A LINE-OF-BALANCE BASED SCHEDULE PLANNING AND CONTROL SYSTEM

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ABSTRACT

This paper describes a line-of-balance based schedule planning and control system, and its connection with lean construction methods, using a commercial software package called DYNAProject™. DYNAProject™ has been developed in collaboration with the Finnish construction industry. The main principle is that constraints on schedule tasks are taken into account as early as possible during the project-planning phase. Line – of – balance allows the planning of the workflow between trades so that interruptions are minimized. The procurement schedule is integrated very early on with the master schedule so that constraints on material availability, labor, contracts, and engineering are taken into account. The probability of interruptions is checked by running a Monte-Carlo simulation of the line-of-balance schedule and the results are used in refining the schedule. During the implementation phase, control features in DYNAProject™ allow easy input of actual completion data and forecasting of future problems.

DYNAProject™ is the first comprehensive line-of-balance tool in the market and has been widely tested in Finland. Benefits of the system include allowing the user to plan a feasible schedule that is not sensitive to disturbances. Managers can see graphically the trade-off between schedule duration and sensitivity to disturbances. Buffers can be planned to minimize the effect of workflow variability. During the implementation phase, the schedule can be implemented as planned. Effects of deviations can be assessed immediately and the effectiveness of available control actions can be evaluated. The fast adoption of the system in Finland proves its added value compared with earlier scheduling systems.

KEY WORDS

Line of balance, schedule planning, schedule control

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INTRODUCTION

The objective of this paper is to show that the Modified Line-of-Balance method can be used as the control tool for a construction project and that the Line-of-Balance has properties that allow the schedule to be implemented as planned.

BACKGROUND

Modified Line–of–Balance has been the dominant scheduling method in Finland since the 1980s. Research on line-of-balance was started in Helsinki University of Technology in 1985 by professors Juhani Kiiras and Jouko Kankainen. The reasons for the research were the poor implementation of schedules and poor economic results during the Finnish construction boom of the early 1980s. Research was conducted using the action research method. The main theoretical results of the sixteen finished research projects can be summarized as follows (Kankainen and Kolhonen 2003):

- the feasibility of the master schedule must be checked before production begins
- when actual production deviates from plans, control actions must be taken to put the project back on schedule rather than updating the schedule
- production control must ensure continuous work flow by use of free spaces

In the early stages of the research, production control was based on weekly planning. However, week planning resulted in the shifting of work (and problems) towards the end of the project. As a result, research began on task planning as a project control method to ensure that production would be implemented according to the master schedule and that the starting constraints of tasks would be fulfilled (e.g. Junnonen 1998, Koskenvesa & Pussinen 1999).

The central finding of the research projects was that scheduling with Modified Line-of-Balance makes it possible to control projects so that the master schedule can be implemented as planned. To achieve this, the master schedule must be planned so that sensitivity to disturbances can be analyzed and resources used continuously. During implementation, control actions must be taken to catch up with the original schedule if there are disturbances (Kolhonen, Kankainen & Junnonen 2003).

The tools have been tested in sixteen Master's thesis level research projects and refined in dozens of projects including both routine production (areas of 2,500 – 12,000 m2) and special projects (office buildings, high tech office buildings, a hospital, an airport terminal, areas of 16,000 – 45,000 m2). Modified Line-of-Balance has become the standard planning and control method in Finland. The biggest benefits have been realized in special projects (Kankainen and Kolhonen 2003).

LEAN CONSTRUCTION RESEARCH

The goal of Lean Construction philosophy is to avoid waste (Shingo 1988). Although the Finnish research has so far been conducted independently of Lean Construction research, the goal has been the same. Planning for continuous resource use aims at minimizing waiting time. Analyzing the sensitivity to disturbances makes buffer size optimization possible.

Optimization of control actions aims at minimizing disturbances if there are deviations from the master schedule.

Mendez and Heineck (1998) describe a production preplanning process that lumps together interdependent work and calculates how many optimal sized crews must be employed to achieve the same production rhythm for the main tasks in the same construction phase. During the implementation phase, the lumped work can be exploded to achieve the desired level of scheduling accuracy. This approach resembles very much the Finnish way of planning master schedules. Similar works are lumped together, synchronized with other tasks by planning similar production rates in terms of places, and rhythmed to ensure continuity (Kankainen & Sandvik 1993). During implementation, the big tasks are exploded by task planning (Junnonen 1998).

Yang and Ioannou (2001) describe the scheduling requirements for repetitive projects and a computational algorithm that fulfills those requirements. The main required attributes can be briefly summarized. Resources can have variable production rates and variable work quantities at different work locations. Activities can have multiple predecessors and successors with a full set of dependency relationships. Tasks can have complex work sequences. Work interruption should be allowed if desired. The non-repetitive portion of work should be incorporated into the framework of repetitive scheduling. These requirements are fulfilled by DYNAProject™ and Modified Line-of-Balance.

Yang (2002) used simulation to show the cost savings gained through continuous use of resources. It is assumed that crews are paid from the moment they start work on the first unit until they fully complete work on the last unit. With this assumption, the cost-saving benefits were demonstrated to be 30 % for the small case project.

DYNAPROJECT™ SOFTWARE

To allow easier use of the Modified Line-of-Balance production planning and control system in practice, a commercial software tool was developed by Dynamic System Solutions Inc. in collaboration with Helsinki University of Technology and four big Finnish construction companies (Skanska, NCC, Hartela, SRV Viitoset). Earlier line-of-balance software on the market started from CPM and Gantt chart methods and allowed conversion from Gantt chart to line-of-balance. This was too cumbersome an approach and lacked the control aspect, so new software was needed. The need for easy-to-use Line-of-Balance software has also been highlighted in recent journal papers (Arditi, Tokdemir and Suh 2002).

DYNAProject™ was planned to implement the whole Finnish production planning and control system. In the planning phase, a bill-of-materials or cost estimate can be imported from other systems, Line-of-Balance is used as the main planning tool, section building order can be easily analyzed, and the feasibility of the schedule can be assessed using simulation. In the implementation phase, the control view is used to input actual start dates and durations for places, actuals are shown in the Line-of-Balance, forecasts are calculated from the actual production rates, and the total effects of deviations are shown graphically. DYNAProject™ enables the user to control the production and evaluate possible control actions. This makes possible the implementation of the master schedule as planned.

PLACE DIVISION OF THE PROJECT

Schedule planning begins by breaking down the project into physical sections. A section is usually defined as the smallest area where the framework of the building can be erected independent of other sections. This means that the sections are alike for every floor. Sections are further divided into floors and/or spaces. The place hierarchy is project-specific: different division principles can be used in different projects.

Section division allows interior works to begin earlier in the first section and thus reduces the project duration. The schedule can be compressed by choosing the optimal construction sequence. Schedule compression requires that the same construction order and section division be used for all tasks. In DYNAProject™, the construction order can be changed at any time; all the dependencies of schedule tasks are preserved and the results of the changed order can be seen graphically.

CREATING THE LINE-OF-BALANCE MASTER SCHEDULE FROM A BILL OF MATERIALS

In DYNAProject™, the planning starts from the bill of materials or cost estimate for the project. The bill of materials or cost estimate items are grouped together to form a master schedule task. Tasks are formed from works that have the same schedule dependencies with other works and that can be done by the same crew.

When creating the master schedule the most important schedule tasks to schedule are those that do not allow other crews in the same place at the same time. These tasks are called space-critical tasks. Significant works that are not space-critical can be left out of the line-of-balance master schedule and be shown in the Gantt chart and scheduled using the critical path method (for example faade work). Other small works can be left unplanned during master schedule planning and used as workable backlog during implementation. However, these small works should not exceed 15 % of total project man-hours. (Kankainen and Kolhonen 2003)

For every schedule task, the following information is needed:

1) Amounts for every place and resource consumption (manhours / unit)
2) Place completion order
3) The optimal crew composition
4) Dependencies to other tasks

Duration for every place is automatically calculated from the amounts assigned to the task, productivity information in the cost estimate or company database, and workgroup information input by the user or taken from a template file. The total man-hours for the schedule task in a place, divided by the number of workers, gives the duration in the place. In Finland, productivity information has been collected as a joint effort by the construction industry since 1975 and this is used to provide good target production rates for different works (Olenius, Koskenvesa and Mäki 2000).

In DYNAProject™, tasks have two kinds of dependencies. Internal dependencies are dependencies between different places in the schedule task. They are automatically created according to the place completion order. Internal dependencies are automatically changed when section completion order or schedule task completion order is changed. This allows for easy evaluation of different construction orders. External dependencies are planned by the user. They are dependencies between two schedule tasks. External dependencies are copied for every place of the schedule tasks, facilitating easy Line-of-Balance use. Non-repetitive portions of the project are scheduled by planning external dependencies between non-repetitive and repetitive tasks. Non-repetitive tasks can be located in one or more places of the project or they can be location-independent.

SYNCHRONIZING TASKS AND PLANNING BUFFERS

To minimize the effects of task duration variability, buffers are planned between the space-critical tasks and the space-critical tasks are synchronized. Synchronization means that tasks are scheduled so that preceding and succeeding tasks have similar paces. To change task pace the number of crews or work content of the task is changed. In DYNAProject™, duration changes based on number of crews are done in the line-of-balance view by dragging and dropping the schedule task. Work content changes are made by cutting and pasting bill-of-materials items from task to task.

A start-up delay and vertical space buffer are planned between space-critical tasks. The buffer sizes and length of start-up delays depend on the desired duration for the project and the chosen risk level. In routine production, the normal values used in Finland are two weeks for the start-up delay and two floors for the space buffer (Kankainen and Sandvik 1993). In special projects, a start-up delay of three weeks is normally used because of greater uncertainty (Kiiras 1989).

In addition to space buffers, schedule buffers are added. Allowances are made for weather (a major concern in Finland) and other unforeseen interruptions. The schedule buffers do not affect the target production rates and are thus better in production control than capacity buffers.

CHECKING THE FEASIBILITY OF THE SCHEDULE: MONTE CARLO RISK ANALYSIS

In DYNAProject™, Monte Carlo simulation is used to evaluate the feasibility of the schedule. Starting time distributions reflect the uncertainty in the prerequisites of the task while duration distributions reflect the uncertainty associated with the production rate of the task. To make it simple for end users only the Beta distribution is used. The user has to input the optimistic, expected, and pessimistic starting date as delta from the planned date. The duration distribution is input by specifying the optimistic, expected, and pessimistic duration as delta from the planned duration.

The most important results of risk analysis are the alarm dots in the line-of-balance. Alarm dots indicate places where there is a high probability of interrupted work. Work is defined as interrupted if a preceding task causes work to become discontinuous. Red dots indicate a very high probability (> 80 % of simulation rounds), yellow dots indicate a high probability (50 – 80 % of simulation rounds), and green dots indicate a moderate probability (30 – 50 % of simulation rounds).

Finnish research has found that every project benefits from risk analysis during master schedule planning. In one research project, four construction projects (areas of 14,000 to 25,000 m2) were analyzed with the tool and the schedules were re-planned, resulting in a much higher quality of final master schedule. Changes prompted by the risk analysis included changing the section building order, re-planning overlapping interior works and rescheduling the tasks most prone to disruptions (Kolhonen, Kankainen & Junnonen 2003).

DYNAProject™ also produces endtime distributions. Distributions can be viewed for the finish date or for any milestone. Distributions are used to assess how much control is needed during the project and to show the schedule effects of change orders. Change orders can be incorporated into an existing schedule task as a new bill-of-materials row and targeted to a place, or alternatively a new task can be added. Using the same distributions and dependencies as the baseline schedule allows the effect on milestones and project duration to be shown. We were consultants in a claim process and were able to show with a simulation that the contractor's original schedule was feasible and that more time would have been needed in order to complete the work because of delays in owner-controlled procurements and design.

INTEGRATING THE PROCUREMENT SCHEDULE INTO THE MASTER SCHEDULE

Once the master schedule is complete, the procurement schedule is planned. Procurement tasks are composed of bill-of-materials items. The selections are independent of the schedule task selections. For example, all the concrete used in different schedule tasks can be lumped together to form a procurement task.

DYNAProject™ calculates the need times and amounts for procurement tasks for different places and different materials. The user inputs the procurement events that have to be completed before the work can start. These events can include making the contract, evaluating bids, making a call for bids, and design specifications. The events are linked by dependencies to the start date of delivery. If the master schedule is changed the procurement schedule changes automatically.

Procurement schedule integration enables the user to plan the fulfillment of starting constraints very early in the planning process. This facilitates the implementation of the master schedule as planned. (Junnonen and Kankainen 2001)

TASK PLANNING – ACCURATE PLANNING NEAR IMPLEMENTATION TIME

In the Finnish production control system, look-ahead planning is done using task planning. Task planning is done before beginning the task. It includes accurate plans of schedule, costs and quality, checking the prerequisites for the task, and analyzing the potential problems associated with the task. The task plan is produced by the people responsible for the work (e.g. Junnonen 1998).

Master schedule tasks composed of many bill-of-materials items are exploded into subtasks. Master schedule task timing sets constraints for subtask scheduling. Production management can choose the way to achieve the master schedule target. Implementation methods, work content, crew composition, and workers can be changed by project management in order to achieve the master plan schedule and budget. Deviations in one task cause deviations in other tasks and this Parade of Trades leads to waste and loss of productivity as shown by Tommelein, Riley and Howell (1998) in their Parade Game simulation. Thus, no deviations can be allowed to happen and goal management in the form of task planning is used to ensure that good solutions are found.

Task plans prepared before the beginning of the task emphasize goal management. You have to start the task when it SHOULD start but you can choose the implementation methods so that you CAN and WILL satisfy all the constraints before the start of the task. If it is impossible to start a task because of deviations in earlier tasks, it is sometimes possible to change the technical design to allow the work to be implemented as planned. For example, in a Finnish case project, precast façade elements had delivery problems and would have impacted the start of roofing work. During task planning, the design was changed so that the technical dependency was broken and the roofing could start as planned. (Toikkanen 1989)

The implementation of the master schedule is ensured by using the task plan as the basis for good contracts with the subcontractors. For example, payments can be tied to the finishing of places to force the subcontractor to do the work in the right sequence.

The master schedule is updated only as a last resort. Sometimes no alternatives satisfying the master schedule constraints can be found. In this case, the objectives are revised so that the effect on other space-critical tasks is minimized.

ACTUAL COMPLETION DATA

During implementation, DYNAProject™ allows the input of actual implementation data in a control chart. The control chart has the place division on the left side and the schedule tasks below the chart. Each square represents a schedule task in a given place. The squares are color coded to signify the status of the place. Green places are ready, blue squares are on the way and are on schedule, yellow squares are places that have been started but are late and red places have not been started and are late. The status of the project can be seen at a glance.

The actual data is drawn in the line-of-balance schedule as a dotted line. The original schedule is preserved and possible deviations can be seen at a glance by comparing the planned and actual lines.

Once two or more places have been completed for a task a forecast is calculated by comparing the actual production rate to the planned production rate. The forecast assumes that work will continue at the same pace. Dependencies planned during the planning phase are used to assess the effect on succeeding tasks. When deviations occur, their impact on the succeeding tasks, project duration, and milestones is shown immediately. Red alarm dots alarm the user when deviation causes deviations in other tasks. (Figure 1)

The forecast lines force the management to take corrective action if the production rates do not fulfill the objectives. It shows graphically when deviation in the preceding task causes the succeeding tasks to run out of space and thus lose the prerequisites for continuing.

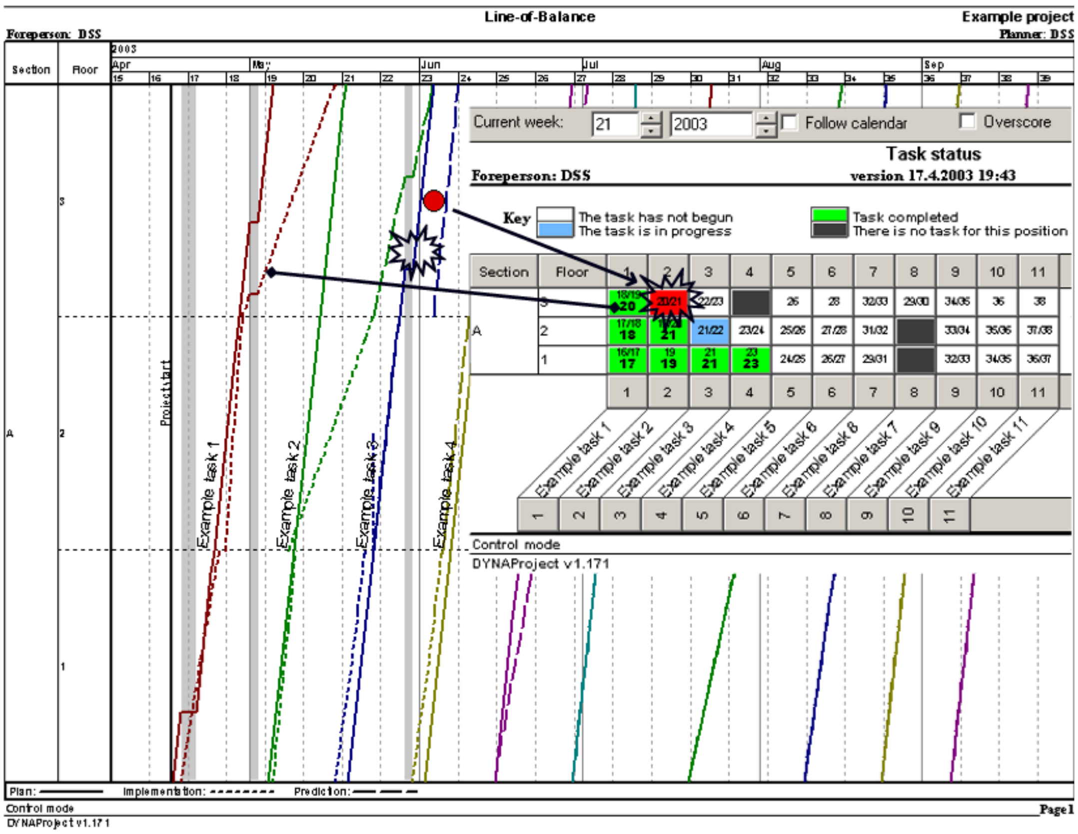

Figure 1: Control chart and actuals in Line-of-Balance, red alarm dot indicates alarm when preceding task causes the following task to run out of space

USING LINE – OF – BALANCE TO MAKE CONTROL ACTION DECISIONS

The master schedule is NOT updated if deviations occur. The reasons for the deviation are documented to facilitate learning and to support possible claims. A control action is planned to minimize the effects on other space-critical tasks and the forecast is updated correspondingly. By double clicking the alarm dot, the user can access the control action dialog.

In the control action dialog the user can select measures to get the project back under control. The available actions include changing the calendar (for example working longer days or at weekends), adding resources, changing the work content, or changing the production rate (for example slowing down an overly fast task). Actions can be selected for all tasks. The accepted plan updates the forecasts and it is documented in the control action log.

The possibility of evaluating control actions is the biggest added value of the software. By seeing the total effects of deviations on the schedule, the management can choose the most cost-effective way of catching up on the original schedule. The software facilitates this by graphically showing the effects of control action plans without changing the original schedule. Control actions can be planned for many tasks and the schedule can be caught up incrementally over a long period.

SCHEDULE CAN BE IMPLEMENTED AS PLANNED

We have cases that have been completed almost fully according to plan. There have been some disturbances but control has been used to minimize the effect of deviations on other tasks and to catch up on the original schedule. To show that this is also doable with special projects we selected Innopoli as the example to present here. Innopoli was constructed by YIT. The implementation on site was managed by Simo Särkkälä and his supervisor Pekka Sipponen. Innopoli is a new business incubator. The contract form was Design-Build. Figure 2 presents the line-of-balance with the actual completion lines. To maintain clarity, only the space-critical construction works are shown. Line-of-balance was the principal planning and control tool.

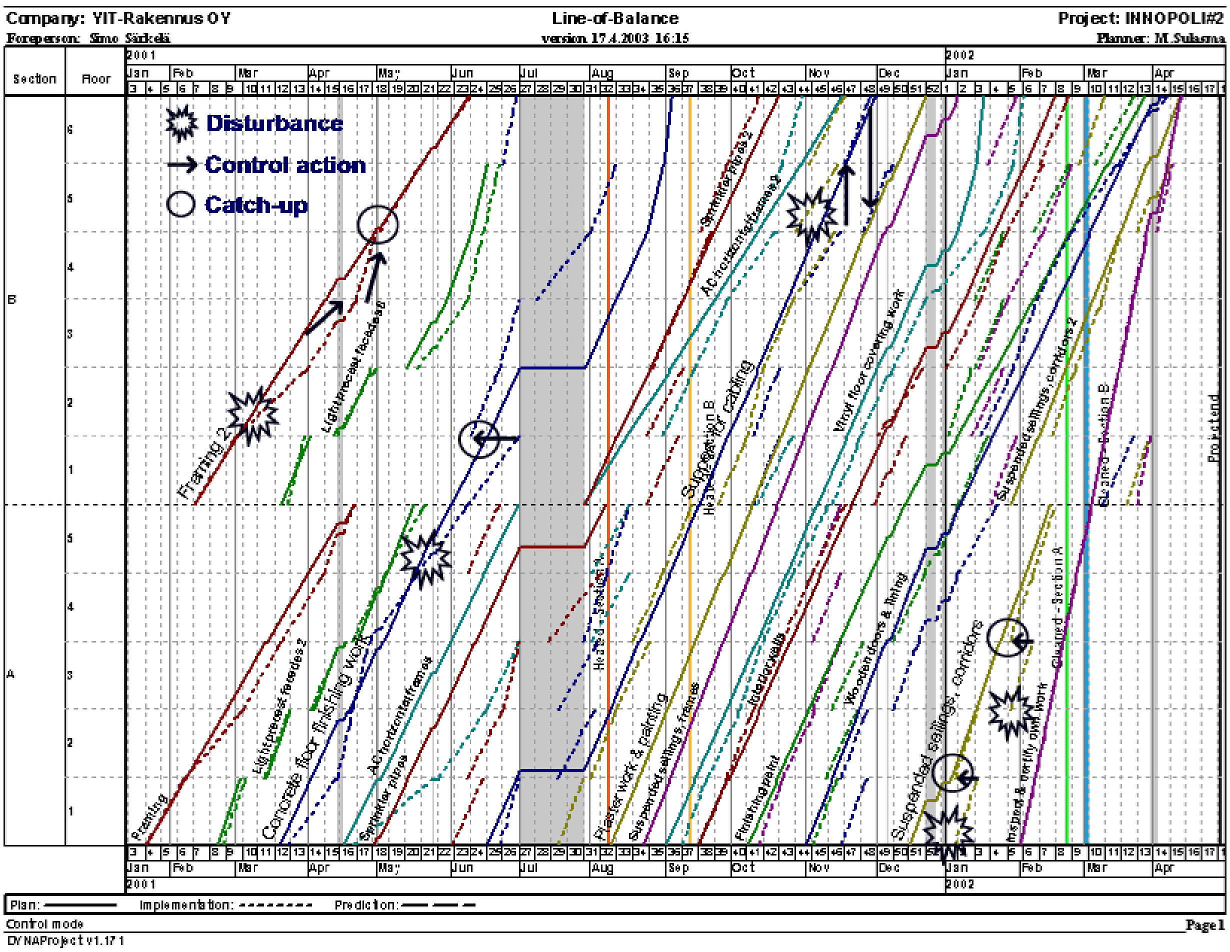

Figure 2: Modified Line-of-Balance in the Innopoli project. Sizes of places on the vertical axis are proportional to the size of the place. Solid lines are planned timings, dotted lines are actual timings. Some disturbance spots and effects of control actions have been emphasised. The schedule has been planned so that it has been possible to work continuously. Works have been completed almost as planned. Control actions have been taken to catch up on the original plan. The project was completed on time.

The project was completed before DYNAProject™ was finished but many software features, including the control chart, were used in this project with manual applications (using MS Excel). DYNAProject™'s risk analysis was used to refine the schedule before implementation.

BENEFITS OF THE SYSTEM

A lot of research has been done in Finland about the benefits of the described production planning and control system. The main result is that production can be implemented as planned if an adequate space buffer has been planned between space-critical tasks and if the procurement tasks have been done on time. Four Master of Science level research tests have shown this (for example Toikkanen 1989, Venermo 1992).

Other benefits include:

- compressing the schedule using place division and overlapping production in sections (for example Kankainen & Sandvik 1993, Kankainen & Kolhonen 2003)
- increasing productivity, less waiting hours and less hurried work (for example Kankainen & Kolhonen 2003, Toikkanen 1989)
- use of resources can be planned to be continuous and level. This results in lower costs (Yang 2002) and less deviations in production (for example Kankainen & Sandvik 1993)
- DYNAProject's control features are graphical and easy to use
- other production control systems can be easily integrated with the system. For example, Kankainen & Seppänen (2003), describe how the Last Planner™ system of production control can be integrated with the system.

LIMITATIONS

Use of DYNAProject™ requires understanding of the Modified Line-of-Balance method. This has not been a limitation in Finland because the Modified Line-of-Balance has been used there for a long time and every construction engineer is trained in the method. In other countries, the theory behind the software is not so familiar. The goal of the authors is to show that Line-of-Balance can be used as a practical tool to schedule and control even special projects.

The more advanced features of DYNAProject™ are not used by all users because of their complexity. Monte Carlo simulation is difficult to grasp for many in the industry. Control action plans are often not analyzed to the full extent possible. In the schedule-planning phase, the more advanced alternative evaluation features are not well used. However, the situation seems to be improving with training and there are many projects where the full potential of the software is being realized.

The benefits of Line-of-Balance scheduling are dependent on the quality of starting data. Because amounts need to be calculated for every place, the section division must be decided very early in the project to gain maximum benefits from the software. If the amounts are not calculated by places, the planner must make assumptions or manually measure the amounts. The first alternative results in loss of accuracy and the second results in extra work. The quality of starting data is rapidly improving in Finland because contractors are demanding the amount information in the form required by the software.

CONCLUSIONS

The purpose of this paper was to show that modified line-of-balance based planning makes implementation according to plan possible and that DYNAProject™ software can be used as a practical tool to help control the project. It is very important in the schedule-planning phase that the starting prerequisites for tasks are ensured by master schedule planning. This is done by planning space buffers between tasks and by using line-of-balance to plan for the continuous use of resources. Simulation is used to evaluate the success of planning. During implementation, the master schedule tasks are exploded by task planning. Control of the schedule is more important than the actual planning. Tasks must be monitored continuously and control actions must be taken if there are deviations. To achieve effective control a tool that shows the total effects of deviations is needed.

With over 200 new users in 2003 DYNAProject™ is rapidly replacing the earlier CPM –based schedule planning systems in Finland.

REFERENCES

Arditi, D., Tokdemir, O.B. and Suh K. (2002). "Challenges in Line-of-Balance Scheduling". *J. Constr. Engrg. and Mgmt.*, ASCE, New York, NY, Vol. 128 No. 6. pp. 545-556

Junnonen, J-M. and Kankainen, J. (2001). *Rakennusurakoitsijoiden hankintakäsikirja*. (Procurement handbook for contractors). Kehitys ja tuottavuus –sarja 70. Confederation of Finnish Construction Industries RT. Helsinki, Finland. 158 pp.

Junnonen, J-M. (1998). *Tehtäväsuunnittelu ja laatupiiriohjattu tuotannonohjaus.* (Task planning and quality circles in production control). Licentiate Thesis, Construction Economics and Management, Department of Civil and Environmental Engineering, Helsinki University of Technology. Espoo, Finland.

Kankainen, J. and Kolhonen, R. (2003). *Rakennushankkeen aikataulusuunnittelu ja valvonta.* (The schedule planning and control of a construction project). Rakennustieto Oy, Helsinki, Finland.

Kankainen, J. and Sandvik, T. (1993). *Rakennushankkeen ohjaus*. (Controlling a construction project). Confederation of Finnish Construction Industries , Rakennustieto Oy, Helsinki, Finland. 103 pp.

Kankainen, J. and Seppänen, O. (2003) "Suomalaisen tuotannonohjausjärjestelmän ja Last Planner –menetelmän vertailu" (A Comparison of the Finnish production control system and the Last Planner system) Rakennustekniikka 1 / 2003. Association of Finnish Civil Engineers. Helsinki, Finland.

Kiiras, Juhani. (1989) OPAS ja TURVA, Erityiskohteiden työnaikaista ohjausta palveleva aikataulu- ja resurssisuunnittelu. (A schedule and resource planning system for the implementation phase control of special projects). Helsinki University of Technology Construction Economics and Management Publications. Espoo, Finland

Kolhonen, R., Kankainen, J. and Junnonen, J-M. (2003). "Rakennushankkeen ajallinen hallinta." (Time management of construction projects). Helsinki University of Technology Construction Economics and Management Publications 217. Espoo, Finland.

Koskenvesa, A. and Pussinen, T. (1999) *Opas urakoitsijan tehtäväsuunnitteluun.* (A guide for contractor's task planning) Kehitys ja tuottavuus –sarja 60. Confederation of Finnish Construction Industries RT. Helsinki, Finland. 82 pp

Mendez, R. Jr. and Heineck. L. F.M., (1998) "Preplanning Method for Multi-Story Building Construction Using Line Of Balance." *Proceedings of the Sixth Annual Conference of the International Group for Lean Construction (IGLC-6)*, Guarujá, São Paulo, Brazil

Olenius, A., Koskenvesa, A. and Mäki T,. (editors) (2000). *Ratu Aikataulukirja 2001*. Confederation of Finnish Construction Industries RT and Rakennustietosäätiö. Tampere, Finland.

Shingo S. (1988). *Non-stock production.* Productivity Press, Cambridge, MA, 454 pp.

Toikkanen, A. (1989). *Erityiskohteen aikataulun laadinta ja työnaikainen ohjaus*. (Scheduling and control of a Special Construction Project). Master's Thesis, Construction Economics and Management, Department of Civil and Environmental Engineering, Helsinki University of Technology, Espoo, Finland. 109 pp.

Tommelein, I.D., Riley, D., and Howell, H. (1998). "Parade game: Impact of work flow variability on succeeding trade performance." *Proceedings of the Sixth Annual Conference of the International Group for Lean Construction (IGLC-6)*, Guarujá, São Paulo, Brazil

Venermo, T. (1992). *Pienen erityiskohteen tuotannon suunnittelu ja ohjaus*. (Control and planning of a small special construction object). Master's Thesis, Construction Economics and Management, Department of Civil and Environmental Engineering, Helsinki University of Technology, Espoo, Finland. 119 pp.

Yang I-T., and Ioannou P.G (2001). "Resource-Driven Scheduling for Repetitive Projects: A Pull-System Approach". *Proceedings of the Ninth Annual Conference of the International Group for Lean Construction (IGLC-9). Singapore*

Yang I-T (2002). "Stochastic Analysis on Project Duration under the Requirement of Continuous Resource Utilization". *Proceedings of the Tenth Annual Conference of the International Group for Lean Construction (IGLC-10). Gramado, Brazil.*