between resource models and duration models. The durations of phases are calculated by phase specific duration models. A schematic idea of dimensioning activities by using resource and duration models is given in Figure 3.

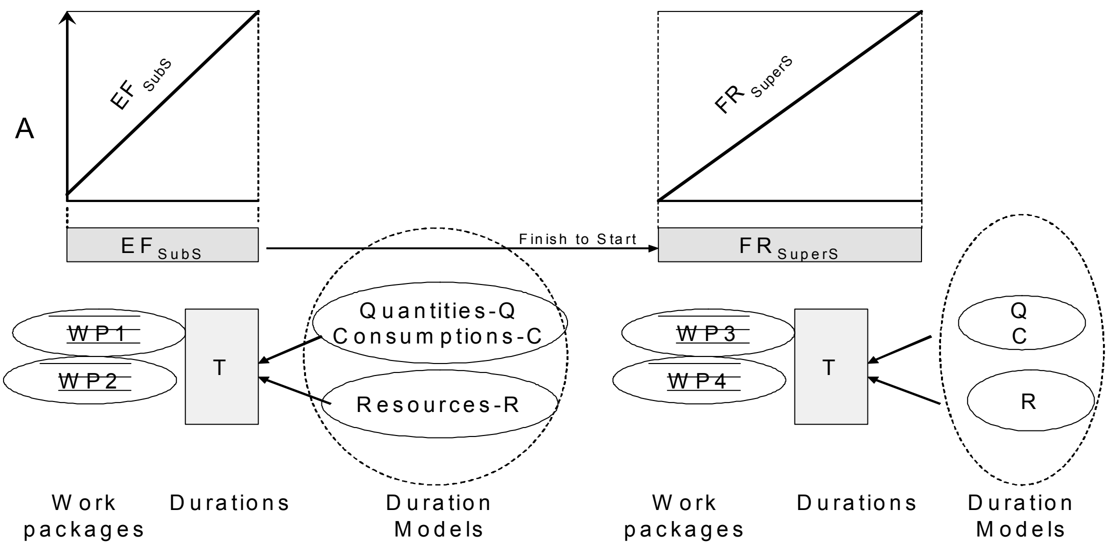

Figure 3. *Dimensioning of activities and the assignment of dependencies in a section.*

3.5 How to integrate a product model and a resource model with a process model to get enough data?

This problem is an integration problem between a product model, a resource model, and a process model. The effective management of information models, data transfer, and communications between models are the prerequisites of a viable solution to this problem. Herein, the ideas of the development of model based production planning is integrated and exploited as part of the integrated Building Construction Information Model (BCIM). The BCIM serves as a **library based information system** to manage construction phases in building projects. For planning a master and other schedules, all necessary information is retrieved from the cost and resource model as well as the product model. In turn, **the targeted novel outcomes** of a building construction process model (BCPM) are semi-automated schedules. In Figure 4, the BCIM and its three sub-models are structured. A rationale behind the BCIM is that all generic model data is stored, updated, and reused via the evolving libraries of a building contractor and its network of designers, sub-contractors, and suppliers.

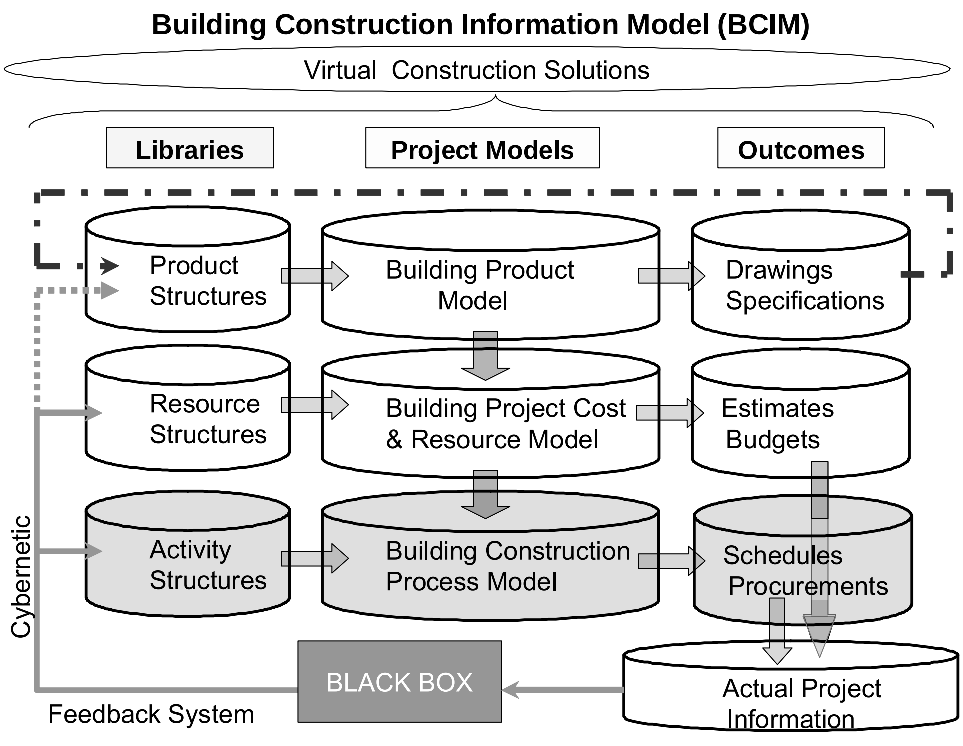

Figure 4. *Building construction information model (BCIM) with its three sub-models and a feedback system.*

The three sub-models of the BCIM are briefly defined as follows: (i) A building product model targets a finished building as design objects, building elements, and their receipts of building products, activity information and technical dependencies (ii) A building project resource and cost model targets a building project as resource objects, the amounts of building products retrieved from a building product model and their installation resource receipts with current prices. (iii) A building construction process model targets a building project as activity objects, i.e. tasks that are coupled with resources retrieved from a resource and cost model and rules for duration calculation by resources [21].

3.6 How to take into account project specific conditions?

This is a problem that is resulting from a gap between project planners and models, i.e. **a planner-model interactivity problem**. A solution to this problem is not to be found from within models only. A viable solution is obtained by using planners and resource groups interactively. Hence, viable for-human-use-models should be developed as modifiable vis-à-vis when decisions are being (re)made according to evolving project specific information such as outside dates, weather conditions (winter), supply dates, etc. A viable model ought to be adaptable during the interaction with planners. Software should be equipped with tools to stretch, squeeze, and modify project activities by using, for example, buffers or the changing amounts of resources.

3.7 How to calibrate and to update models to correspond to real, changing building world?

This is **a usability problem** of the BCIM or any information model which is used to enable PM/CM and scheduling processes. Only a few of existing information models are applicable to practical uses in project based industries. Herein, **the cybernetic modeling principles** of Stafford Beer [22] are being adopted in order to solve the usability problem in model based systems. In Figure 4, the BCIM is readily designed as a calibrating and updating planning system. In the product model, an orthodox feedback system is used. New accepted design solutions with the product structures of building elements are being moved to a library. A ratio between a model and actual information is used to update the resource and process libraries. The cybernetic modeling principles, e.g. an ‘ameba effect’ (Beer 1966), is then followed as an updating mechanism.

Project specific information, gathered from a ‘real building world’, is processed in a black box which feeds information back in the libraries of the resource and activity models. **A black box** is needed to ensure feedback in model based systems especially if one is modeling a complex system such as a construction process. In complex systems, modeled results and actual data together update the models and adapt them to a real, changing building world.

4. Conclusions

The development and leveraging of **new expert knowledge** plays a critical role within a new trend in scheduling, i.e. viable model based scheduling in all contexts of managing projects effectively. The literature review revealed that there are some theoretically advanced stand-alone models that, however, are not highly applicable. Instead, most practicing PM/CM planners and schedulers are exploiting existing commercial software that has been designed with the bottom-up logic.

(i) It is herein posited that both researchers and commercial software developers need to recognize **the fundamental problems in model based scheduling,** to understand alternative solutions for such problems, and to solve them, too, in viable ways. In turn, it is proposed that the integrated use of product, resource, cost, and process models creates a dynamic platform and provides proper data for solving the seven recognized problems. At the same time, it is admitted that such integrated models will bring along some new problems that are fundamental to this next wave of modeling as well as model based PM/CM and scheduling.

(ii) It is suggested that **the BCIM** be a dynamic information provider and **the ALoB** be an effective method for enabling model based scheduling and understanding the modeling of building projects. Proper sectioning addresses a project size variety and joint phasing tackles an activity scope variety. A top-down principle is a novel rationale in the suggested scheduling system, i.e. breakdowns are planned from a total project level downwards, and not bottom-up like in conventional scheduling systems. Phases are balanced together and activities are balanced within respective phases. The technical sequences of activities are retrieved from a product model and activity durations are retrieved from resource models by using dimensioning rules. Interactive planner-system solutions ensure the adaptability and updating of models. Feedback systems follow the cybernetic modeling principles. Overall, the suggested system results in the transfer, storing, and exploitation of actual project knowledge for viable scheduling and PM/CM as a whole.

(iii) It seems that there is, however, space for **developing the ALoB and similar methods further.** Namely, **the ideal location based scheduling of projects** can be characterized and perhaps oversimplified, by applying Kenley [23] as follows: (a) multiple locations or more accurate multiple work places, (b) the continuous on-site assembly of components (including pre-fabricated work), (c) a complex assembly involving repetitive but variable activities (work is repeated in locations with a quantity variety and a context variety), (d) equally parallel and sequential paths, (e) balanced resource management is a flow optimization problem. Nevertheless, it is herein argued that the current ALoB methods are effective enough (despite their particular problems) so that their use and development could be escalated across the borders of national building sectors in the future.

(iv) As expected, the literature review also revealed that **linear production planning** has been advanced significantly outside construction such as in **manufacturing industries** [24] and in particular in **the air vehicles industry** [25]. It is anticipated that the applications of such advanced planning solutions will offer faster tracks for the development of model based scheduling also through the sectors of construction in the future.

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