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Case Studies of Using Flowline for Production Planning and Control

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Abstract

Flowline, or Line-of-Balance, has recently gained attention in Lean Construction literature because of its capacity for facilitating control of production flow and planning of continuous work. In the broader technical literature, previous work has concentrated on the analytic properties of flowline, such as learning curves, and is generally silent on how the method should be used to improve productivity. This is because internationally the technique has received relatively little application. However, in Finland, flowline has been used as the principal scheduling method since 1980s.

This paper takes a practical approach and describes the use of flowline based planning and control in two real case projects. One of the projects is a large residential construction project in Sydney, Australia. The other project is a Finnish retail park construction project. These pilot projects were done at the same time and the projects were able to learn from the experiences of the other. The cases highlight the differences between the Finnish way of planning a schedule with buffers between activities with synchronized production rates and the Australian way of driving a schedule with a tightly constrained CPM schedule.

A methodology using flowline as a visual planning tool but using familiar CPM logic as the underlying engine was appropriate in the Australian case. In this methodology the objective is to improve site control by including information about location and to be able to plan continuous work for subcontractors and to visualize the effects of planning decisions. The result is much clearer communication to the trade contractors about the timing and location of their work, improved control systems and better work flow. The Finnish project team was already familiar with the basic use of flowline so the more advanced risk management based approach was used. The risk management based approach includes using quantities estimated by location as the starting point and optimizes the crews so that the risk of schedule disturbances is minimized. The planning happens on two levels: the master schedule has less detail and the task plans are detailed plans of individual tasks which are done by persons responsible for the work when all the necessary information about implementation is available. The results from the Finnish case include a methodology for effectively controlling production flow and how to include the subcontractors in the process.

Comparison of the two different strategies reveals important knowledge about the role of custom in scheduling, and reveals potential barriers to adopting innovative approaches.

Keywords: Flowline, line of balance, scheduling, implementation

1. Introduction

1.1 Flowline and its Applications

There are two main methodologies for scheduling work: activity-based scheduling and location-based scheduling. These two methodologies in turn have many methods and techniques, often designed to achieve the same purposes in different ways [1].

The dominant scheduling technique is activity-based scheduling and it was first developed in the 1950s [2]. The technique relies on the construction of a logical network of activities in three visual forms; activity on the arrow, activity on the node and logical dependency constraints [3], with four levels of complexity; deterministic (for example: CPM), probabilistic (for example PERT) generalized activity networks [3] and arguably the more recent critical-chain method [4].

A familiar to many, but relatively little used, alternative scheduling technique is that of location-based scheduling, more frequently known as repetitive scheduling. Originally developed by the Good Year Company in the 1940s and expanded by the US Navy in the 1950s [5], the suite of techniques has found strong support in continuous production systems (more typical in engineering construction) but only limited support in commercial construction. Finland is a notable exception to this, as the technique is the dominant method in the Finnish construction industry. Harris & Ioannou [6] summarize the various names (and sources) given to the variations in the method, including ‘Line-of-balance’, ‘Construction planning technique’, ‘Vertical Production Method’, ‘Time-Location Matrix model’, ‘Time Space Scheduling method’, ‘Disturbance scheduling’ and ‘Horizontal and vertical logic scheduling for multistory projects’. Interestingly they do not identify perhaps the most evocative term, that of ‘Flow-Line’ [7]. Harris & Ioannou [6] also identify the terms used in engineering construction such as highways, pipelines and tunnels, as ‘Time versus distance diagrams’ (TD charts), ‘Linear balance charts’, ‘Velocity diagrams’ and ‘Linear scheduling’. [8] also identify ‘Horizontal and vertical scheduling’, and ‘Multiple repetitive construction process’–but aims these at the specific case of vertical replication repeated in multiple buildings.

All these methods involve repetitive activities and for this Harris and Ioannou suggest a new generic term ‘Repetitive scheduling method (RSM)’. However the methods also strongly suggest location or place, and thus the use of the term ‘Location-based scheduling’ proposed by Kenley [1].

1.2 Background

Activity-based scheduling dominates most of the world's construction industries. This is certainly the case in the Australian industrial context. Little needs to be said to describe the common methods for planning projects, as they will be familiar to most. Essentially they are driven by software such as Primavera (the most commonly used package), Microsoft Project and equivalent CPM tools.

The education system in Australia generated students with a deep understanding of the underlying mechanisms of CPM planning until the mid 1980s. These students were also generally exposed to alternative manual methods such as Flowline [7]. Students of Walter Mohr [7] were more exposed than many. The advent of powerful software on micro-computers subsequently lead to a reliance on packages for the teaching of planning. It is fair to say that nowadays, construction management courses teach the use of software, paying only a cursory interest in the underlying principles and methods. A consequence of this is a lowering of planning skills, except in the use of software, and a reliance on common approaches. Accordingly, it would be extremely rare to see application of location-based scheduling in Australia, indeed few people would have the skills to understand the method.

Furthermore, location-based scheduling is best driven by location-based measurement (BOQ). The standard method of measurement in the Australian industry does not allow for location-based measurement. The industry has also substantially moved away from measurement of commercial building projects, particularly those procured using Design and Construct methods, and many commercial contractors simply do not have adequate measurements to support location-based techniques properly.

In contrast, location-based planning methods have been used widely in Finnish construction since the 1980s. The methods were brought to Finland and adapted to commercial construction by professors Kankainen and Kiiras from Helsinki University of Technology [9], [10]. In research tests it was established that the use of modified flowline planning increased productivity and decreased waiting hours for own workers and for subcontractors [11].

Finland suffered from severe economic recession during 1990s during which many construction companies went bankrupt and the value of real estate plummeted. During the recession, training of construction management professionals and construction engineers practically stopped because jobs were not available. This has resulted in a lack of skilled engineers in the field when the economy began to recover. During the recession the flowline scheduling skills were forgotten and the industry reverted back to using gantt charts which could be easily drawn by using computers. The only available flowline software was a drawing tool and wasn't suitable for complex planning.

New research efforts to improve the scheduling skills of the industry were started at the end of 1990s by professor Kankainen's research group. The results included tools such as task planning [12], project control charts, checklists to assess schedule's feasibility [11] 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 software DynaProject™ have been described [13].

Because of popularity of the location-based graphical methods, Finnish construction companies had never really adopted CPM –based methods. Activities which are linked by precedence logic are rare in Finnish schedules. The schedule is used as a visual planning tool and the planners check for logic errors by examining lines which cross in the flowline diagram.

It is clear, therefore, that a comparison between the Australian industry and the Finnish industry, the methods and practices of planning, would cast valuable light on the culture of planning in both countries. In this paper, the experience of planning using location-based scheduling techniques on a specific project case study from each country is discussed; allowing comparisons to be made and conclusions drawn about the differences in the culture of planning in each country.

2. Case 1: Residential Construction Project in Sydney

2.1 Description of the Project

Victoria Park stage 302 is a residential complex in inner Sydney. It comprises four residential towers of varying heights, joined through a common podium. The largest tower was fifteen floors, the next nine, then eight and four. There were approximately 300 apartments in total. The schedule was from May 2004 to June 2005.

2.2 Available Starting Data

Walter Construction Group was totally new to flowline based production control systems. All their systems revolved around CPM and Primavera. As this was a trial to develop more efficient management systems, both CPM schedules and flowline schedules were developed.

There was no quantity take-off done corresponding to the physical locations of the building. Nor was there any available database of production rates. This is common within the Australian industry, where sub-contract packages are generally allocated a number of days of work for each task, in precedence logic, and no attempt is made to ensure continuity of work flow.

2.3 Scheduling Process

Because of the poor starting data, it was difficult to schedule the project using location-based methods. It was necessary to take the CPM schedule and artificially apply it to a location-based methodology. This presented the first significant barrier to implementation: the automatic systems designed into the software could not be used and the inability to use quantities and productivity data exposed the shortcomings of CPM only systems which are not sensitive to designed productivity changes.

The CPM schedule was never fully completed due to the complexity and scale of the projects. Therefore, the CPM schedule calculated a typical floor in detail, then replicated this for each floor. This is understandable, as with 300 apartments and with approximately 50 activities to schedule, it would be necessary to schedule around 15,000 activities. In contrast, the location-based methodology required only 50 activities, with the approximation of quantity in each of 300 locations. A simple trick was employed to achieve this: The unit of quantity measured was a standard shift, with the number of days of work being the actual measurement. This rough approximation allowed reproduction of the CPM schedule, but exposed the problem of manipulating the productivity to improve the schedule (and indeed the problem of a culture of fixed durations existent within the industry – a topic for future research).

One important lesson is that this sort of power leads to extremely rich and complex schedules. The loss of dominance of the critical path, replaced by dominance of work-flow, results in project models with large quantities of information – all very powerful for managing the project. To illustrate the complexity, a small section of the finishes schedule for one part of one building is displayed in figure 1.

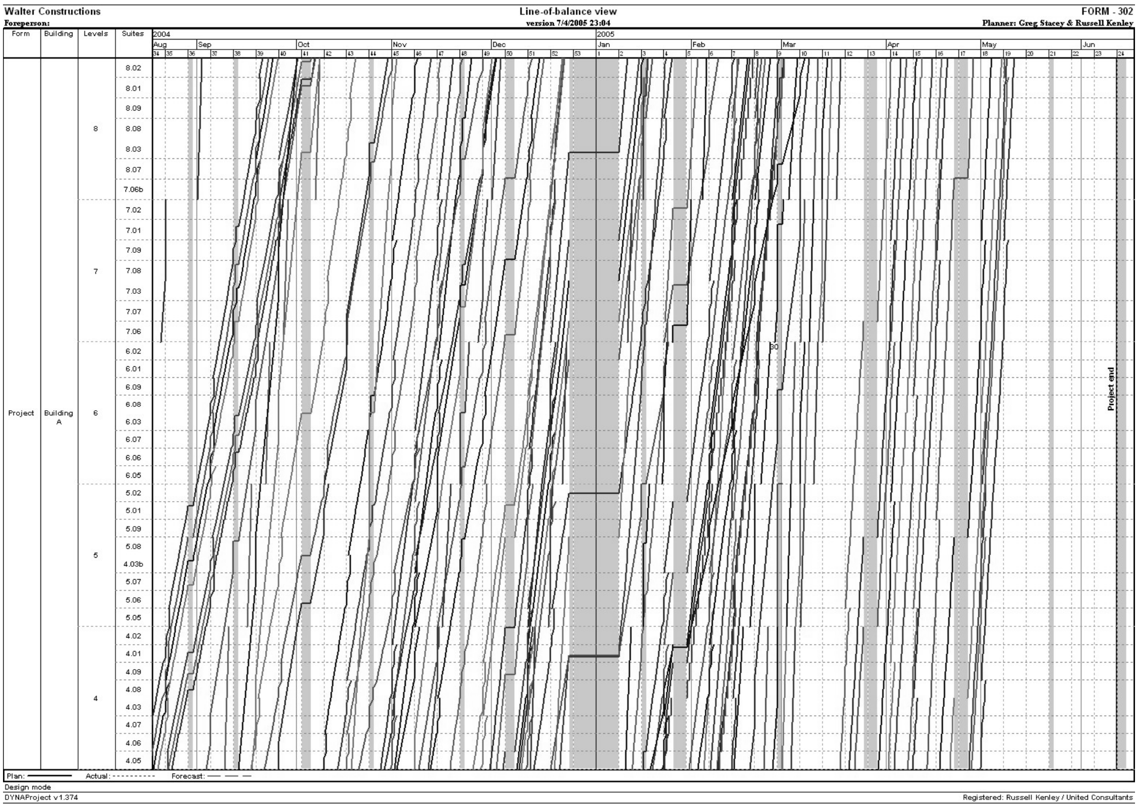

Figure 1: Section of finishes schedule for Victoria Park.

The initial schedule resulted in a duration far in excess of the required duration. In order to simulate alteration of work-crew productivity (the normal method), activities were resourced with work-crews with $1/10^{th}$ productivity – and a base multiple of 10 units. Thus 20 units would double productivity and 5 would halve the productivity.

After manipulation, a schedule was developed which conformed to the duration requirements, but which ensured that each work-crew was able to work continuously, without interruption, from start to end of the project. In the words of one site manager on a later project, “Do you mean to say that we can not only finish on time, but also have continuous work?”

In contrast to the finnish methods described below, the contractor wanted to continue their use of scheduling in extreme detail. This may be termed micro-management [1] and scheduling to such detail was considered most unusual by our Finnish colleagues. Their risk management approach results in less detail and simpler schedules. The detailed approach dictated by a CPM culture results in much more detailed schedules, more complex models but powerful management tools when used correctly.

2.4 Control Process

The project schedule was completed prior to commencement of the finishes work on-site. The planned control process was to work with the sub-contractors to ensure their productivity rates matched with the plan. Once this was done, each work-crew would be able to work continuously, systematically and without interruption – this greatly enhancing their financial performance and that of the project.

The reality was very different. A competing process was being employed on the project in the design stage and unfortunately spilled over into the site-work phase. This process, called *Project Blue* [14] involved intensive focus on team work and integration – very valuable aims. However, the methodology for site work was strictly CPM – and followed the original CPM planning method. A typical floor was worked out according to the original plan and trades were told to "pass work on" to following trades. Unfortunately, this method fails due to the conflict between a typical floor schedule and the need to flow resources through multiple floors and buildings. The result was largely chaos, work out of sequence and a loss of control. Such performance was largely accepted however, because this is unfortunately normal practice on any Australian project.

The result of this conflict is that the location-based control system was never implemented. The company subsequently reviewed the project and determined that on future projects the method would be implemented rigorously and not be sabotaged. A special project team was initiated to follow this through.

Unfortunately, it must be reported that, due to the failure of the German parent company, Walter Construction Group failed in February 2005 and this implementation project has now stopped.

2.5 Lessons

This project highlighted that CPM scheduling done in the traditional way presents major problems for site management which are generally managed by the site staff though working out of sequence, discontinuous work and work interruptions.

In contrast, a location-based approach such as flowline has the capacity to deliver more efficient site work. However, successful implementation requires significant cultural change before it can be successful. Even with senior management support, the project management team must support the innovation.

3. Case 2: Business Park Project in Helsinki

3.1 Description of the Project

Opus business park is a 14 500 m2 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 August 2004 to December 2005.

3.2 Available Starting Data

NCC Construction has devoted a lot of resources to implement flowline based production control systems [15]. The quantity take-off is done corresponding to the physical locations of the building. In this example, all the quantities had been distributed to sections and floors so that they could be directly utilized in flowline planning. Labour consumption information has also been standardized within the company allowing 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 is impossible.

3.3 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:

- Completely continuous schedule
- 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 neighboring 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 a buffer has 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 [16]. The final master schedule is shown in figure 2 (only the space-critical activities shown).

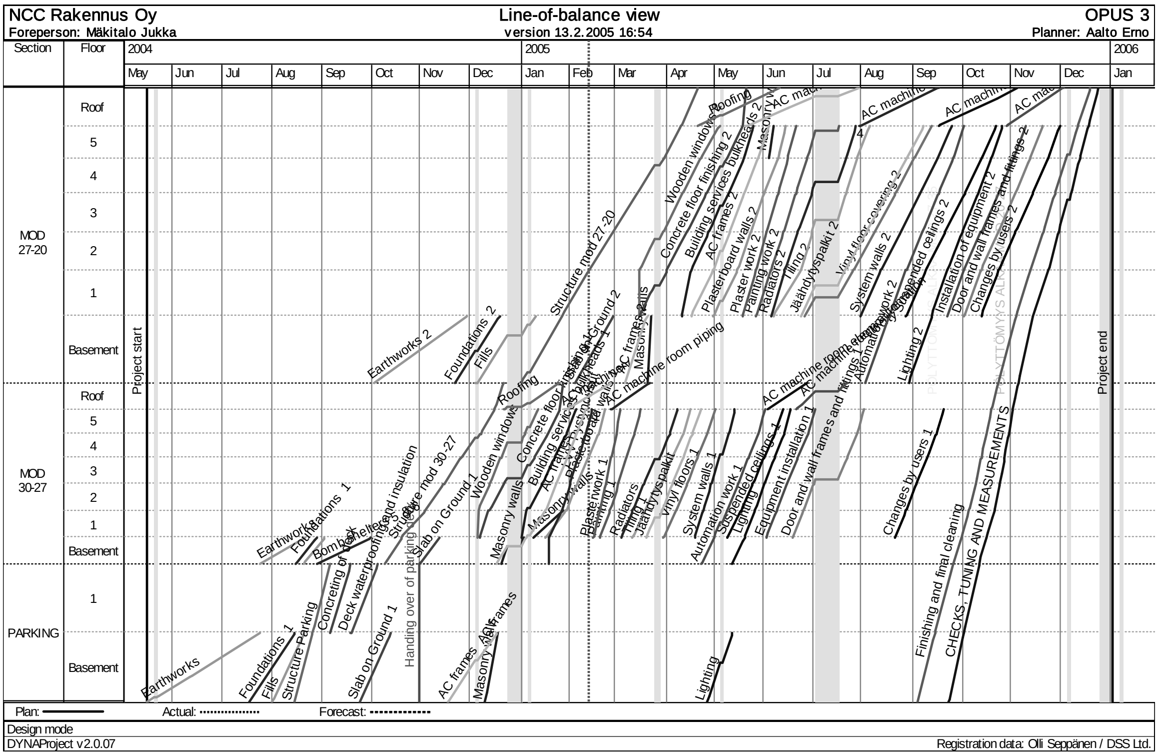

Figure 2: Master schedule of OPUS project – only the space-critical activities are shown

3.4 Weekly Control Process

The weekly control process was based on task planning method [17]. 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 at “macro” level, the task schedules schedule continuous work for each worker and assure that the same worker won’t be in two locations at the same time. Task schedules are constrained by the master schedule so that 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 has been shown to fool the site management into false sense of safety. In reality updating the schedule shifts the problems towards the end of project and leads to hurry in the end of project [11].

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 [13]. 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. [18]) but the assignments are the result of flowline-based task planning process.

All existing task schedules were updated next to take changed circumstances and actual production into account. Actual production rates were used in task schedule updates to make schedules more accurate and to show increased resource needs. The master schedule sets the boundaries for planning so the problems couldn't be pushed farther than the end of master schedule task in a location. All the updating was done using best possible information. The aim was to make 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 next week's task schedules were commitments by the planners.

If there was sufficient information on a master schedule task which was about to begin in the next few weeks, 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 site engineer. Before beginning of production, the task schedule went through multiple rounds of comments by the subcontractor, the superintendent and procurement people.

After updating the task schedules the status of master schedule was evaluated based on computer-calculated forecasts. [19] 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 subcontractor 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.

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 superintendents. Their success was evaluated in the next Tuesday's schedule update by calculating the PPC.

This weekly control process took two to four hours time from the project engineer and one of the authors (OS). In addition, the project engineer used time in communicating the plan, assessing the circumstances and getting the actual data from site.

3.5 Results

The project was still on way during the writing of this paper. The structure of the first section and the parking hall were finished and the interior works of the first section were on way. In spite of many deviations from the plan, the project was overall on schedule. Main problems included earthworks and structure. Structure had too tight a schedule in the master schedule, a fact taken into account in risk analysis. Because of the buffers between structure and interior work, the delay of structure didn't have an impact on the interior works and their flow wasn't disturbed. However, the structure of the second section started late because it was using the same tower crane. Control actions are needed in the immediate future, or there will be interference in the second section. Figure 3 shows actuals (dotted lines) and forecasts (dashed lines) on top of the original schedule (solid lines). Master schedule hasn't been updated and can still be used to control production. The results indicate that the master schedule was on sufficiently rough level of detail that it could accurately forecast how the project would be carried out.

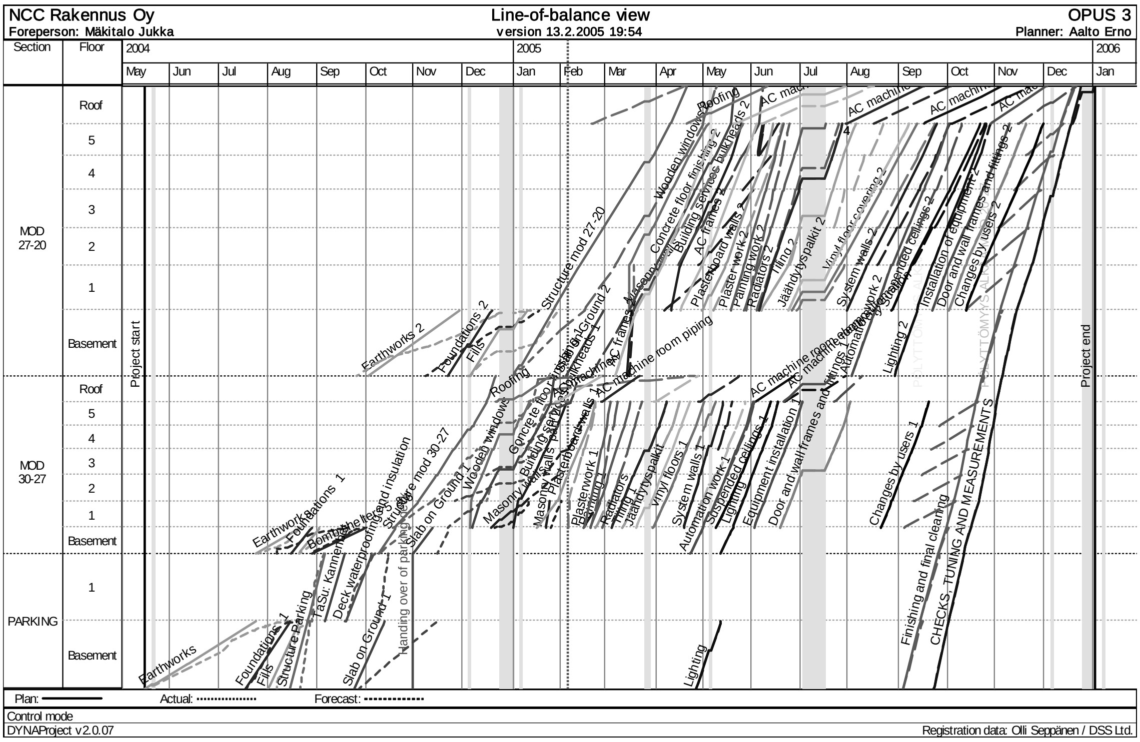

Figure 3: Master schedule of the Opus project planned lines (solid), actuals (dotted lines) and forecasts (dashed lines)

Systematic weekly control process improved the project team's feeling of control. Measuring the percentage of weekly assignments completed (PPC) was found to motivate the team to take planning more seriously and to strive for best possible results. This showed in an increase of the PPC from 50 % level to near 80 % level during the initial stages of the project. Improvement in PPC correlated with the catch up of the schedule.

Combining task planning with master schedule based schedule forecasts worked well because if the site set too relaxed weekly targets, the master schedule forecasts alarmed that there will be problems in the future. If the site set too tight, unrealistic objectives, the PPC value plummeted. Catch up can be planned to be incremental by updating the task plans. By combining the systems, the site can set realistic objectives, commit to them and maintain control of the overall schedule.

4. Discussion

There are very significant cultural differences between the methods, despite the fact that the same software tool was being employed. Indeed, it was realised that neither group could really understand the schedules generated by the other.

The Australian planners, while they liked the idea of the risk management schedules and the rapid construction of schedules from quantities and templates, could not accept their validity in their context and insisted on their detailed CPM-like, micromanaged, flowline schedules. They didn’t understand the concept of buffers, preferring instead a fixed lag (delay) between activities in the network.

The Finnish planners, in contrast, had never seen such large and complex models, and were fascinated by the complexity, but equally could not justify the approach, fearing that such precision and detail without buffers in time or location, would lead to problems in implementation.

This illustrates that the risk management approach and the CPM approach provide two completely different planning systems. Improving our understanding these differences, now identified, will be an important research project for the future.

5. Conclusion

Flowline, as a technique, and DYNAProject™ as a software tool, have demonstrated their capacity to be used in completely different ways according to the underlying planning culture. This project demonstrated that flowline can provide a powerful planning and control tool for projects, with two completely different methodologies available.

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