A PROCESS MODEL FOR CONSTRUCTION SYNCHRONISATION USING TIME-SPACE PLANNING METHODS AND FIELD FORCE AUTOMATION

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ABSTRACT

This paper explores a proposed process model for construction synchronisation. The aim of the paper is to show the potential of working according to the Last Planner System of production and control by combining time-space planning methods and Field Force Automation. In addition, the paper aims to show the benefits of working with real time support regarding taking control actions in the schedule and to collect data for follow-up analysis. The paper first provides a background of the research and a description of the various methods and tools used in the process model. A process model is proposed based on the last planner and control system for the implementation of a new ICT tool with the purpose to enhance, planning and control in order to enhance construction synchronisation. It is concluded that site managers needs tools to change their view of planning from static view of the schedule which can be revised once or twice per project to the view that the schedule is a total dynamic instrument to be used to develop prognosis and measure for avoiding waste and delays in the realisation phase of the construction project. The paper is concluded with suggestions for how the method can be further developed and improved.

KEYWORDS

Construction synchronisation, Last Planner, 4D modelling, location based scheduling, field force automation

1. INTRODUCTION

During latest time the construction industry, in comparison with other industries, has been fighting with profitability problems. This has resulted in higher demands on lower production costs, shorter production-times, faultless buildings and longer guarantee periods. To meet these requirements the demand for just-in-time deliveries, supplier output and precision of deliveries has been higher, both concerning materials, equipment and subcontractors. Several studies indicate that both the level of material waste and thieving at construction sites are high. The materials are damaged or the quality is reduced because of bad handling. This has lead to poor quality of the finished building. Studies also indicate low productivity. A Swedish study of non-value adding work at the construction site indicated that the low productivity follows as a consequence that only 15-20% of a construction worker’s time is spent on direct work. Approximately 45% is spent on indirect work (preparations, instructions, getting material, etc.). The remaining 35% is spent on redoing errors, waiting, disruptions, etc., i.e. room for improvements, (Josephson & Saukkoriipi 2005).

In the light of these facts, the interest of industrialized construction has been grown during the last years. Industrialized construction can be interpreted differently depending on who is talking about it. Some refer to the car industry and mean that houses should be built like cars, i.e. make use of the effect of repetitiveness and a high degree of prefabrication, supported by an advanced ICT-system. Others interpret industrial construction as an efficient and well planned traditional construction process but with less trades and decisions on site, (Apleberger et al 2007). From studies regarding production philosophies and concepts, like the Toyota Production System (TPS), Supply Chain Management (SCM), Just-In- Time (JIT), following subjects are taken to as aspects of industrial construction (Lessing 2006):

1. Planning and control of the processes
2. Developed technical systems
3. Off-site manufacture of building parts

4. Long-term relations between participants
5. Logistics integrated in the construction process
6. Customer focus
7. Use of information and communication technologies
8. Systematic performance measurement and re-use of experience

Using today's advanced information technology it would be possible to create an ICT-tool system to manage the most of the subjects mentioned above. Further, these tools must be arranged in a process model to suit the end user. This research is made to evaluate if improvements can be made in planning and management of construction projects using such a system, i.e. if production managers are able to plan and manage their construction project with better results and less time spent. In long term this will lead to less waste on site, which results in lower production costs, which in turn will lead to lower house prices.

2. OBJECTIVES

The objectives of the paper is to find a suitable process to support and synchronize the flow of information, materials, labours and needed resources on the construction site. It is also assumed that needed information from the design can be extracted from a building information model

3. THEORY

According to Koskela (1999) the preconditions to complete a construction task is dependent on seven resource flows, construction design, components and materials, workers, equipment, space, connecting work and external conditions, each of these has to be planned and controlled.

According to Bazjanac (2004), the construction industry has been using specific CAD software for more than 20 years. Today, the industry is in the process of utilising CAD information in downstream applications to model the performance relevant to the building's life cycle. The problem is that unless the applications belong to an integrated suite of software tools, these applications are often not able to exchange or share data. This results in duplication of data causing information errors in downstream activities, (Jongeling 2006). Vendors have developed their own propriety data models but these are just designed to support the work of data exchange within a particular vendor's suit of tools.

Creating 4D models is to link 3D CAD objects with scheduling activities regarding procurement and construction. The result allows project stakeholders to view the planned construction over time on a screen and to review the planned or actual status of a project. In construction projects, site managers run mental 4D models in their heads to think about the best construction sequence of the project. General contractors can use 4D models to coordinate the workflow of their subcontractors and site logistics over time. There are also examples of using 4D models communicate the scope and schedule of the project to subcontractors to solicit their input in a timely manner. Is has been shown that 4D models can reduce the time for communicating the schedule to subcontractors while increasing the amount of subcontractor feedback. 4D models can be used live during subcontractor coordination meetings to review the sequence of work and related logistics and thereby prevent time-space conflicts between general contractors and subcontractors, (Fischer and Kunz 2004).

One of the most effective ways to increase productivity in construction is to plan more efficiently, improving production by reducing delays, getting the work done in the best constructability sequence, matching manpower to available work and coordinating multiple interdependent activities, (Ballard 1994). Ballard (1994) also states a number of obstacles that must be overcome to improve planning: 1) Management focus is on control. 2) Planning is understood in terms of the skills and talent of planners instead of seeing it as a system. 3) Planning is only understood as scheduling, not a crew level planning. 4) The planning performance is not measured. 5) Deviations from planning are not followed up to identify causes.

Most construction projects create a master schedule at the beginning of the construction phase, extending from beginning to end of the project. Such schedules cannot be detailed too far into the future because of lack of information about actual durations and deliveries. Most construction projects use some form of short term schedules to coordinate and direct the various trades and crews working on the job, lookahead schedules. Usually the lookahead schedule is simply a drop out from the master schedule with a greater level of detail, but no screening of schedules soundness or other criteria. (Ballard 1997)

The Last Planner System of production and control consist of three components: 1) lookahead planning, 2) commitment planning (often in form of weekly work plans) and 3) learning. Activities are dropped from the project master schedule into the lookahead window, typically 6 weeks ahead the planned start of the construction activity. During this period the activities are constantly screened for constraints. The constraints that prevent activities from being a sound assignment are identified and actions are taken to remove those constraints. This is done by adding ‘make ready’ tasks to the activities in the lookahead window. No activity is allowed to retain its scheduled start time unless the planner is confident that all constraints will be removed in time. This assures that problems will be surfaced in an early stage. The primary categories of constraints are directives, prerequisite work and resources. Directives mean guidance about which work should be done. Prerequisite work is work that has to be prepared or done before the assignment can start. Examples include access to material, information and shop drawings. Resources are labour, tools equipment and space. (Ballard & Howell 2003)

Commitment planning is a commitment to what WILL be done, after evaluating SHOULD against CAN based on actual receipt of resources and completion of prerequisites. This strategy imitates one of the rules in the Toyota Production System (TPS). The rule is to stop production rather than send bad quality products down the line. The construction analogue to stopping production is assuring that only quality assignments will be released for production. Commitments to specific activities and tasks are often made weekly. The requirements for a quality assignment are definition, soundness, sequence, size and learning. Definitions means that assignments are specific enough that the right type and amount of materials can be collected, work can be coordinated with other trades, and it is possible to tell at the end of the week if the assignment was completed. An assignment is sound if the answer to questions like: Are materials on hand? Is design complete? Is prerequisite work complete? is yes. The intent is to do whatever can be done to get the work ready before the week in which it is to be done. The sequencing is about selecting assignments in right order according constructability etc. and to identify workable backlogs in case assignments fail. Assignments should be sized to the productive capability of each crew. The assignment should produce work for the next production unit in the size and format required. (Ballard & Howell 1998).

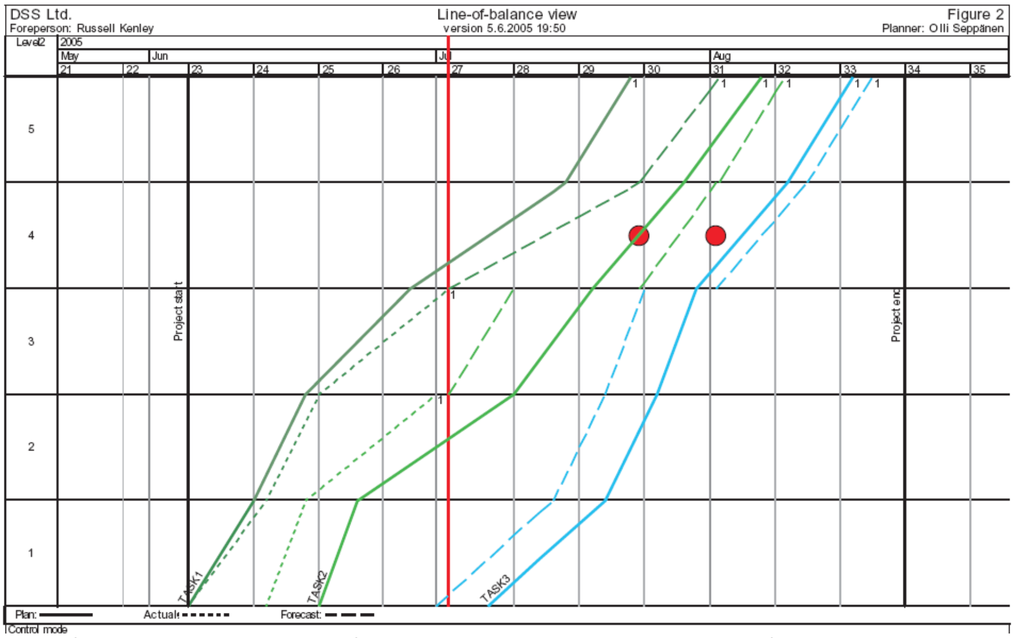
Each week, last week’s weekly work plan is reviewed to determine what commitments were completed. If a commitment has not been kept, the reason is provided. The reasons are analyzed to root causes and actions are taken to prevent repetition, (Ballard & Howell 2003). The quality of the weekly work plan is measured by taking the number of committed assignments completed divided by the total number of committed assignments expressed as percentage. This is called Percent Plan Complete (PPC), (Ballard 1994).

Location based scheduling is a method to provide information about the location of work and work crews. The ability to manage work tasks through locations of a project increase, thereby it is possible to ensure work flow, work reliability, avoidance of interference, improved quality and reduce work. Scheduling the precise location of multiple work crews makes the site management easier. The chart indicates where crews should be on a given moment and if crews are in wrong place it can rapidly be corrected. For site operatives, it is extremely powerful to know the precise location of a work crew. Consider the situation where there is a 50 level building with ten apartments per level. That is 500 locations where you might find a work crew. It certainly provides a lot of opportunities to hide or work out of sequence. With location based scheduling there can be no dispute about where work crews should be physically located, and especially where they should NOT be. This is very useful when managing subcontractors because with location based scheduling this is clearly documented and sequenced. (Kenley 2004)

Seppänen and Kenley (2005) states that location based scheduling are convenient to measure actual productivity versus planned productivity. This is done by recording the start date and finish date, actual quantities and average resources used in each location with the planned values. The location based data gives the ability to measure within tasks unlike PPC that only reveals completion of the different stages. Furthermore, the knowledge of planned, and actual, quantity data, production rates and resources, provides more information than is available with PPC. According to Seppänen and Kenley (2005) experiences on real case studies, the monitoring should be done at least weekly to get accurate enough results. Daily follow-up would give more accurate results but is very difficult to implement using manual systems. The follow-up of location based schedules makes it possible to forecast activities in the future. The forecasts are based on the assumption that the production continues with the same productivity as before. Figure 1 is showing three tasks in five locations where the continuous lines are the planned tasks, the dotted lines are the actual work and the dashed lines are the forecasts. The red vertical line shows the actual date.

Figure 1: Location based schedule displaying planned, actual and forecasted work. (Seppänen & Kenley 2005)

Task one has started when scheduled but has been slower than planned. Using the current productivity the task will have a total delay of approximately one and half week. Task two started almost one week before schedule and has been working a bit faster than planned. If task two continues with same pace it will soon be in conflict with task one and have two wait for task one to be finished before it can continue. Task three has also started about one week before scheduled but have worked with same pace as planned. Because of the delay of task two it will be a delay of at least one week between level three and four. (Seppänen & Kenley 2005) A combination of location based scheduling using model based quantity take-off per location can be used to enhance workflow and the production of 4D models, (Jongeling & Olofsson 2007).



Field Force Automation (FFA) is a generic term for mobile field services applications used for real time support of orders, scheduling, supervising and reporting in the field. A FFA system consists of a number of components to give real time support of dynamic fieldwork operations like scheduling, allocation, dispatch, reports and follow-ups. The generic access is independent of hardware platform and network, i.e. it is possible to connect from mobile phones and hand terminals etc. to the Internet connected terminals. The applications in the system give a lot of opportunities e.g.:

- work orders can be distributed by the planner or received on request from field workers
- field workers can announce accepted, rejected, started, interrupted and finished tasks
- work orders can be reported to the office for inspection, attest and invoice handling
- GPS tracking of the geographic position of workers and work locations
- Statistics for analysis of lead times and utilization of resources

The integration with IT environment of the company results in an efficient workflow. For example, master schedules activities can be decomposed for operation and follow-up in the FFA system on a daily basis. (Olofsson and Emborg 2004)

From the literature survey it can be conclude that there exist a number of model-based tools and methods that can be used to enhance the coordination on the construction site. However, these tools are today not integrated in an overall process that supports the pre-condition for a productive work.

4. PROCESS MODEL

The presented process model, which is based on interviews with project managers, is a proposal of how different systems and software applications can be integrated to manage and control the dynamic of the construction process according to the last planner system of construction and control. Experts in each system and software application have been involved during the creation of the process. The model includes *Building Information Models (BIM), Location Based Scheduling, 4D modelling* and *Field Force Automation (FFA).* The FFA is divided into several phases which will be described below. The process of the proposed system is described in a flow chart in Figure 2.

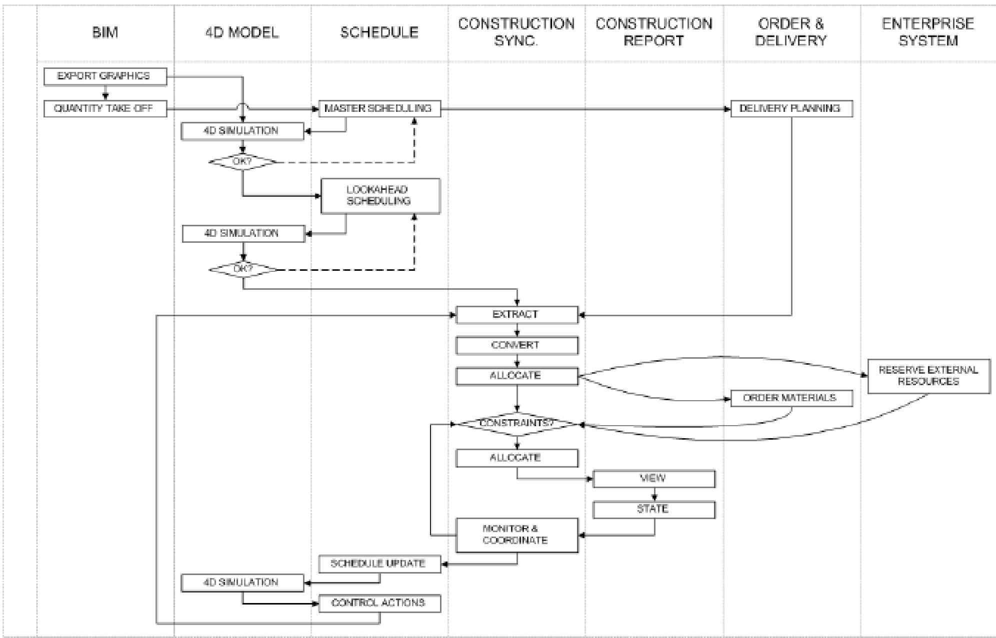


Figure 2: A flow chart for integrating software application in the managing and control of the construction process.

The system need to have access to the order and delivery system and to the enterprise system of the construction company responsible for the project. A model server is used for data storage and exchange with software applications and is accessible via web services. The architecture of the system is based on the theory of the Last Planner System of production and control.

4.1 BUILDING INFORMATION MODELLING

The scope of BIM in this system is to serve the 4D model with graphics and the scheduling with a location based Bill of Quantities (BOQ). The quantity take off can be made directly from the BIM with the help of a plug-in application which has access to company specific database including recipes, see Figure 3.

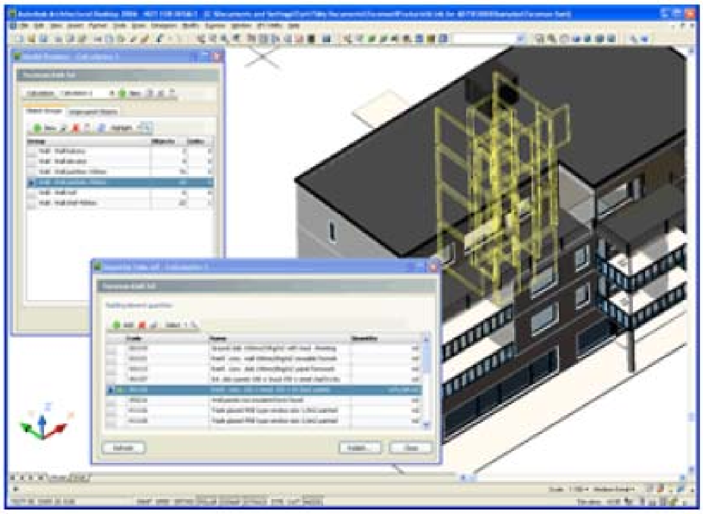


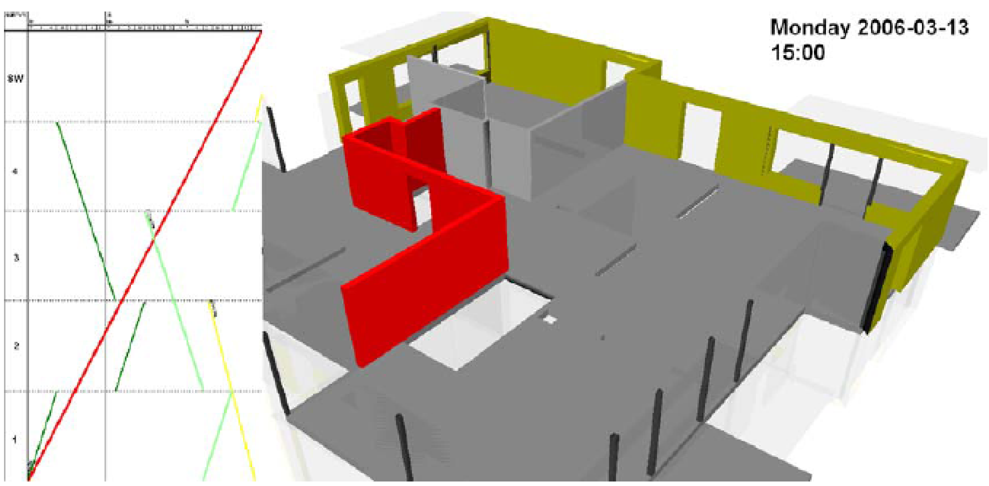
Figure 3: Model based quantity take off. (www.tocoman.se)

The BOQ and recipes are then extracted to the scheduling software. When the BOQ is created the work with purchasing materials can start.

4.2 SCHEDULING AND 4D MODELLING

The scheduling can be made in a traditional activity based scheduling applications, i.e. using the Critical Path Method (CPM) method shown with a Gantt chart. However, we recommend using location based scheduling software to support workflow, but also to link material supply to specific work locations on site. The master schedule, according to LPS, should only consist of main activities. The master schedule can be simulated in a 4D environment to communicate with involved stakeholders in the project which also provides a quality check of the master schedule. Figure 4 is showing a location based schedule simulated in a 4D environment.

Figure 4: A 4D simulation of a location based schedule. (Norberg et al 2006)



Tasks are dropped from the master schedule into the more detailed lookahead schedule, typically 6 weeks ahead the planned start. Actually, the span of the lookahead window decides when a task is detailed in the lookahead schedule. The span of the window is decided by the longest lead times, i.e. procurement, delivery of shop drawings etc., for each task in the master schedule. This schedule can in turn be simulated once again using 4D on a more detailed level.

4.3 FIELD FORCE AUTOMATION

As described in chapter 3 the FFA consists of a number of components. The main components, shown in Figure 5, in the proposed system are *Construction Synchronisation* and *Construction Report* where the *Synchronisation* tool is mainly used by the on-site manager and the *Reporting* tool is used by the construction crews on site.

4.3.1 CONSTRUCTION SYNCHRONISATION

The *Synchronisation* tool consists of several functions, *Extract, Convert, Allocate, Status, View, Monitor & Coordinate* and *Statistics.*

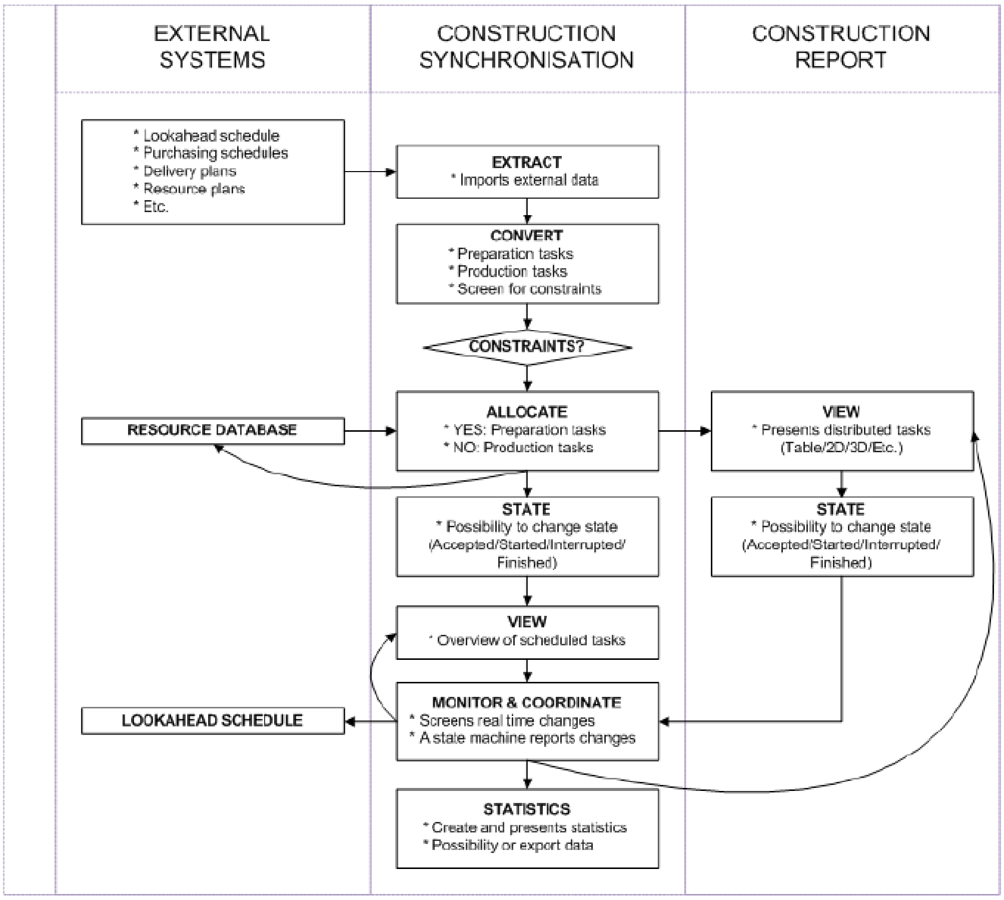


Figure 5: The FFA architecture.

The *Extract* function imports all the data needed to the system, where the most important input comes from the lookahead schedule complemented with data from purchasing schedules, delivery plans and resource plans etc., necessary to manage and control deliveries of resources and material to the site. The more information that are put into the system the less information the site manager have to keep in mind. When all data are extracted into the system each task has information about, scheduled start, earliest start, latest start, duration, demand for competence, prerequisite work and resources, duration for preparation and deadlines for when different specific task must be started and finished.

In the *Convert* phase it is possible to create *Preparation* tasks and *Production* tasks. *Preparation* tasks are tasks which have to be done to make ready a production task. *Production* task are part of a main activity from the lookahead schedule, i.e. a main activity usually consist of several production tasks.

The preparation and productions tasks mentioned are distributed to team or individuals. This is done with the *Allocate* function.

A task has different kind of a state, i.e. allocated, accepted, started, interrupted and finished. These are changed in the *state* function.
The *view* function gives the site manager an overview of the scheduled tasks. This can be presented in different ways depending of how the site manager wants to present the tasks. Figure 6 shows an example of how the interface of view function can look like. Alarms with different kinds of severity are also possible to define to indicate or prevent delays.

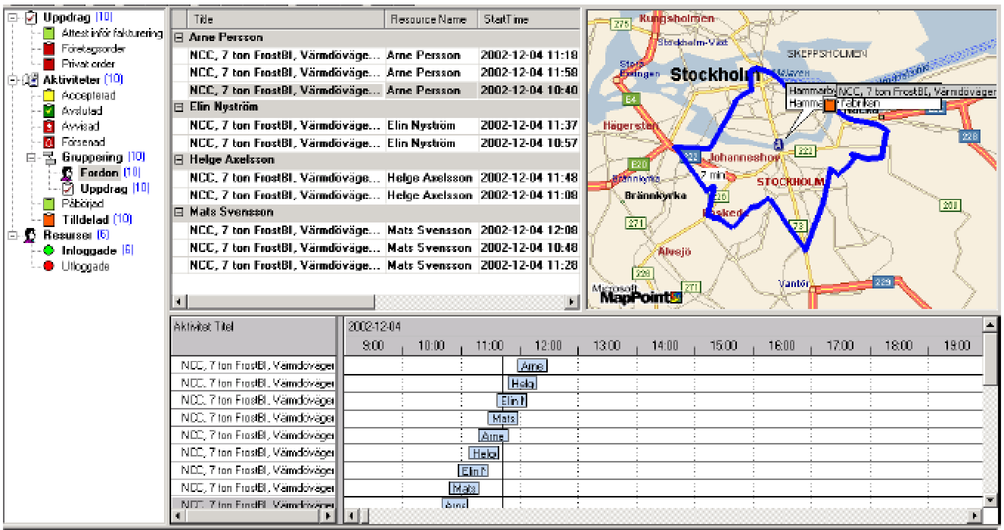


Figure 6: An example of the view function. (Olofsson & Emborg, 2004)

The *Monitor & Coordinate* function is one of the most important functions of the system. This function continuously screens the process for changes and calculates risks caused by delays. Alarms can be defined in different stages, e.g. risk for delay, delayed and critical delay. Coordination between different tasks can also be defined using a state machine defining the relations between different tasks. Signalling between tasks can be setup to be done automatically. For example, if one task is active several recourses are blocked to other tasks. When the active task is reported finished, the resources will be available for other tasks and the following task can be notified of the possibility to start a new production task on a specific location, pulling the next team to start a new production task. This function also reports actual state of a production task back to the lookahead and master schedules.

Monitoring the process enables finished work to be analyzed. This is done in the *statistical* function. This data can be further exported to applications designed for statistical research.

4.3.2 CONSTRUCTION REPORTING

The *Reporting* tool consists of the functions *View* and *Status.* This tool is used on site by the workers on site with use of Smart phones or Pocket PCs.
When tasks are distributed from the site manager to teams or individuals they are shown in the *View* function. In this function it is possible choose how the tasks will be presented, e.g. a table with listed tasks, a 2D view with colour coded tasks, a 3D view with highlighted objects, see Figure 7.

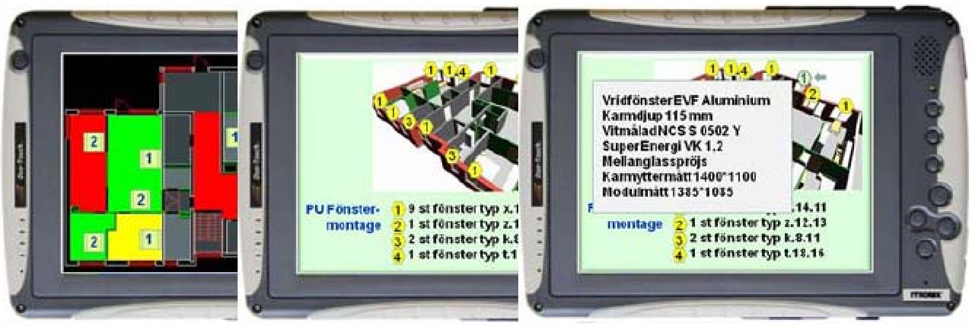


Figure 7: Examples of the interface of the View function.

When selecting a task it is possible to get all information needed to execute that particular task. It is also possible to see where and when other tasks are being performed at the building site.
As in the *Synchronisation* tool the state of each task can be changed between accepted, started, interrupted and finished. This is done in the *State* function, see Figure 8.

Figure 8: Examples of the interface of the State function.

The different states are automatically registered in the *Monitor and Coordinate* function in the *Synchronisation* tool. In case when a task is interrupted the reason can be reported back to the site manager.

4.4 CONNECTION TO OTHER SYSTEMS

The data reported should also be able to be imported by other systems, e.g. to the order and delivery system and the enterprise system for resource and material purchasing normally used at the head office.

5. DISCUSSION AND CONCLUSIONS

The proposed system is defined to support the theory of the Last Planner System of production and control. The connection between the monitor & control function in the construction synchronisation tool and the location based schedule result in a continuously updated schedule that can be communicated in real time. The 4D model complements the planning when communicating the schedule with subcontractors and suppliers. Today, most 4D models visualize the workflow but collected information makes it possible to visualize flow of material within and to the site.

The construction synchronisation tool supports the lookahead planning in the LPS. It is in this phase where sound assignments are created and made ready for execution. The construction reporting tool corresponds to the commitment planning in the LPS. Commitments are made by accepting (WILL in LPS) distributed tasks. The learning phase in LPS corresponds to the monitor & coordination function in combination with the statistical function in the construction synchronisation tool. Theses functions can be setup to automatically measure PPC, production rates etc. Follow-up on construction tasks can be made automatically from reports produced by the FFA system. Otherwise, reporting that requires extra efforts by the construction crews tends not to be performed.

The process model needs further developments and the most important is to get a case study to evaluate the model. It is also important to focus on an open environment so it is possible to choose whatever software you want. Site managers needs tools to change their view of planning from static view of the schedule which can be revised once or twice per project to the view that the schedule is a total dynamic instrument to be used to develop prognosis and measure for avoiding waste and delays in the realisation phase of the construction project. This system enables managing the dynamics on a construction site. Connecting the proposed system to the order and delivery system of the company, enables a better communication between suppliers and the building site which in turn will most probably generate better precision of deliveries. However, the supply chain needs to be able to quickly respond to changes in delivery times to the site.

This type of system also promotes the delegation and distribution of responsibility for the work to the work crews on the site. With a better and more feasible work flow on site the variability and the stress will be reduced leading to better quality and productivity as a result. The follow-up on reasons for failure will also make it possible to benchmark and learn from project to project. It also give more opportunities for the construction company to coordinate use of crews and procurement of material for many for more that one projects running at the same time.

We believe that better linking of the supply chain to the work on-site is a corner stone in transforming the traditional craftsman construction way of working to a more industrialized construction process.

We are currently interviewing site managers to ensure the possibility of implementing the system and change the traditional way of working on the construction site. The next step in this research is to evaluate the model in a real case study.

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