IMPLEMENTATION OF LINE-OF-BALANCE BASED SCHEDULING AND PROJECT CONTROL SYSTEM IN A LARGE CONSTRUCTION COMPANY

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ABSTRACT

Line-of-Balance has been successfully used as the principal scheduling tool in large construction companies in Finland. It has been utilized to improve the production flow in the projects. The problem in full-scale utilization was that there hasn't been a comprehensive Line-of-Balance software tool in the market. In international literature the usual view has been that the Line-of-Balance is only suited for highly repetitive routine construction. However, regardless of the difficulty of project, the main activities are the same in every project. In this paper it will be shown that resource-based Line-of-Balance can be successfully implemented as the main scheduling tool of a large company if there is an easy-to-use software tool to support the implementation.

Many of the possible applications and benefits of the Line-of-Balance have not been realized before the development of a commercial software tool, DYNAProject™. With DYNAProject the quality of schedules can be checked, the schedule risks can be analyzed, the project flow can be systematically controlled and control actions can be graphically evaluated and optimized. Line-of-Balance is used for planning but the familiar Gantt Chart can also be printed out. NCC, a large contractor in Finland, was one of the pilot companies of the development project. NCC has started a large-scale implementation project with DYNAProject which has resulted in significant improvement in the quality of schedules. DYNAProject is the first computer tool which makes possible the systematic controlling of the schedule. The challenges of implementation included the difficulty of embracing new thinking in planning and controlling projects and how to systematically utilize the cost estimation data in schedules. In the long run, the anticipated benefits include minimizing the risk level of the projects, increasing the quality of service to the customer and optimizing the logistics of the project.

KEY WORDS

Line-of-Balance, Scheduling, Implementation

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INTRODUCTION

Line-of-Balance is a graphical scheduling method which considers location explicitly as a dimension. This allows for easier planning of continuous resource use, which in turn enables cost savings and less schedule risk as subcontractor crews can be kept on site.

In earlier papers Line-of-Balance has been considered mainly a tool for highly repetitive construction (e.g. high-rise apartment buildings or road construction) and not suitable for non-repetitive, one-of-a-kind special projects. (e.g. Arditi et al. 2002)). In contrast, in Finland, the Line-of-Balance has been the principal scheduling tool in large construction companies since 1980s. (e.g. Kiiras 1989, Kankainen et al. 1993) The Finnish clients demand the use of Line-of-Balance scheduling both in challenging special projects and in residential construction. The biggest benefits have been achieved in special projects.

In Finnish research, a schedule controlling philosophy has been built on the principles of Line-of-Balance (LoB) method (e.g. Kiiras 1989, Kankainen & Sandvik 1993). The features of LoB based schedule planning and control system have been described in more detail in (Kankainen & Seppänen 2003). Despite the widespread use of the method there have been problems in implementation. Many users of the method just drew the schedule without considering all the logical links between activities. The control features require a lot of time if they are implemented manually. The decisions underlying LoB lines were badly documented. Because of these problems, the Finnish construction industry started a software development project. The result, DYNAProject™, is a LoB –based software tool, which makes it easy to schedule and control a project. However, a software tool is useless unless it is supported by a standardized way of scheduling and checking the quality of schedules.

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 downstream schedule effects if there are deviations from the master schedule.

This paper differs from other papers about LoB in its practical focus: the ideas presented here have been successfully implemented in real projects. Earlier papers 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) While these papers give good theoretical foundation to the method, they don't describe utilization of these concepts in real projects. This paper describes a comprehensive schedule planning and controlling methodology based on LoB, a software which is based on that methodology and successful implementation in a large construction company.

The objective of this paper is to describe a better way to schedule and control projects and how this standardized scheduling methodology has been implemented in a large construction company supported by a commercial software product. The differences between new – standardized - way of LoB scheduling and the old use of LoB method are described first. Then the implementation process is described. Some of the potential benefits are shown with the use of case examples. Finally, the benefits and challenges of implementation are described.

METHODS

The study was conducted by examining the standardized scheduling process of NCC Construction Ltd, a large Finnish construction company. The process was studied by interviewing managers and trainers (one of the authors is a senior vice president of the company responsible for development). The implementation process was studied by interviewing the trainers and examining the training logs (one of the authors is in charge of the implementation process). Benefits were evaluated qualitatively by examining a few case examples selected by management.

NCC'S VISION OF SCHEDULE PLANNING AND CONTROL

NCC has developed a standardized way how the construction should be scheduled and controlled in the company's projects. The standardization makes it possible to standardize the quality of scheduling and to quickly analyze feasibility of schedules. It also enables standardized and effective schedule reporting to management and client. Earlier every planner had his / her way of scheduling and most of the decisions were not documented in a consistent way.

LoB has a critical role in the new methodology as the main scheduling tool. Critical Path Method dependencies are used to facilitate feasible LoBscheduling. All scheduling decisions are made by using the LoB method. The traditional Gantt Chart is used for communication with subcontractors and with clients who may not be familiar with the LoB method. Earlier LoB was used in planning but often the Gantt Chart was drawn first and then converted into LoB. Dependencies weren't explicitly planned so it was difficult to check if the schedule was feasible or not.

All planned activities are based on quantities and are resource loaded. Quantities are calculated for every location in the project. All schedules are based on resource consumptions of the cost estimate of project. The main principles of planning include that similar work should be scheduled continuously with as little changes in the amount of resources as possible. All important tasks should be included in the schedule and the total schedule coverage should be at least 80 % of project's manhours. Cost estimate has usually about 150 tasks whose costs are controlled. A typical master schedule has about 30 tasks depending on the share of building services (heating, ventilation, electricity, air conditioning, plumbing, telecommunications). 15-20 most important tasks are selected to be scheduled in the LoB and are synchronized (crews are sized so that tasks proceed at the same pace) and paced (crews proceed continuously through locations). The important tasks are those that can't be done simultaneously in central locations of the project. (i.e. form a parade of trades (Tommelein et al 1998)). The rest of the tasks are scheduled using the CPM and shown in the Gantt chart. Regardless of project type the main tasks are always the same (i.e. have similar work content), which makes schedules easy to compare. Earlier the quantities weren't consistently used as basis of planning or at least weren't properly documented. Task lists and work contents differed remarkably in different projects. Resources weren't explicitly shown in the LoB, which often meant wildly fluctuating resource needs.

Tasks should be drawn to locations where they will actually be done. This makes it possible to locate deviations and to react to them before they occur. Location hierarchy must be designed so that all the critical locations of the project are included. In residential construction, the location hierarchy is usually quite simple with sections or individual buildings as the highest level and floors as the second level and individual apartments at the lowest level. In special projects, the location hierarchy is more difficult to design. Advantages of planning a hierarchical location breakdown structure include possibilities of optimizing construction sequence (which sections should be built first?) and the possibility of modeling very complex projects. Earlier applications of LoB usually consider locations on one hierarchy level (for example just floors of the building) (e.g. Harris & Ioannou 1998).

In interior works all the tasks should be synchronized to proceed with the same pace regardless of their work content. The number of crews is selected so that the tasks have similar durations. A synchronized schedule optimizes the use of space and makes every activity and location critical. To prevent disturbances schedule buffers are planned between critical tasks. Before, the work content of tasks wasn't explicit and resource needs were unknown because quantity information wasn't well utilized.

Before the schedule can be accepted, its feasibility is checked and corrections made. The checking of feasibility includes:

- checking the work contents of tasks
- examining the resource needs of the project
- checking the synchronization of interior works
- ensuring that there are enough schedule buffers in the schedule
- checking the quantities and their distribution to locations
- checking that the schedule covers at least 80 % of project's manhours and all the critical tasks
- checking the sequence of sections to optimize project duration

Checking the feasibility of schedules in a consistent way was very difficult before, because the quantities and resources were unknown.

Earlier on a separate rough schedule was made in the bidding stage. The aim of NCC is to make a full resource-based LoB schedule already in the bidding stage to optimize the construction sequence and to achieve duration cuts. In special projects a Monte-Carlo simulation is made to assess the risk level and to show points where more control is needed during implementation. Having a good schedule in the bidding stage lowers the bid as implementation alternatives can be evaluated. If NCC wins the project there is already a good schedule from which to begin planning of actual implementation.

Scheduling should happen on many levels. In the beginning, a feasible master schedule is made. The master schedule is exploded into phase schedules and they are in turn exploded into task schedules. All of the different schedules should be linked together so that all parties can get information about the schedule on the accuracy level that is most relevant to them. Before, all the different schedules were in different files and didn't have links to each other.

As a result of following the new methodology the site can report the progress to the management in a consistent way. It is possible to directly compare the quality and progress of different schedules and thus promote standardization of the schedule quality. During implementation the site reports the actual status of each task in every location providing real-time control data to management. The original master schedule is used for reporting to management and the client. Systematic control enables collection of vast amounts of actual data which can be used as basis for future projects.

To be able to implement the new methodology, NCC participated in the development effort of DYNAProject™. The development was a joint effort of four big construction companies, Helsinki University of Technology, Federation of Finnish construction industry and Dynamic System Solutions Ltd. To actually realize the benefits a major implementation effort was needed.

IMPLEMENTATION PROCESS

The implementation of the new methodology started in November 2002 after DYNAProject had been tested for six months in real projects. The implementation was divided into two rounds. In the first round, the objective was to improve the quality of schedules and to ensure their feasibility. After the second round, the progress should be reported to management in a standard way from every project and the project control should be optimized. After 1,5 years of implementation effort most of NCC's project engineers have completed the first round of implementation and are ready to start the second round in their next project.

A critical part before the actual implementation process was to standardize NCC's quantity take-offs and cost estimates. Without standardization the software would have been much more difficult to sell to projects because more manual work would have been needed. Earlier on quantity calculation was just a tool of calculating a bid price. With implementation of DYNAProject the quantities are calculated just once and they are utilized in all stages of the project. To accomplish this, every project scheduled with DYNAProject needs a quantity take-off start-up meeting in which the accuracy levels of quantities and location breakdown structure of the project are agreed on with the project team.

Actual implementation began already before the system was finished by informing staff of coming system. When the system was ready for implementation, a major effort to sell the new system to beginning projects was launched. The main principle was that the site should see the benefits and be willing to adopt the new system. Nobody was forced to use the software but the benefits and availability of the software and training were demonstrated to everyone. The demonstrations were done by concentrated sales campaigns to one business unit at a time. The sales effort succeeded remarkably well with 90 % hit rate in the first year. The usual reason for projects that didn't want the software was that the project was on way and there was no time to learn a new system in the middle of project.

If the project decided to adopt the system, training was given to project manager, project engineer(s) and their superiors in line management. Project engineers were the actual users of the software but the commitment of project manager and line management was needed to ensure success of the implementation. They were trained on how to use the information given by the system and what results and benefits should they expect. The interest of management increased the motivation of the users. The training included half a day of LoB scheduling theory, half a day of software training using the actual project data and half a day of checking the quality of the schedule and training the monitoring and control aspects of the system. In addition to training, coaching was given to project team so that they were able to finalize the schedule with good results. This lowered the scheduling tool switching resistance.

After 1,5 years of implementation 200 users have been trained including 11 managers, 36 project managers and 42 project engineers.

CASE EXAMPLES

The benefits of the system can best be shown by using actual case projects. The first case project was a small university building project of 4000 m2. The schedule was originally planned by using CPM and Gantt chart. Figure 1 shows the original schedule which has been transformed into a LoB schedule. (just the most important, critical tasks shown)

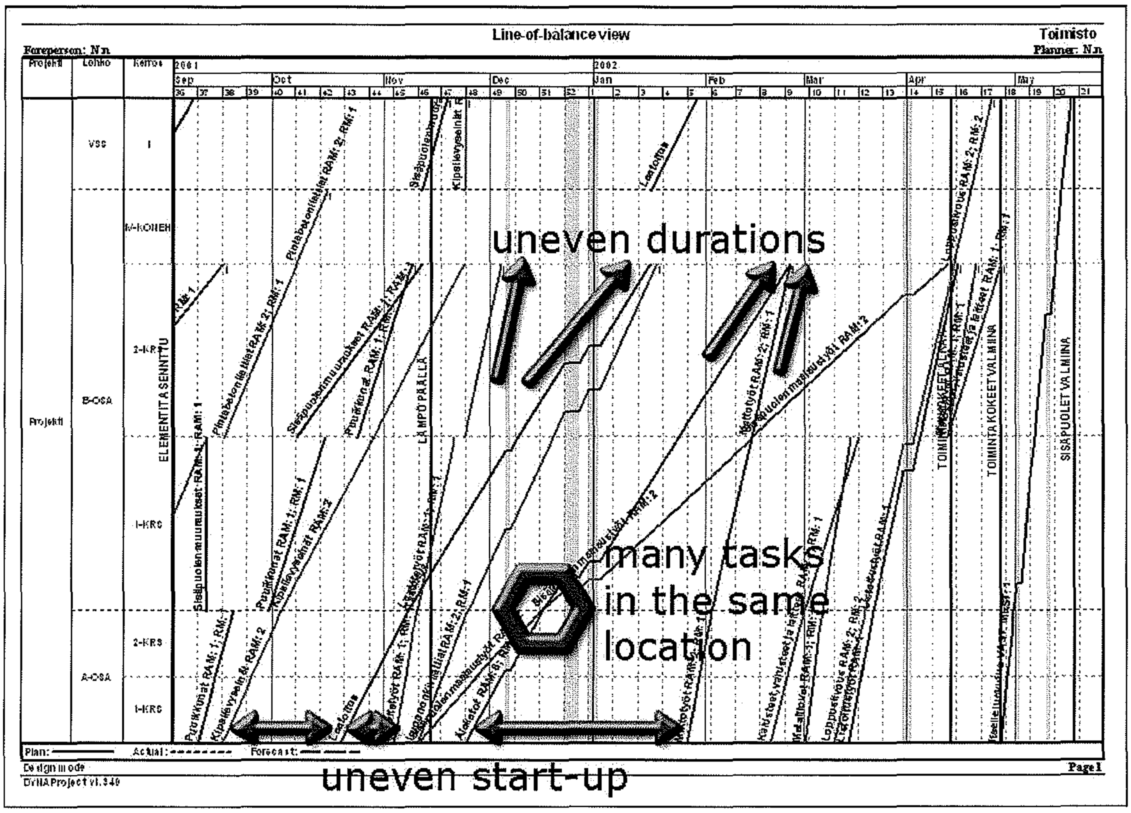

Figure 1: Original schedule planned with CPM and transformed to Line-of-Balance schedule.

In the original schedule there are a number of problems which can be seen at a glance from the LoB schedule. Some of the tasks intersect which means that the sequence of the tasks changes and the crews interfere the work of each other by working in the same location at the same time. The schedule is not synchronized which means that lots of time is wasted in the project. Each individual location is empty for a long period of time because start-up delays aren't even. Task durations are not based on productivity data but have been estimated. The effect of construction order of sections has not been examined.

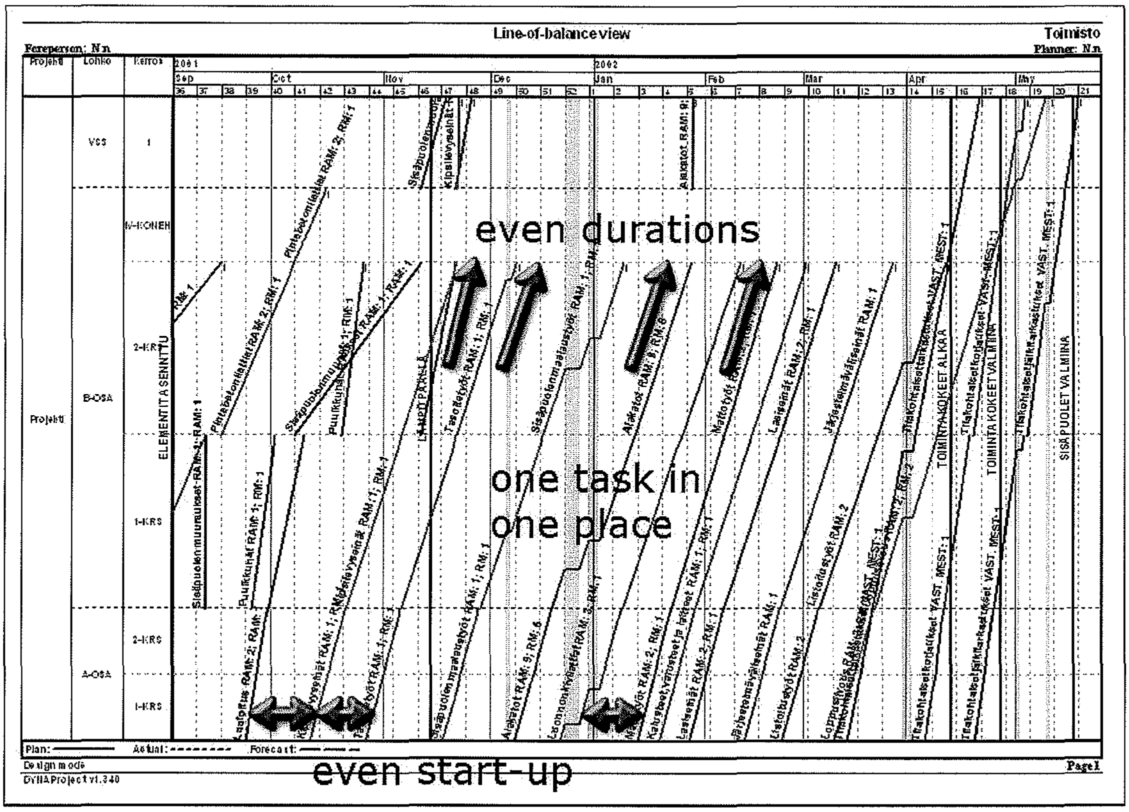

Figure 2: The same schedule planned with LoB.

The schedule planned again from the beginning by using the new methodology has solved these problems (figure 2). The tasks have even start-up delays and their durations are similar which makes all the locations critical and cuts wasted time. The tasks don't interfere with each other. The same duration is achieved with much less schedule risk and using 30 % less resources than in the original schedule. All task durations are based on quantities and productivity data. Project management agreed that the new schedule was better. The next similar project with the same team will be done from the beginning using the new tools.

The second example is an office building project of 27 400 m2 and a budget of 40 million euros. The example illustrates how duration savings can be achieved by changing construction sequence. Originally the site wanted to build the bigger part of the office building first without analysing the decision further. However by changing the sequence of sections using the same resources enabled duration savings of 8 weeks. The analysis was done with a few mouse clicks in DYNAProject. With two sections it would have been easy to see the difference just from task durations without using software. The true power of construction sequence optimization is realized in projects of four or more independent sections. Observations made in earlier real projects have shown that many of the projects have been implemented in wrong sequence. Figure 3 shows the schedule with the larger section built first and the associated 8 week time loss and figure 4 shows the optimized schedule with the smaller section built first. The analyses were done in the bidding stage and the cost estimate was based on the shorter duration.

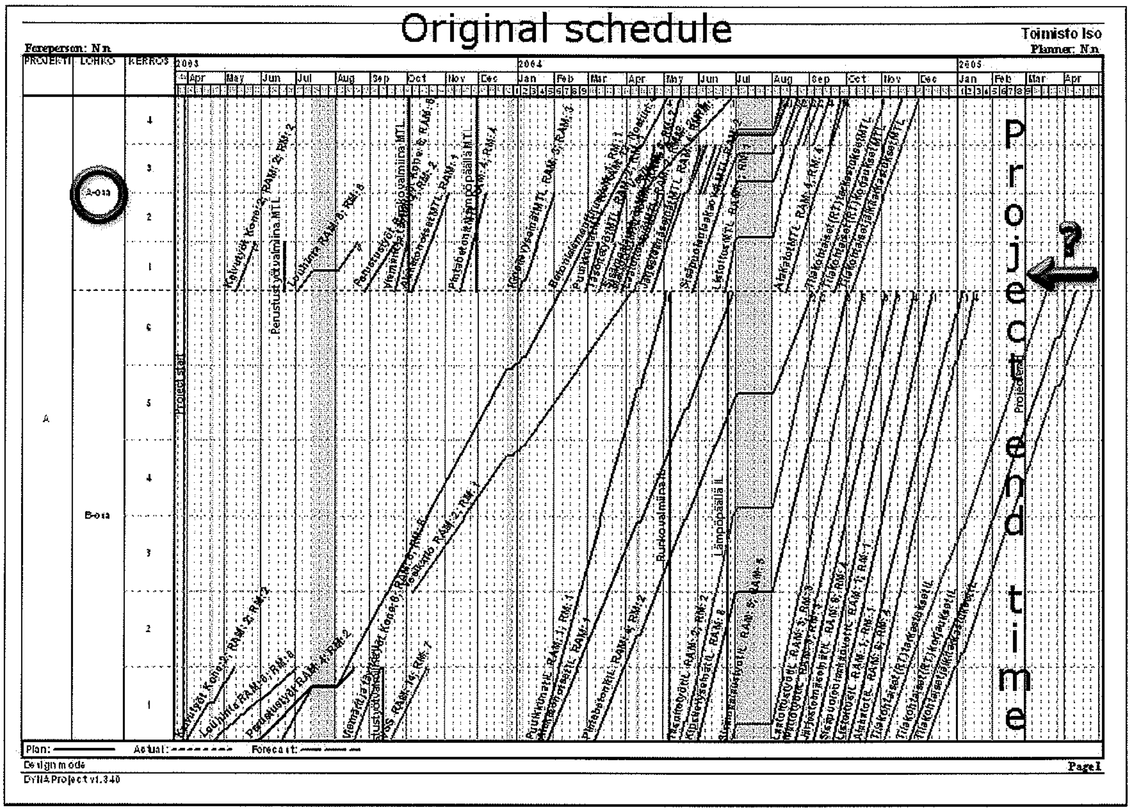

Figure 3: Original schedule: bigger building built first

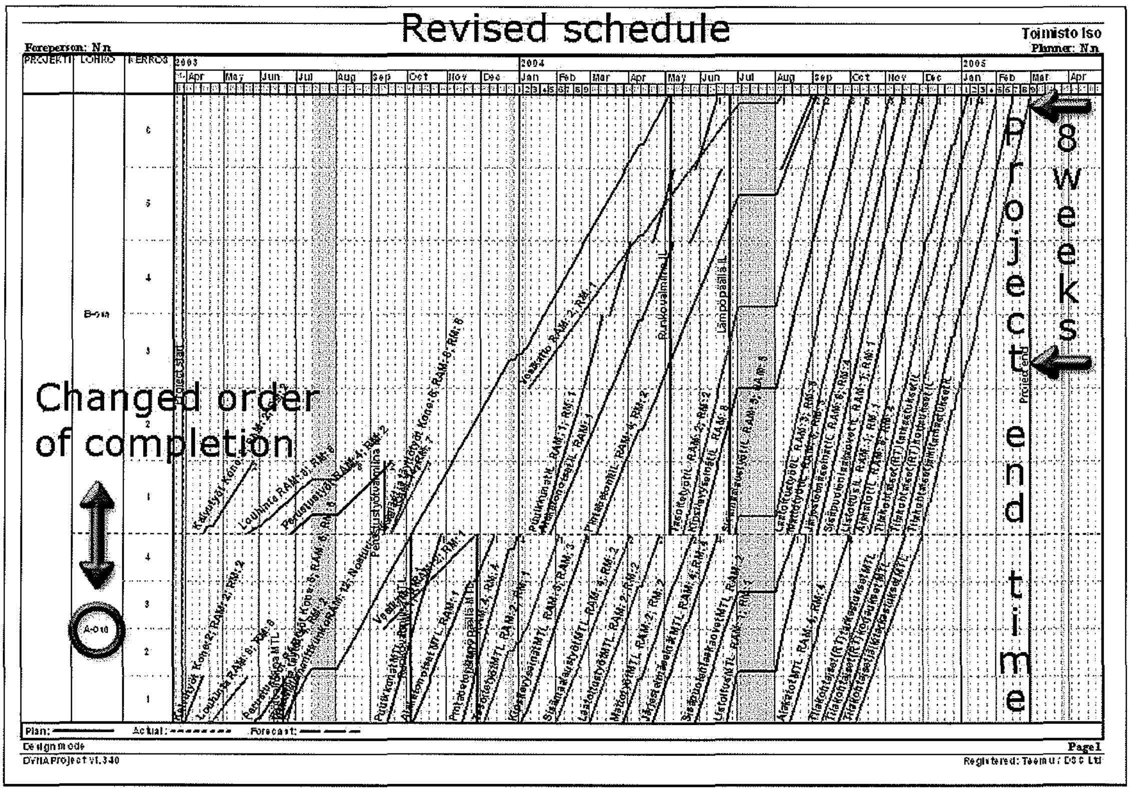

Figure 4: Changed order of completion cuts project duration 8 weeks.

In another case example the new methodology was adopted to optimize the final stages of a project which seemed to be doomed to disaster. The project was late 4-5 weeks and there was a feel of chaos on site. After an optimized schedule was planned with the site personnel and the control mechanisms of the system were introduced, the site finished on time with zero-errors level of quality.

REALIZED BENEFITS

The results of the training and adoption of the system have already delivered significant benefits. The quality of schedules has increased dramatically as sites adopt the new methodology. The quality of scheduling is now meeting management expectations: all schedules are planned in relation to location and time and different implementation alternatives are actively evaluated. In some cases evaluation of alternatives has enabled substantial cuts in project duration while using less resources and having less risk than in the original plan!

CHALLENGES OF IMPLEMENTATION

Overall the results have been promising. However, there have been some setbacks and challenges on the way. In a company of NCC's size there are a lot of projects beginning at the same time. The quality of starting data should be standardized so that there wouldn't be extra work to site personnel. The problems are related to relative undeveloped state of cost estimation tools. For example, the best cost estimation tools available in Finland allow just three place hierarchy levels while in special projects it is meaningful to plan with five or six hierarchy levels to model all the locations effectively. This results in manual work of having to distribute the quantities of cost estimate to more accurate place hierarchy.

Adoption of new ideas and ways of thinking always faces resistance in the organization. Old traditional ways of working are being changed by the implementation project. Quantity calculators must adapt to increased demands from projects. Projects must adapt to increased reporting demands from management. The new methodology makes mistakes done in the field transparent. It is very difficult if not impossible to falsify reports with the new control system. Increased interest of management in the schedule status brings benefits to organization but has led to resistance from some of the projects.

OBJECTIVES FOR THE FUTURE

In implementation side, NCC aims to have consistent management reporting and use of all the important features of the system by end of year 2005. All the projects should have quantity take-offs by location. Earlier scheduling systems have to be completely replaced to achieve the full benefits of the new methodology.

DYNAProject™ offers many options for future development. NCC is participating in a major development project which adds site micromanagement features, site logistics optimization, quality control and cost control to the system. Controlling of costs based on LoB becomes very important because the current cost estimate productivities have a lot of waste included in them. It is possible to show the effects of hurry and disturbances in productivity and cost. By adding costs on the control features, it is possible to collect data about cost effects of disturbances and optimize the schedule in terms of schedule, cost and risk. The new methodology offers fantastic opportunities for development of logistics optimization systems because it is the first scheduling system with quantity and time information for all the locations and all the materials of project.

Reporting to clients and management becomes more important when all the projects start using the system. Recently a database management reporting tool, which shows in a standardized way the status of ongoing schedule tasks and schedule problems of the project, has been developed. The managers can see the status of all their projects, the current problems and how the site has reacted. The reporting system will be implemented beginning in June 2004 and its functionality will be increased to include also costs, quality and logistics after the development project is finished. Some of the Finnish clients are demanding better schedule reporting. In the future systematic monitoring and control will be required from General Contractors. With the new system it is possible to answer the reporting challenges.

CONCLUSIONS

LoB can be adopted as the main scheduling tool in a large construction company. Implementation of new ways of thinking is never easy in a large organization but NCC's good experiences in Finland show that it is possible. NCC's success can be used to promote also other Lean ideas.

The benefits of implementing the new methodology include less schedule risk, better ways of analyzing alternatives, cutting of project durations, quick checking of schedule feasibility, real-time standardized reporting of progress to management and the possibility to optimize control actions and actually get the sites to control. In future, cost effects of adopting the system will be researched by utilizing data from actual projects. The benefits need to be quantified after the use has been established.

However, the biggest benefits and biggest challenges are still ahead. To achieve the full potential of the system, all projects should use it. Some of the project teams are reluctant to accept new ideas. The focus on controlling the project is new thinking for many project managers and the greater transparency towards management and the client is scary to some.

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