MODEL BASED SCHEDULING IN BUILDING PROJECTS – IS IT OXYMORON?

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ABSTRACT: In building, most projects are still planned and scheduled based on the randomly accumulated, contextual experience among planners and managers. The key inputs for scheduling tasks, i.e. the dependencies, man-hours, and durations of activities may have never been organized well in the focal planner's mind. The aim of the paper is to introduce some new viable ways of modeling scheduling activities in the context of building based on the integration of a product model, a process model, and complementary IT solutions. The integrative rationale of the new Building Construction Information Model (BCIM) is herein justified in terms of combining the building product model, the building construction resource and cost model, and the building construction process model. Some new feasible ways of automating building project planning are explored, in particular in terms of using template schedules to automate scheduling activities as part of the advancement and exploitation of the suggested BCIM.

KEYWORDS: building projects, information technology, modeling, process models, product models, scheduling.

1 INTRODUCTION

In building, most projects are still planned and scheduled based on contextual experience even if 4D modeling techniques are being adopted more and more across the globe. So project plans are seldom optimal due to the dependence on planners' randomly accumulated experience. The key inputs for scheduling tasks, i.e. the dependencies, man-hours, and durations of activities may never have been organized well in the focal planner's mind. Thus, it is posited herein that the integrated, seamless use of product, resource, and process models can be a decisive way of gaining major advancements in building project management. Combined product and process modeling is a useful way of increasing the effectiveness and efficiency of building management, design, and construction tasks. In the early 2000s, both academia and industry are investigating the plausible ways of applying process models to both the construction of new buildings and the renovation of the existing building stocks with the help of evolving information solutions and systems.

In part, modeling processes will be automated with a model where the key inputs, e.g. resources and site conditions for a given project are pre-assumed. "Model based" in this context refers to a process of a creating a schedule from descriptive information. A user builds a model by specifying some information and using/modifying a template schedule.

The combined use of process and product modeling in building production management, planning, and control is the subject of the primary author's doctoral study. As a whole, this study aims at designing an integrative model where scheduling will be based on rational planning rules, besides each planner's experience. The study will be validated by testing the initial model with the help of some case studies.

The aim of the paper is to introduce some new viable ways of modeling scheduling activities in the context of building based on the integration of a product model, a process model, and complementary IT solutions. The paper consists of two parts: (1) to introduce and justify the integrative rationale of the new Building Construction Information Model (BCIM) composed of the building product model, the building construction resource and cost model, and the building construction process model, and (2) to explore some new feasible ways of modeling building project planning, in particular scheduling activities vis-à-vis the advancement and the exploitation of the suggested BCIM. Initially, the outcomes of one modeling exercise are reported upon, i.e. retrieving accumulated individual (tacit) scheduling knowledge from planners' minds and storing this knowledge into specific repositories and/or libraries to enable its reuse through some automated procedures and templates for the making and updating of actual master schedules in real projects. Thus, template schedules are presented as an example for providing actual planners or schedulers with generic or semi-contextual scheduling knowledge in order to improve the schedule preparation process and, at the end of the day, to have a complete BCIM solution.

2 LITERATURE REVIEW

The generic theoretical basis for construction project planning and scheduling is briefly addressed. Thereafter, some primary process flow oriented construction scheduling methods are reviewed. In particular, the Advanced Line of Balance (ALoB) method is introduced as one of the feasible ways of managing overlapping in the case of repetitive activities and/or many locations.

2.1 *Basis of current methods and tools*

Planning is concerned with setting objectives and deciding on the means of achieving them. It forms a basis for control and steering, i.e. the measurement of the performance via various parameters (Alsakini et al. 2004). Planning within PM relates to a process of quantifying both time and cost (Kumar 2005). According to Clough and Sears (2000), the planning and control of construction activities include the selection of construction methods, the definition of tasks, the estimation and assigning of required resources, and the identification and coordination of any interaction among tasks and the use of common resources.

Scheduling is the determination of the timing of the project operations and their assembly into the overall completion time (Antill and Woodhead 1990). Schedules are needed for improving a probability to manage a project on time, on budget, and without disputes (Callahan 1992). Scheduling is one of the enablers for achieving more effective production, better quality, and reduced construction times (Koski 1995). Therefore, new scheduling systems must enable the hierarchical planning and the handling of large information flows quickly and effectively. The most importantly, planning should be proficient of integration. All scheduling is based on activities and/or locations for same or differing purposes with many methods and techniques. Common scheduling methods involve bar charts, linear programmes, network analyses, and the lines of balance. For network analyses, the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) are frequently relied upon. CPM tools (e.g. Primavera Project Planner and Microsoft Project) are dominating construction planning in both thought and execution (Kenley 2004). The third method available for projects with long duration activities is the linear scheduling method (LSM), also called the vertical production method (VPM) in the case of high rise buildings (Callahan 1992). The work of Harmelink and Rowings (1998) and Harris and Ioannou (1998), i.e. repetitive scheduling method (RSM) determined the critical activities of linear schedules.

Huang and Sun (2006) have exposed the features of many linear or repetitive scheduling methods. Yamin and Harmelink (2001), Arditi et al. (2002), and Tokdemir et al. (2006) have compared and dealt with the various aspects of scheduling also repetitive operations in construction. In turn, many software vendors, e.g. Graphisoft have started to develop new solutions even for combined used of various planning methods.

2.2 *Process flow oriented scheduling methods*

A typical repetitive scheduling method is the Line-of-Balance (LoB), also known as “flowline” (Kenley 2004). The LoB is a graphical and visual scheduling technique to plan and manage continuous flow of work together with location (Seppänen and Aalto 2005). The definition of spatial subdivisions, defined as the Location-Breakdown Structure (LBS), is a backbone of LoB diagrams. LBSs and related quantities go hand in hand with the definition of the Work Breakdown Structure (WBS) for a project (Jongeling 2006). So far, the LoB has not penetrated the construction globe. However, the location based scheduling is supporting the link between work planning and lean thinking since it enables continuous work flows with balanced resource uses. On the one hand, both the “FLOW” concept and the LoB aim at achieving the same goal, i.e. planning for continuous resource use and, thus, minimizing waiting time and avoiding waste. Jongeling (2006) combines the work flow and location based scheduling. The satisfactory results in managing work flows have been gained by combining the 4D models and the LoB into a process model. On the other hand, Kenley (2004) points out to the problem of identifying work flows in a production system based around discrete activities as part of activity-based critical path management. He argues that the usefulness of the Last Planner method by Ballard (2000) is limited to activity based applications.

In the case of Finland, the LoB has been used as the principal scheduling tool since the 1980s (Kiiras 1989). For a general contractor, the advantages of the LoB scheduling include less schedule risk because subcontractors can be kept on a continuous basis on site, productivity benefits because crews are less likely to interfere with each other, and more realistic schedules when buffers can be easily planned and analyzed. More recent results and the features of the developed software, i.e. DynaProject™ (lately Graphisoft Control) are reported on in Kankainen and Seppänen (2003).

In particular, the Advanced Line-of-Balance (ALoB) enables to manage large and small projects as well as to control overlapping and/or many locations. The ALoB allows *the segmentation,* i.e. to divide a project further into working spaces. In each location, activities are completed entirely. In a working space, only one critical activity can take place at a time, it is setting the pace, and all activities are scheduled to continue from one location to another without any interruptions. Through the segmentation and LBSs, all dependencies can be planned on a finish-to-start (FS) basis. The time between activity lines (buffer) is shown on the x axis and the location where the activity is taking place is shown on the y axis (Figure 1).

The slope of a line gives a production rate. In Finland, a common productivity database has been established among construction companies (Olenius et al. 2000). In Figure 1, an example of “flow-line view” of a sample of the location based schedule is given with the location breakdown as an example of the balanced, synchronized workflow, and a non-continuous workflow as an example of one of the most common deviations.

In the ALoB, the second step is *the joint phasing* of the activities that are dependent from each other. In Figure 2, the dependencies between the phases of a typical housing project schedule are given. The interior works are divided into the space division phase and the interior phase. The former is started after the completion of the structure work. The remaining interior phase waits for the roof work to be completed. For example, dependency levels for earth, foundation, and structure works are at the segment level of the project in hierarchical leveling. Interior phase dependencies use smaller locations from the project hierarchy level. The place hierarchy is project specific: different principles can be applied to different projects.

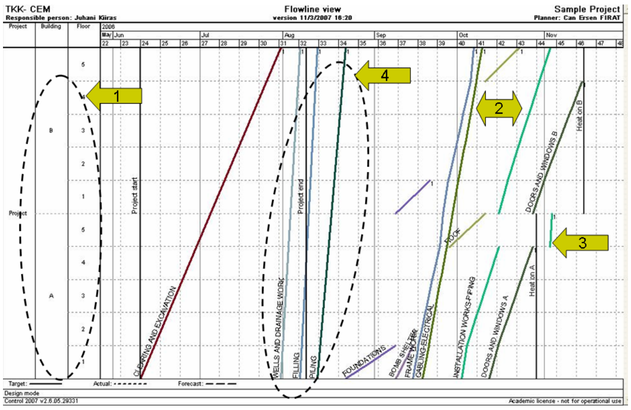

Figure 1. Flow-line view as a sample ALoB: (1) Segmentation of LBS and hierarchy levels, (2) an example of scheduled building service installation work, (3) an example of a deviation, a non-continuous workflow, and (4) an example of balanced workflow.

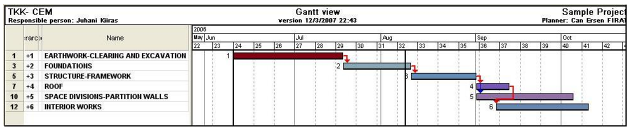

Figure 2: Phasing of a housing project schedule in terms of dependencies between six phases

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 have similar paces, ensure similar production rates within activities, i.e. as parallel lines in a diagram that show a constant time-space buffer between different tasks. Work packages are synchronized by changing their contents or workgroups. Sub-activities are not synchronized at the master schedule level. Instead, a work order is assigned to each of them. Thus, elastic time-space scheduling fulfills the demands of production control, i.e. (i) scheduling is based on spaces and (ii) activities are located to prevent interferences. Phases have different inner structures and calculations of duration. The durations of phases are calculated by phase specific duration models. Thereafter, individual schedule tasks are balanced. Proper phasing and assigning dependencies between them enable forming generic model activities list that opens the way to model based scheduling. The last step involves *the balanced phasing of building systems installations*, i.e. adding and synchronizing electrical and mechanical installation activities to the schedule. In Figure 1, an example of the planning of the building systems is shown as part of the master schedule.

3 NEW INTEGRATED MODEL

As information technology evolves, virtual solutions for managing construction processes such as product models and/or building information models become more and more effective (Björk 1995). Both researchers and software vendors have attempted to develop library-based modeling. A construction system may be unique. However, the operating processes of its component resources are usually somewhat generic. They can be predefined as the atomistic models or the basic and unique descriptions of particular processes and be stored in a model library (Shi and AbouRizk 1997).

Herein, the new Building Construction Information Model (BCIM) is suggested. It is composed of three sub-models: the building product model (BPM), the building construction resource and cost model (BCRCM), and the building construction process model (BCPM). The BCIM exploits library based modeling. The emphasis is on the storing of relevant reusable information in the three kinds of the libraries as part of the sub-models. The basic idea is the integration of the sub-models corresponding to the management of the sub-phases of a construction process. Phase by phase, each sub-model is pulling necessary information which is stored in its sub-library, processes the relevant information, and produces the targeted outcomes or building-related documents, respectively. It is posited that the BCIM serves as a dynamic platform where information is created and transferred to each of sub-phases on a just-on-time-and-task basis. The two sub-models, the BPM and the BCRCM include the main information pools that provide the data for each of processes, activities, and tasks (e.g. project scheduling).

In Figure 3, the integration of three sub-models of the BCIM is shown. The design of each sub-model is based on the following principles. A building product model targets the finished building as a set of interdependent design objects, i.e. spaces (space model), building elements, and product structures or receipts (building products or construction materials), at minimum. A building construction resource and cost model targets the building project as a set of interdependent resource objects, i.e. the amounts of building products (retrieved from the building product model) and the resource structures or receipts, with current prices, planned to be exploited for the manufacturing and installation of these building products. Resource and cost models are needed to rationalize the resource consumption and reuse as well as to trigger ‘productivity jumps’ in the near future. A building construction process model targets the building project as a set of interdependent activity objects, i.e. the frequencies of project activities or tasks that are coupled with their resource structures (retrieved from the building construction resource and cost model) and resource-use-based durations. The generic building project activities, their planning rules, and interdependencies are stored, updated, and reused via the activity structure library (Firat et al. 2006).

Across national building industries in the OECD countries, it can be roughly summarized that the three sub-models of the BCIM have been adopted only partially, and differently by each industry. The BPM is adopted well and has been used widely. The use of the BCRCM is increasing, i.e. more and more companies are building their resource libraries and resource and cost models. In turn, the BCPM is least developed and exploited. Thus, the focus is herein on this third model (BCPM). In general, process models list down interconnected management tasks that need to be executed for fulfilling the management objectives and functions (Shi and Halpin 2003). The BCPM incorporates three features of enabling (i) the automatic calculation of task durations based on the coupled, known use of resources, (ii) sensitivity to flexibility under changes and (iii) communication for effective integration.

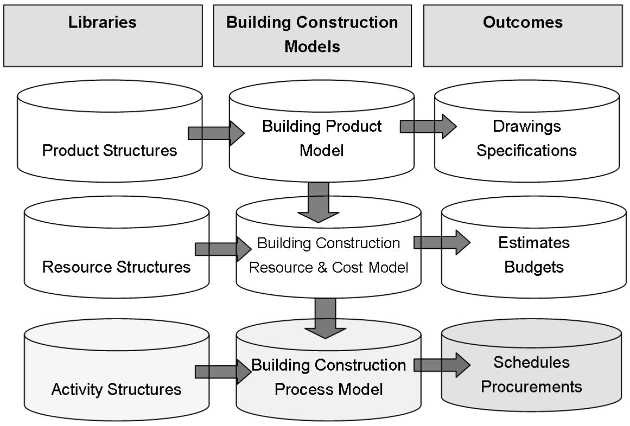

Figure 3. Integration of three sub-models to Building Construction Information Model (BCIM).

4 MODEL BASED SCHEDULING

Many parts of production planning contain today manual processes, which cause slowness, demand more resources, and make control much harder (Koski 1995). In building, the latest 4D systems have been adopted well, but they are still based on normal scheduling by experience. In the case of building construction projects, interdependencies among scheduling tasks as well as between tasks and assigned crews are similar. Therefore, many parts of manual planning processes could be performed automatically. Herein, the idea is to elaborate how model based, i.e. automatic data processing can be adopted and used as part of production and resource planning as well as how the model based production planning could be developed further. For example, the ALoB can be integrated and exploited as part of the BCIM. The segmentation function of the ALoB enables the controlling of various building construction projects. It is well-known that many pioneering software packages have had many limitations vis-à-vis the use of such template schedules.

The selected example, Graphisoft Control (GS Control) is a location and resources-based management system that has been specifically designed for the construction industry (Graphisoft 2007). The idea of GS Control and template schedules can be used to test the idea of model based scheduling. The model based scheduling features of Graphisoft Control version 2007 are applied and exposed in terms of (i) creating a template schedule and (ii) using this template schedule for making actual schedules for real building construction projects (Figure 4).

4.1 *Creating a template schedule*

The main difference between the creation of a template schedule and an actual schedule is that a template schedule does not need all the information that is required for actual schedules such as quantities and/or costs. Schedule tasks, dependencies, resources (i.e. crews), and risks can be retrieved from template schedules for the use in a real project (Appelqvist 2002). However, a template schedule must contain all possible necessary tasks that can exist in any similar project and, thus, allow to eliminate or to include each of them when forming the actual schedule. The steps in the creation of a template schedule are as follows.

Step 1- Defining reference items. The idea is not to define quantities but output items, i.e. which output items should be included into a schedule task, in which they work as references in a template. At the outset, cost and quantities fields are left blank since they will be retrieved from the real project data pool. Herein, a term schedule task is used as a discrete construction operation, with or without dimensioning e.g. a start time, a duration, resources, and a location. Moreover, output items are defined as the results of the earlier processes that took place before scheduling starts such as location based project quantities produced through estimation.

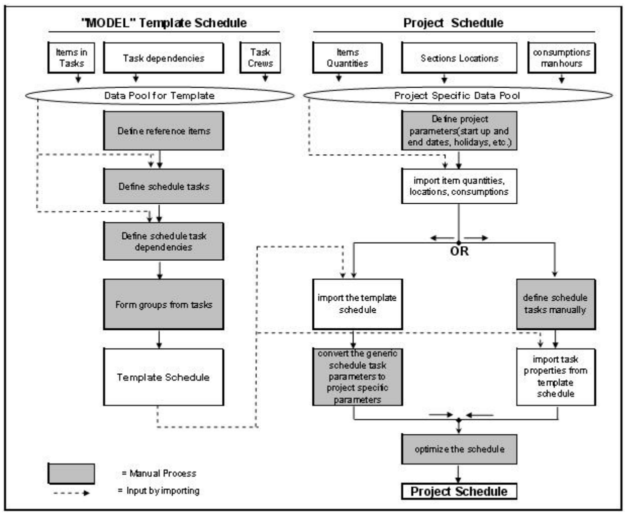

Figure 4. The process model of creating and using a template schedule to make a project-specific schedule (Applying Kiiras and Angervuori 2007).

The definition of reference items is done by selecting button "Add/Edit Quantities" in bill of quantities section (See Appendix 1a). If this value of person hour consumption is set and even a consumption datum is still empty, the consumption value will be automatically retrieved from the template schedule. This is very useful in tasks that are performed by special groups such as subcontractors. The character "*" can be used as a wildcard search character in the code field meaning that every output item from the actual project, having a code beginning with the number before the character "*", will be included later to replace this initial output item. This requires the usage of (inter)national/corporate specific standards in coding in both template and project specific quantities data.

Step 2- Defining schedule tasks. The schedule tasks are defined in a template only at the general level excluding the project specific tasks such the ones in weekly plans.

Differences in the precision of the tasks have to be taken into consideration as well. For example, a framework phase is harder to breakdown into general tasks than an interior work phase.

Step 3- Dependencies between schedule tasks. The dependencies are defined using, for example, the task editing view noting that not every template schedule task, e.g. piling, will be found from the real schedule. Hence, it is advised to link dependencies to such tasks that are expected to exist in every similar project such as a framework and partition walls. Hierarchy levels are determined by filling the level of precision field in the window (Appendix 1b). There are no standardized hierarchy levels (real projects have different meanings for hierarchy levels). There is a risk that dependency levels will be incorrect in the created schedule, since GS Control 2007 matches only the hierarchy levels between the template and the project data.

Step 4- Grouping schedule tasks: Due to a high number of schedule tasks, the fine tuning of the output is needed (to avoid users sticking to the old habit of creating schedules manually). One way to do this is to group, by using summary tasks, similar schedule tasks such as all partition wall tasks into one group. The upper grouping including the formerly combined tasks is also used actively, since the idea is to make the output more readable for adjustments. Summary tasks are set to correct construction phases. This enables to produce more detailed schedules via selecting construction phase views and opening up summary tasks. Summary tasks are needed to avoid the unnecessary bulk of information and messy flowlines. After exporting the template schedule to the project data as default, only the top level summary tasks are shown in the Flowline and Gantt chart views.

4.2 *Using a template schedule*

For the use of template schedules, only generic schedule tasks and parameters are first imported and project specific details are still left to planners adjusting the actual schedule. The steps in making an actual schedule for a building construction project are as follows.

Step 1- Setting up a new project. The start up and end states and the calendar for the construction period are planned and set. After importing item quantities for project locations and person hour consumptions, a double check is carried out.

Step 2- Importing schedule tasks. “Project>importing” is selected from a template file ”>tasks.” After selecting the required data, values are imported from the template schedule. Alternatively, the tasks can be defined manually one by one and only the properties for single tasks can be imported from the template schedule as shown in Figure 4.

Step 3- Converting parameters from generic to project specific. All the tasks that contain the correct items and the consumptions are checked. Items that are not included in any schedule tasks are shown in the bill of quantities section as a free quantities line with no items. These tasks should be cleared, i.e. filtered from the task list. The natural, condition, technical, and resource dependencies in the template schedule have to be manually modified because they vary among real projects (Koski 1995). Without standardized hierarchies, the precision levels of the dependencies are inaccurate and needed to be set manually.

Step 4- Optimizing the schedule. The adjustment of the construction time is completely left to a planner, since only tasks and dependencies are imported. (i) Segmentation is done in early phases, i.e. quantity surveying phases. Work orders for such segments are defined by adjusting the location display order in the flowline view. (ii) Also resources assigned for the tasks that affect the total duration of the project are optimized. The template schedule contains only the default crews for the schedule tasks. Thus, the number of the crews is adjusted to fit the required limits. If the work crew is the constraint in the same location, this task is subdivided into different locations. (iii) Resources are balanced as well. When many tasks have the same start-up date due to the similar dependencies for the preceding task in the template, they cause a peak in the resource graph. This is solved by changing the start up dates or the task dependencies. It is also in planners’ control that the demands of the resources are met with the available resources.

4.3 *Future advancement*

In practice, regular project schedules are used as template schedules for making an actual schedule when there are several very similar projects. With GS Control, schedule tasks are planned for real projects by using the information retrieved from the template schedule. Despite the automation control features (e.g. default tasks) of the management systems used, all the project specific optimization has to be done manually by the scheduler. Hence, the idea of using a template as a process model is to automate the similar and/or repetitive tasks of real schedules of building construction projects. The benefits include easier and faster scheduling processes and the higher quality of schedules due to the use of the correct schedule tasks, dependencies, crews, etc.

In addition, template schedules are being exploited in the guiding and training of schedulers, under some key conditions. (i) Because template schedules hide the tedious and time consuming but teaching pre-work of schedules, the properties of created tasks need to be checked. Otherwise, mistakes are even harder to fix. (ii) The quantity data used for creating project schedules must contain the codes for each output item. The quantity data is assigned to correct project sections by using the standardized project hierarchies i.e. location based quantities. In principle, the use of information tools through construction project life cycle phases increases design and estimation loads but at the same time improves the accuracy of construction phase management and, thus, avoid or at least decreases the costs of changes in later phases.

In turn, Kiiras and Angervuori (2007) tested the idea of using a template schedule for the development of a real schedule in the case of the residential project (AS Oy Espoon Hassel) and observed that template schedules can be used for the first step to model-based scheduling within some remaining limits. It seems that more effective optimization, the true interaction between a model and a planner, is the key for the further advancement and, thus, optimization is also one of the vital area for future R&D efforts.

Further development work is needed to automate the dimensioning, i.e. to determine the durations of project tasks. For users, the visual outcomes of the template schedules should be improved as well. Now, dependency graphs may appear too cluttered due to the assignment of dependencies to all schedule tasks in the eyes of potential users. Currently, actual project schedules derived from template schedules are so complicated and it is so hard to pull information that one may find traditional fully manual scheduling process more attractive and easier.

5 CONCLUSION

Overall, its is herein posited that the integrated, seamless use of product, resource-cost, and process models is the decisive way of gaining major advances in building construction management in the future. Today, interaction between sub-models is not solved in an adequate manner in the existing models and their applications. Thus, the suggested BCIM and similar process models need to be developed further and completed to serve as platforms where all sub-models interact with each other, integrate, and communicate to fulfill correctly the information needs as part of the advanced future management of building construction projects.

The main idea of the BCIM is that necessary information for any phases such as the exemplified scheduling is pulled from the appropriate sub-models. The minimization of the routine scheduling work opens up new time windows for planners to utilize their accumulated knowledge better even in tight situations. It seems that the adoption of template schedules is the first progressive step in model based scheduling in order to make master schedules easily and more effectively. Namely, template schedules can now be used as a process model to automate the similar and/or repetitive tasks of real project specific schedules. In turn, the primary author's ongoing study aims at enabling project planners to build much faster more accurate draft schedules. Some proto templates will be tested in the selected case projects in the near future.

Finally, the conditions for successful interaction between sub-models need to be investigated and understood fully in the case of each activity and process, phase by phase, in the near future. In the area of scheduling, the estimation of the durations of schedule tasks is the vital topic for further research. This is where the quantity take-offs, which strongly take advantage of building product model data, become a true part of the modeling game.

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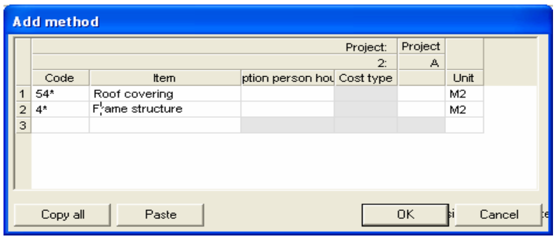
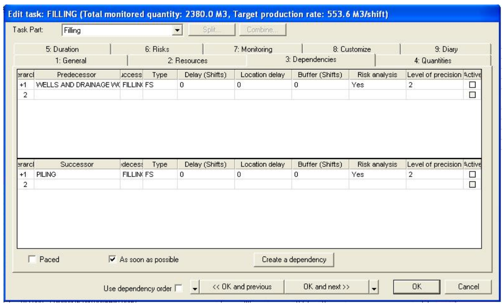
APPENDIX



Adding items for a template schedule



Creating a schedule task window