

# A CASE STUDY OF LINE-OF-BALANCE BASED SCHEDULE PLANNING AND CONTROL SYSTEM

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## ABSTRACT

Line-of-Balance is a graphical technique which can be used to plan and manage work flow. It is suitable for construction projects because of their large degree of repetition. Despite its strengths Line-of-Balance has not gained widespread use in construction industry internationally. However, it has been used as the principal scheduling tool in Finland since 1980s. As a result of two decades of research and use in industry, a comprehensive schedule planning and control system has been developed around location-based techniques. A computer software has facilitated implementation in construction companies.

This paper describes a case study of 15,000 m<sup>2</sup> office building project using location-based methods for schedule planning and control. Master schedule is based on Bill of Quantities where quantities have been calculated based on the project's Location Breakdown Structure. Before implementation, different schedule alternatives were evaluated based on risk of interference, total duration and cost. During construction, the master schedule sets constraints on lower level task schedules, which were used to ensure the continuity of work for crews on a more detailed level. The master schedule was not updated even when there were deviations from the original plan. Instead the task plans were updated to catch up with the original schedule. This prevented the problems from accumulating in downstream production.

In this case study the combination of PPC measurement (calculating the percentage of weekly assignments complete) and task planning was piloted. Weekly plans were made by combining assignments from all the task schedules. If the starting constraints had not been removed the task plan was updated to assess the effect on total production and to plan control actions. PPC measurement was found to improve task plan reliability.

Benefits of the approach included better schedule control and possibility to examine how deviations from weekly plans affected the total schedule. Task planning provides information about how long a master schedule task actually reserves a location. This information can be used in planning master schedules of similar projects in future.

## KEY WORDS

Line-of-Balance, Scheduling, Task planning, Production control

## INTRODUCTION

### BACKGROUND

The graphical line-of-balance scheduling method is a planning method for continuous flow of production. Advantages of line-of-balance scheduling for the General Contractor include less

schedule risk because subcontractors can be kept on site, productivity benefits because the crews are less likely to interfere with each other and more realistic schedules as buffers can be easily planned and analysed (Kankainen & Seppänen 2003). Despite its strengths, the method has not gained widespread use internationally. According to the technical literature, lack of easy-to-use soft-

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ware solution implementing the method has been one of the reasons for slow adoption. (Arditi, Tokdemir & Suh 2002).

In Finland, location-based planning methods have been used widely in construction since 1980s. The methods were brought to Finland and adapted to commercial construction by professors Kankainen and Kiiras from Helsinki University of Technology (e.g. Kiiras 1989, Kankainen & Sandvik 1993). In academic research tests it was established that the use of modified flowline planning increased productivity and decreased waiting hours for own workers and for subcontractors (e.g. Toikkanen 1989, Venermo 1992).

New research efforts to improve the scheduling skills of the Finnish industry were started in the end of 1990s by professor Kankainen's research group. The results included tools such as task planning (Junnonen 1998), project control charts, checklists to assess schedule's feasibility (Kankainen & Kolhonen 2005) and new contracts to support location-based control. The research results were used in a software development project to design a new software able to be used as a planning and control tool. The features of the resulting software DynaProject™ have been described in Kankainen & Seppänen (2003).

As a result of two decades of research, a complete schedule planning and controlling methodology based on managing schedule risk has been developed. Because of the shared aims with Lean Construction, namely reduced waste and interference, Finnish results and tools have been presented in IGLC conferences during the last few years (Kankainen & Seppänen 2003, Junnonen & Seppänen 2004, Soini & Leskelä & Seppänen 2004, Seppänen & Kankainen 2004). This paper describes a case study using the risk-management based planning and control methodology of using location-based tools to give a better idea about how the system works and how it can contribute to Lean Construction knowledge. In addition to using the location-based tools, the case study experiments with measuring reliability of task schedules by use of PPC measure from Last Planner™ system of production control (Ballard 2000).

#### PREVIOUS RESEARCH AND PRACTICE

Earlier papers about Line-of-Balance describe algorithms and heuristics to optimize continuity of resource use, to achieve duration cuts and to model learning curves (e.g Kang et al 2001, Arditi et al 2001, Harris & Ioannou 1998). Research methods have been based mostly on simulation, not on real case studies or empirical research of projects. While this previous research gives good

theoretical foundation to the method, it doesn't describe utilization of these concepts in real projects.

However, experiences from using Line-of-Balance in real projects indicate that most of the benefits are currently lost in implementation stage (Seppänen & Kankainen 2004). This is because of variability of production rates and inadequate control mechanisms on site. Variability has been widely discussed in Lean Construction literature, for example by Tommelein, Riley and Howell (1998) in their Parade of Trades simulation. The Last Planner System™ has been proposed to reduce variability by ensuring quality assignments, enabling learning during projects and making and committing to decisions near implementation time and by the people responsible for the work (e.g Ballard 2000). The Last Planner System can be criticized because it doesn't take into account production rates and it is easier to continue already begun work than begin work again after interruption. Thus the Last Planner can achieve good results on one week but simultaneously destroy prerequisites for continuing on succeeding weeks. (Seppänen & Kankainen 2004).

The objective of this paper is to show that the benefits of the Line-of-Balance scheduling can be achieved in practice by using location-based production controlling tools. The research method is case study with minimal researcher intervention (2 to 4 hours a week just to gather the data). To be able to compare the results with Last Planner case studies also PPC (percentage of weekly assignments completed) was measured.

### CASE STUDY

#### DESCRIPTION OF THE PROJECT

Opus business park is a 14 500 m<sup>2</sup> office building in eastern Helsinki. It is composed of two sections, which can be built independently of each other and of parking hall below the main building. Both sections have six floors. The total schedule is from May 2004 to December 2005. Figure 1 shows summary of the project. The project is the second part of larger three -part Opus Business Park development.

#### AVAILABLE STARTING DATA

NCC Construction has devoted a lot of resources to implement flowline based production control systems (Soini et al. 2004). The quantity take-off is done corresponding to the physical locations of the building. Labor consumption information has also been standardized within the company allow-

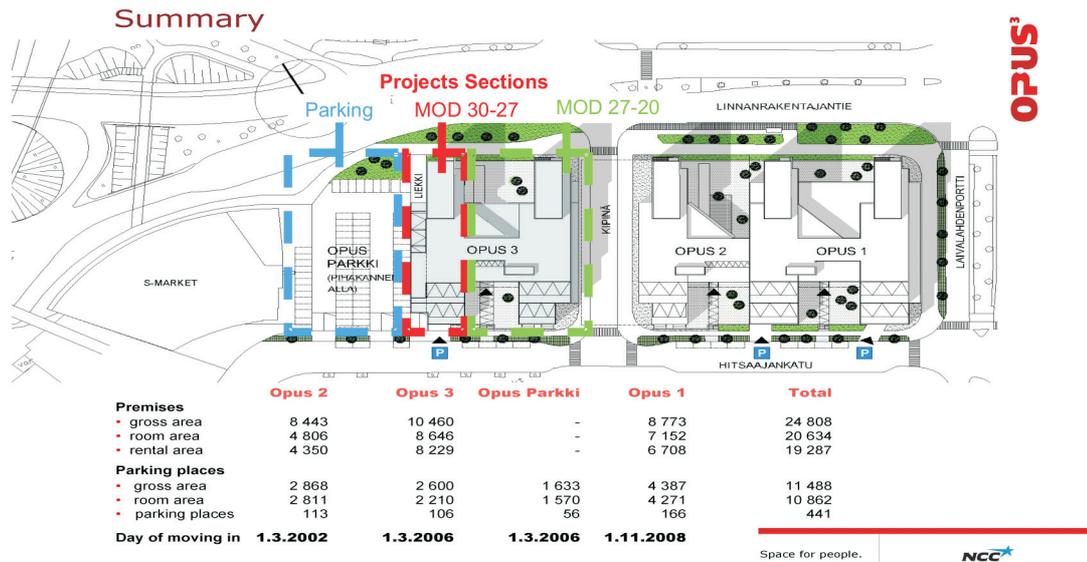


Figure 1: Summary information about the Opus Business Park development

ing for a very fast planning of first drafts of the schedule. Also the building services quantities are estimated based on project characteristics and size. The productivity and quantity databases include information about subcontracted work. The main principle is that subcontracted work should be planned as if it were done with own resources because otherwise effective control of production flow is impossible.

In this case study, all the quantities had been distributed to sections and floors so that they could be directly utilized in flowline planning.

### SCHEDULING PROCESS

Because of good starting data, it was possible to create many different alternative schedules in a short period of time. Two main alternatives were examined: 1) completely continuous schedule and 2) work continuous in sections but a break between two sections.

Completely continuous schedule would have had the same end date as partially continuous schedule but both sections would have been finished at approximately the same time. Partially continuous schedule achieved much of the same benefit but enabled the first section to be finished earlier thus reducing the risk of exceeding the total duration. The project team decided to implement the partially continuous alternative and take the break between sections into account in contracts with subcontractors.

It was not possible to change the sequence of sections because the parking hall had to be handed over before the second section could be started. This was because the second section was used as a temporary parking lot for customers of the neigh-

boring supermarket. If the second section could have been built first, the project duration would have decreased by one month.

In the final schedule the production rates have been synchronized and buffers have been planned between the most important activities. All task durations are based on quantities, resources and productivity data from earlier projects or from Finnish productivity database, which has been created as a joint effort of the industry (Olenius et al. 2000). The final master schedule is shown in figure 2. The project has been divided into three sections. Parking hall deck has to be completed before earthworks of module lines 27-20 could begin. Otherwise the sections are independent of each other so they could be built in any sequence or simultaneously. The schedule has been planned so that the structure is built from down up to section in module lines 30-27 first and then the same resources continue to the larger section 27-20. Finishes have been planned to be continuous within the section. When the same subcontractor was used in the both sections the break of one month before the work could continue in the next section was taken into account in the call for tenders and the actual contract. There was a contractual milestone after the finish date of the first section for all major subcontractors.

Risk analysis of the schedule indicated that the structure was the riskiest part of the project. As a consequence, buffers were added between structure and finishes. For example, there is a lag of three floors before concrete floor finishing works starts in the building.

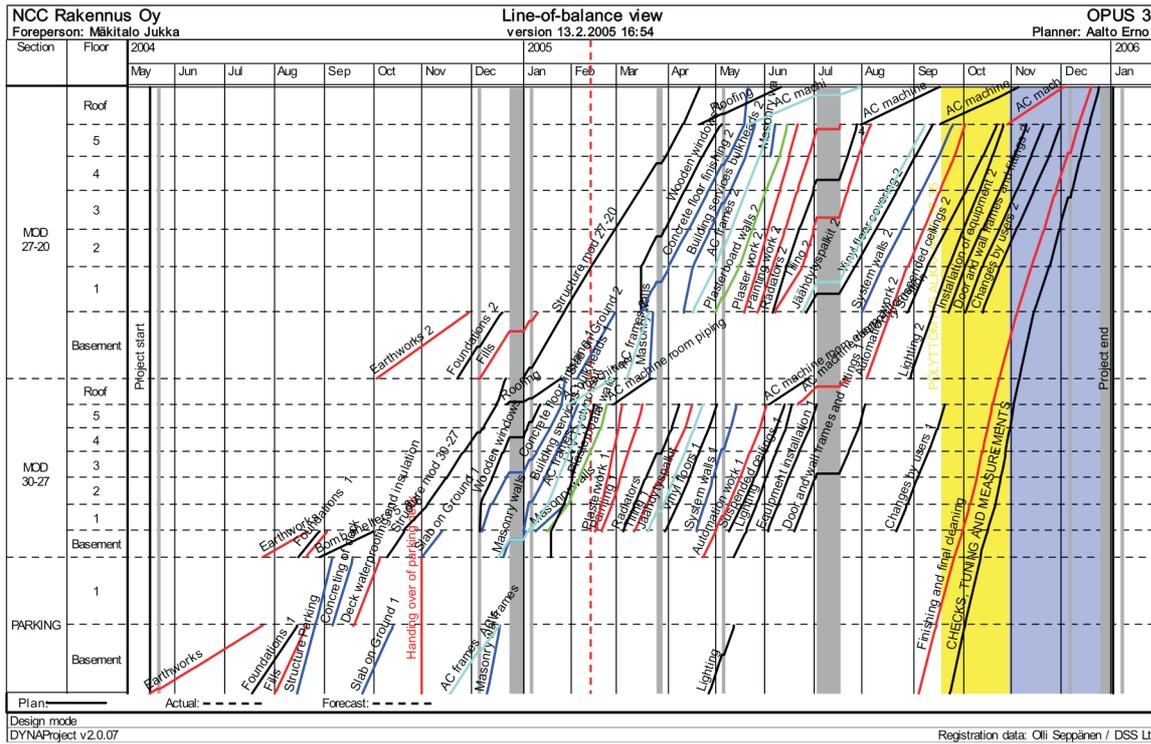


Figure 2: Master schedule of the Opus project—For clarity, only the construction and building services tasks which reserve the whole location are shown

WEEKLY CONTROLLING PROCESS

Task scheduling

The weekly control process used throughout the project was based on task planning method (Junnonen & Seppänen 2004). The schedule of upcoming master schedule tasks was exploded into more accurate level and the quantities were updated. This process started in the beginning of the project so by planning just one task accurately each week it was possible to always be well ahead of production. While the master schedule looks at production flow and required production rates at “macro” level, the task schedules are used to plan continuous work for each crew. Task schedules are constrained by the master schedule so that the task schedule must finish all subactivities in a location before the next master schedule task begins in that location. Task schedules are updated weekly to always correspond with the current situation but the master schedule is never updated. This is because updating the master schedule may lead the site management into false sense of safety. This is because updating the schedule shifts the problems towards the end of project and leads to hurry in the end of project (Kankainen & Kolhonen 2005). Updating the task schedule may have the same effect but because the master schedule sets the boundaries in which it can be updated, the effect is more localized and it is possible to react earlier.

Example of task scheduling: plasterboard walls

“Plasterboard walls” task illustrates the use of task scheduling and how the buffers were actually utilized in the project. Figure 3 shows part of the master schedule of the first section. The original intention was to build plasterboard walls only after the roof was completely waterproof so that the risk of walls getting wet because of rain would be removed. However, because of delay of the structure and the roof, the walls would have started at least 4 weeks late with the original constraint.

The problem was solved in task scheduling by exploding the master schedule activity to three subtasks: wall frames and installing board on one side, electrical piping inside walls and insulation and installing board on the other side (figure 4). The sequence was changed so that the first floor which was more complex (auditorium, dentist and other special spaces) than the other floors was done last. Contract was made with one subcontractor to install both the bulkheads and the plasterboard walls. One crew went through all the locations installing bulkheads. The next crew started a bit later and followed in the same sequence installing wall frames and the board on one side. When the bulkheads crew had gone throughout the building, they started to install the insulation wool and second board. Buffers were

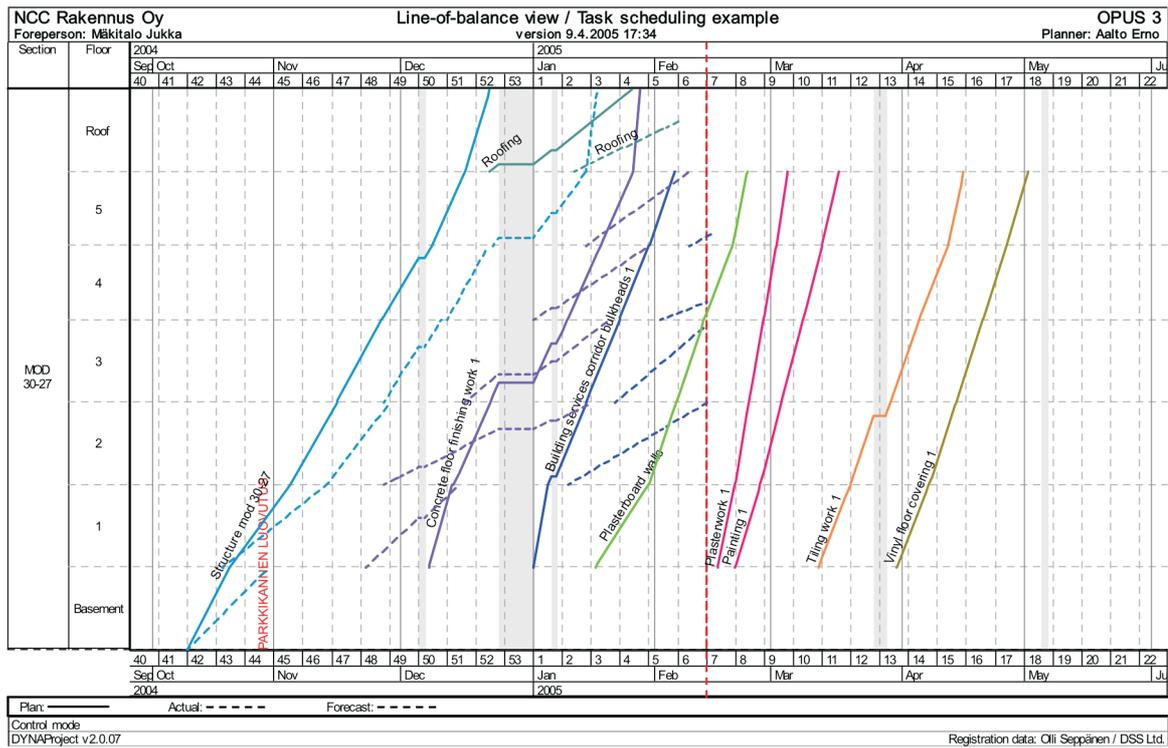


Figure 3: Original master schedule plan and actuals for plasterboard walls task and its predecessors and successors. Solid lines indicate the original plan, dotted lines the actual

planned between the first board and the second because different subcontractor was involved in installing the electrical piping. Even though the plasterboard walls task ends two weeks later than in the master schedule, the succeeding trades incrementally catch up the delay. Tiling work and

vinyl floor covering work can start according to the original master schedule.

The example above also illustrates the fact that buffers are needed if the master schedule is needed on rough level of detail. They give flexibility in task scheduling phase. In this example, the subtasks flowed through all the building instead of finishing all the subtasks first in a loca-

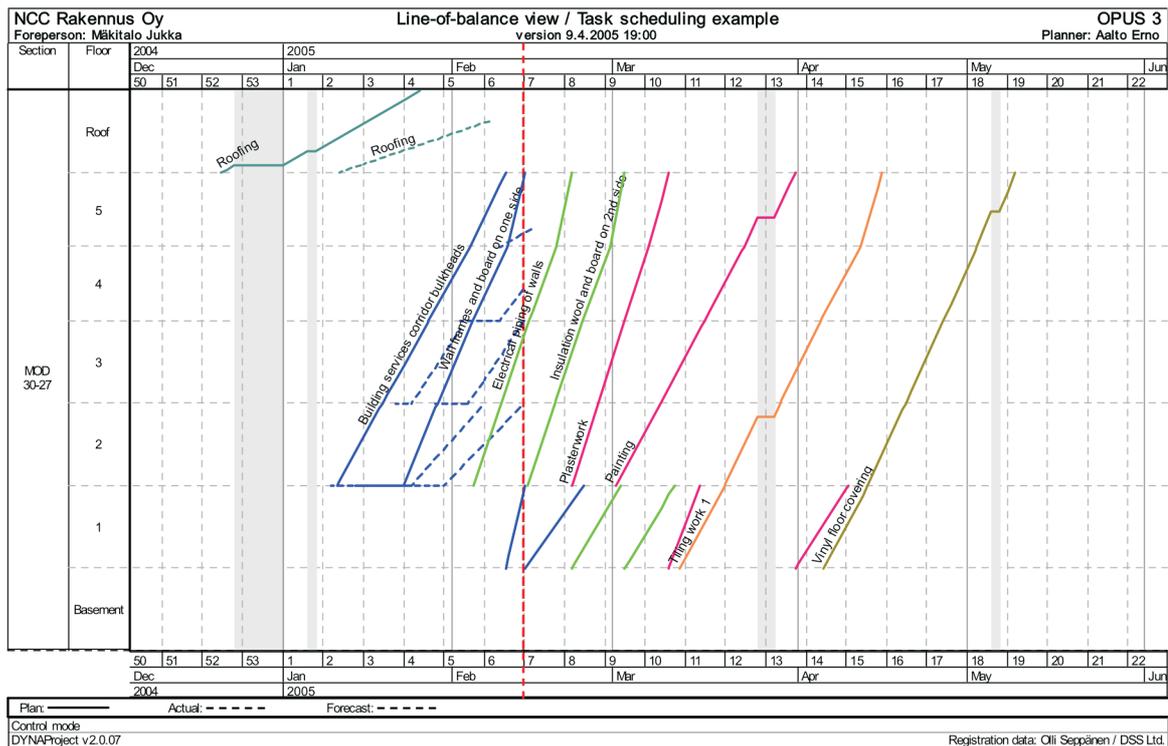


Figure 4: The task schedule for plasterboard walls task and its predecessors and successors

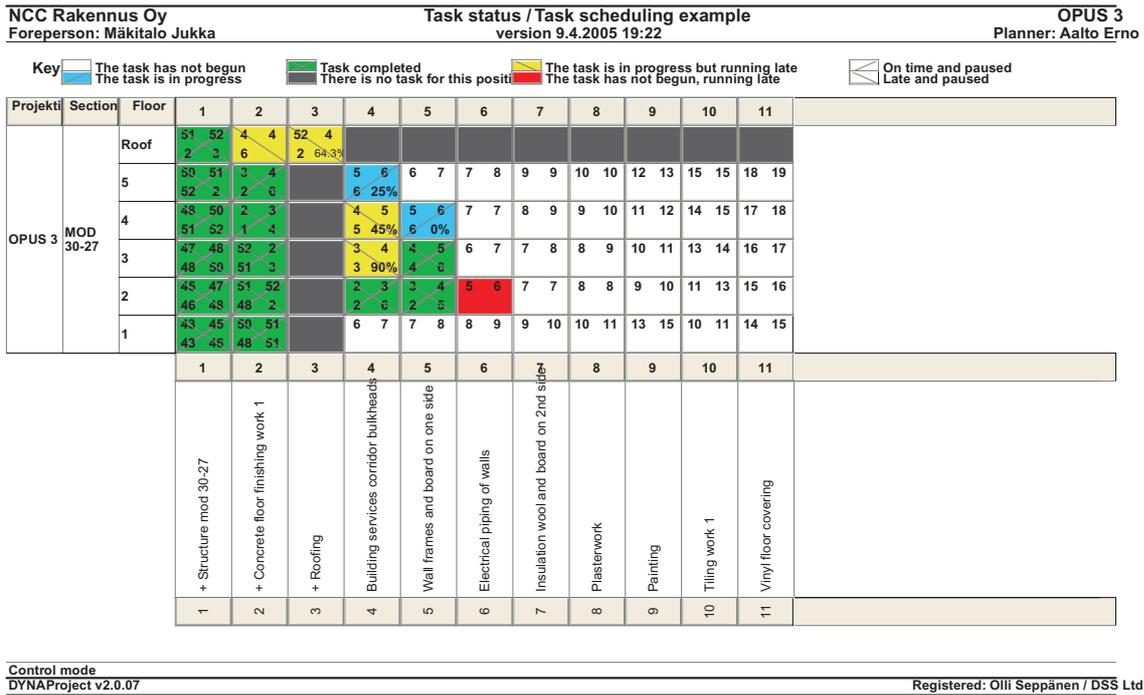


Figure 5: Control chart shows graphically the schedule status of each task and location

tion before moving on to the next location. The location is reserved for each trade longer than in the master schedule.

**Collecting actual data from the site by using control charts**

Every week on Tuesday, the actuals from the last week were compared with the weekly assignments derived from all of the task schedules. The data was collected from site by using the control chart, a matrix of locations and tasks which shows with color codes the status of each location (Kankainen & Seppänen 2003). The control chart was prepared for each task schedule of the project. It was used to communicate the schedule status to subcontractors and the management team in subcontractor meetings every Wednesday.

Figure 5 shows the control chart of the task schedule presented above. Each cell has four numbers and a color code. The top left number shows the planned calendar week when the task should begin in a location. The top right number indicates the planned finish week. The bottom left number indicates the actual start week and the bottom right number actual finish week or the completion rate if the task has begun in the location but hasn't been finished yet. Green color means that the task has been completed, yellow color that the task has begun but is running late, red color that the task hasn't been begun and is running late and the blue color that the task has begun and is on time. In this example, the subcontractor used the same men to install bulkheads and

wall frames which slowed down the progress. They also had problems in completely finishing a location before moving on to the next location. This can be seen immediately from the control chart because the second and third floors of bulkheads task are yellow. The impact on the electrical trade is also readily apparent by the red square on the second floor of the electrical piping task.

**Measuring reliability of task schedules by using PPC**

The reliability of task plans was measured by calculating the percentage of planned assignments completed (PPC) during the week. This measure is the same as in the Last Planner™ system of production control (e.g Ballard 2000) but the assignments are the result of Line of Balance -based task scheduling process. PPC was used in this research in order to calculate a baseline reliability for just using location-based techniques without actually using the Last Planner™ system. This would allow comparison between the two systems and show the benefits of possible combination.

Calculating reliability of task schedules is a new concept in Finnish projects. Earlier just the control chart and plotting actuals to Line-of-Balance charts or status line to Gantt chart have been used to measure success of the control system. Some evidence was found that the PPC measurement improved the results. The PPC increased from the base 50 % to about 70 %. However, the PPC couldn't be consistently held at the 70 % level and the average PPC for the whole project was 63 %. This is probably because the subcon-

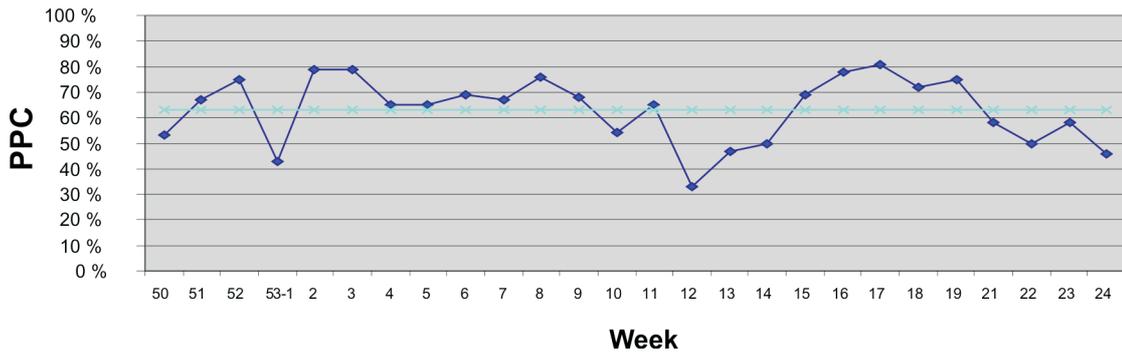


Figure 6: Percentage of Plan completed as function of time (calendar week)

tractors committed to the task schedules but not to weekly targets based on the task schedules. The PPC measurement wasn't exposed to other people than the authors. Figure 6 shows the PPC as function of time.

Bad PPC weeks usually had one or two critical tasks going with lower production rate than planned or in wrong sequence, which also impacted all the following trades causing everyone to fail in their assignments. In addition the impact of some holiday seasons (Christmas week 53-1, Easter weeks 12-13) was inadequately reflected in weekly plans (Estonian subcontractors had more days off than anticipated). Deviations were mainly concentrated on a few trades (bulkheads / plasterboard walls and electrical trade). Bulkheads / plasterboard walls subcontractor was an Estonian company with another large job in Finland which caused excessive resource demands. The subcontractor wasn't familiar with

the Line-of-Balance technique and tended to work in wrong location or in multiple locations at the same time. Most of the deviations of electrical trade were caused by long lead times of switchboards and resulting material problems. The deviations in the end of the observation period (weeks 21-24) were caused by resource problems because the required production rate in the second section was higher than in the first section and the subcontractors continued with the same amount of resources.

### Updating task schedules

All existing task schedules were updated next to take changed circumstances and actual production rates into account. Actual production rates were used in task schedule updates to make schedules more accurate and to show if more resources were needed. The master schedule sets the boundaries

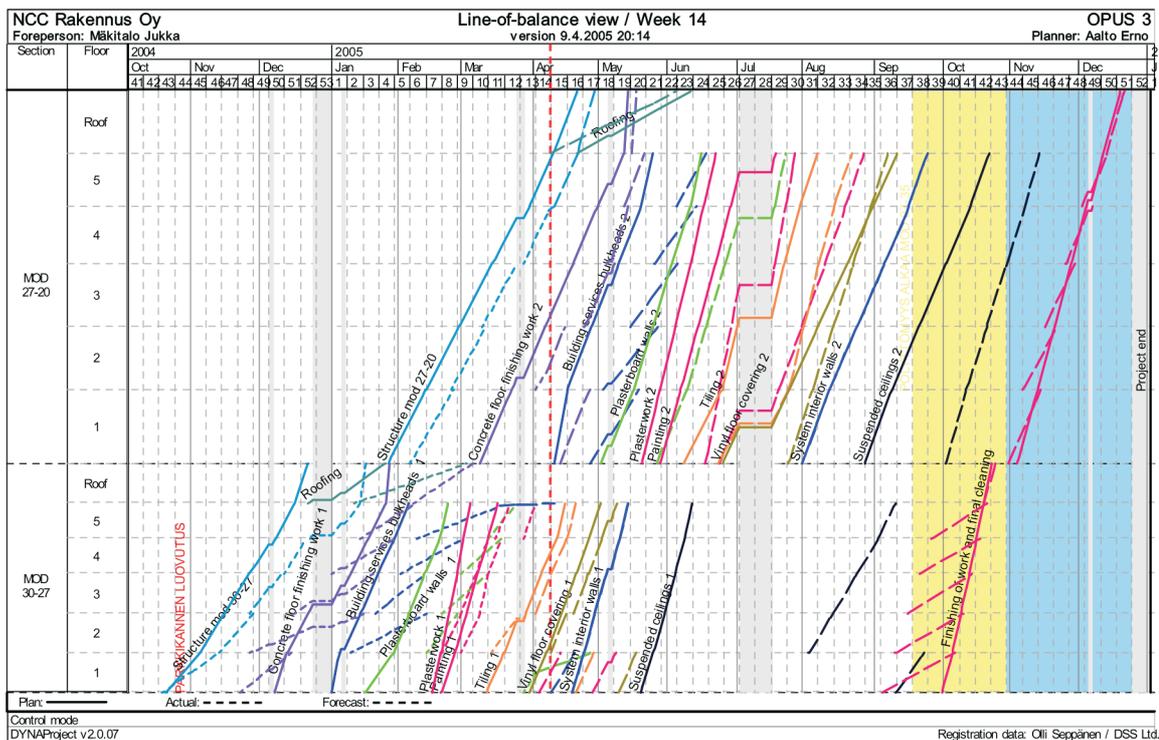


Figure 7: Actual situation (dotted lines) compared to the master schedule (solid lines). Forecasts based on the current task schedules are shown with dashed line.

for planning so the problems couldn't be pushed farther than the end of master schedule task in a location. The aim was to make the best possible forecasts for the rest of the task while preserving continuous production for as many workers as possible. Most effort was expended on updating the next week's plan because the reliability of the next week's task schedules was measured by PPC.

If there was sufficient information on a master schedule task which was about to begin in the next few weeks, a new task schedule was planned. The first draft of the task schedule used accurate quantities taken from current drawings and estimated production rates. It was planned by the authors. Before beginning of production, the task schedule went through multiple rounds of comments by the subcontractor during contract negotiations, the superintendent and procurement people. The comments were used to refine the task schedule until everyone was ready to commit to it. The finished task schedule was included as part of the subcontract.

The resulting set of task schedules were up-to-date, took into account the availability of resources and were based on actual circumstances. From these task schedules the production objectives for the next week were established. These objectives were communicated to the subcontractors and foremen. Their success was evaluated in the next Tuesday's schedule update by calculating the PPC.

### **Comparing actuals to the original master schedule**

After updating the task schedules the status of master schedule was evaluated based on computer-calculated forecasts (Seppänen & Kankainen 2004). If the delay of a task endangered the continuous flow of another task, control actions were planned by updating the task schedules to minimize the risk of interference. Actual situation and resource availability of the subcontractors as well as the cost effects of acceleration were evaluated to arrive at the best solution. If interference couldn't be avoided, task planning was used to estimate the optimal time to continue production for the disturbed trade. Figure 7 shows a few activities with the status of calendar week 11/2005.

It can be seen from the figure that the schedule of the first section has been caught up. The first floor being late doesn't matter because there is a lot of float in the first section. Each task has had continuous work and the second section can be caught up because the same subcontractors will be used. An example of learning effects is the structure which had problems in the first section but

had the planned production rate for the entire duration of the second section.

The project management was very satisfied with the schedule performance of the project. In their earlier projects the deviations in the structure would have affected all the trades until the end of the project. Now the original schedule was mostly caught up before summer holiday season.

### **CONCLUSIONS**

Line-of-Balance based schedule planning and control system in combination with PPC measurement worked well. The system allowed the project team to see the total effects of deviations compared to the original master schedule and simultaneously measure the reliability of short-term task schedules. Because of measurement the project team was motivated to plan better task schedules and to implement them better. By combining the systems, the site can set realistic objectives, commit to them and maintain control of the overall schedule. The 63 % mean PPC achieved is a moderately good result because optimizing it wasn't the main purpose of the research and it was not exposed to subcontractors or workers.

The main result of the case study was that weekly task scheduling ensures effectively the implementation of the original master schedule and prevents the problems from shifting to the end of project. Just monitoring and controlling the master schedule isn't enough because the subcontractors should be involved in the planning process to get their commitment. However, the start dates and production rates planned in the Line-of-Balance master schedule were found to be mostly relevant throughout the project so they can be used as basis of procurement. Evidence for importance of continuous production with constant production rate was found because there were deviations in the second section which required higher production rate. The actual production rate for all the trades was equal to the production rate in the first section.

Largest problems in the case study arose from the lack of subcontractor resources and overlapping production in many locations, instead of finishing one before moving to another. If the production overlaps in many locations, the next trade can't begin on time and problems with cost effects occur. Prerequisites of starting (especially design) caused some problems which could have been prevented by doing detailed constraint lists and controlling them before starting of production. However, most of the other constraints are already explicitly planned in task scheduling (for example resource constraints, space constraints, procurement needs).

Because of the clear benefits in terms of production continuity and predictability of the master schedule, location-based planning and control can be recommended. Planning a location-based schedule isn't enough without effective control tools. To ensure good implementation, mutual understanding of the schedule and effects of resource decisions by all parties is critical. For this purpose, the control chart proved to be the most powerful communication tool of the current status because it was easily understood by everyone.

In future research, the cost benefits of location-based control should be shown. Other project types should be studied to find out whether the results generalize to less repetitive project types.

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