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# SIMULATION-BASED FINITE SCHEDULING AT ALBANY INTERNATIONAL

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## ABSTRACT

Simulation-based production scheduling approaches are emerging as alternatives to optimization and simpler approaches such as priority rules. This paper presents an application of a simulation-based finite scheduling at Albany International, the largest manufacturer of paper machine clothing in the world. Simulation is used as a decision support tool for manual schedule creation. User experiences have been encouraging. We argue that an optimization-based approach is not necessarily the most economical and identify a number of tentative key enablers of a simulation-based solution. The case indicates that a simulation-based solution is a viable option when the production process does not include combination of materials and local sequencing is adequate. A simulation-based solution capitalizes on this existing source of tacit knowledge by giving expert human schedulers tools for testing and improving schedules.

## 1 INTRODUCTION

Finite scheduling approach in manufacturing planning and control has been well-known for decades. Easy-to-use tools for that purpose are only recently emerging. Transaction processing orientated ERP and MRP-based solutions apply to infinite capacity models. They are acceptable when the goal is to get an alert of potential problems and based on that, take actions in e.g. increasing capacity. With the emergence of memory-resident Advanced Planning & Scheduling (APS) software the simultaneous consideration of materials and capacity constraints is becoming a viable planning option.

The idea of using discrete-event simulation (later referred to as simulation) in finite scheduling dates back at least in the 1980's. Strandhagen (1994) tells about the Norwegian SIMMEK project 1985-1990 where one goal was to develop simulation tools suitable for production scheduling. The interest has since grown considerably and Winter Simulation Conference 2002 had an entire track on simulation-based scheduling approaches. According to Musselman et al. (2002) simulation is well suited to the scheduling task since it can handle as much detail as is necessary to capture the subtleties of the manufacturing process. While the manufacturing simulation software domain has huge future, at present, however, there does not appear to exist a robust market like ERP (Bansal, 2002). Simulation-based finite scheduling solutions are proposed but they are far from dominating the market. There are different views on the usefulness and applicability of simulation-based finite scheduling.

This paper presents a new application of a simulation-based finite scheduling environment at Albany International, the largest manufacturer of paper machine clothing in the world (`http://www.albint.com`). We present key features of case production scheduling environment in order to explore general features of the environment where the simulation-based scheduling at present looks most promising. We also explain how simulation is used in finite scheduling at Albany and compare that to other APS approaches (optimization). The aim is to explore how simulation can be successfully applied in finite scheduling.

## 2 PRODUCTION SCHEDULING

Operations planning and control systems cover three stages: planning, scheduling and execution (Vollmann et al., 1997). The planning stage is concerned with balancing supply with demand. It includes demand management, resource planning and master scheduling. The scheduling stage produces more detailed plans for material and capacity requirements. Finally, in the execution stage orders are dispatched and fulfilled using the materials and resources that were allocated in earlier stages. In the classification of Scheer (1994), scheduling is concerned with sequencing orders that have already been released for production and with deciding exactly when and on which machines jobs should be processed. The primary goals of scheduling are to avoid late job completion, minimize flow times and to maximize resource utilization (Vollmann et al., 1997).

In infinite scheduling, also known as infinite loading, work is assigned to work centers simply based on what is needed over time (Chase et al., 2001). Although easy to implement, infinite scheduling often ends up in infeasible schedules that cannot be executed as planned. Finite scheduling (loading) considers exactly what each resource should do throughout the day. In theory, a finite schedule will always be feasible, as long as all possible constraints are considered and the schedule fulfills them all (Chase et al., 2001).

In forward scheduling, the system starts from the date when an order is released and calculates the earliest date when the order can be completed. The opposite approach is backward scheduling, where the system calculates the latest possible start date based on given a due date (Vollmann et al., 1997).

In job shop scheduling, any job can be processed on any machine in an order that is predetermined but can be different for each job. In a flow shop, all jobs are processed on the same sequence of machines but all jobs can have different processing times (Jain and Meeran, 1999).

## 3 SIMULATION IN PRODUCTION SCHEDULING

Simulation is emerging as a part of decision support systems for production scheduling. It provides an alternative when optimization approaches are too heavy and simple approaches such as priority rules are insufficient. Classical optimization techniques use an appropriate mathematical description of the scheduling problem that is minimized through the application of an algorithm (Sellers, 1996). Unfortunately, real-life scheduling is often so complicated that an optimization algorithm that takes all constraints into consideration would not give an answer within an acceptable timeframe. Alternatively, the time and cost required for developing the algorithm and implementing it as software may be so great that development efforts are not justified. This can also be the case with less complicated scheduling problems if the company that will use the software is not very big. On the other extreme, it is possible to schedule using simple heuristic rules such as first come, first served (FCFS) or earliest due date (EDD). They are easy to understand and implement and require little computer time. They can usually be implemented on a spreadsheet or even without a computer. Heuristic rules do generally not provide optimal solutions to complex problems (Sellers, 1996).

The simulation approach provides a great level of detail without being computationally too heavy. A schedule is created by simply simulating the execution of the factory and taking the recorded execution history as the schedule (Smith, 1992). The result will be a feasible schedule if all the relevant constraints are included, which is easy as a simulation model can include a large number of details. The approach works especially well for forward scheduling.

However, the simulation model does not necessarily come up with the best schedule, although it will be a feasible one. Roy and Meikle (1995) recommend discrete event simulation for estimating the operative performance of proposed schedules that are generated using other methods. As a part of a decision support system, simulation provides a way to get detailed information about the consequences of scheduling decisions, regardless of whether they are based on manual or optimization-based schedule generation.

## 4 SIMULATION-BASED SCHEDULING SYSTEMS

Simulation-based scheduling systems tend to include at least two modules: one for generating a preliminary schedule and another module that verifies or refines it. Simulation is used in the latter module. In addition, the systems contain a connection to company ERP systems so that operative data can be downloaded. Unlike tactical simulation models used for policy formulation, operative simulation models are usually deterministic. If a random event such as a machine failure occurs, a new schedule can be quickly generated and evaluated (Gupta and Sivakumar, 2002; Musselman et al., 2002).

The way of generating the preliminary schedule varies. In the systems presented by Ram and Patel (1998) and Andersson and Olsson (1998) the schedule is generated using heuristic rules. Musselman et al. (2002) choose the orders that can be completed within the given timeframe. The multi-model based system of Artiba and Riane (1998) includes expert system techniques, discrete event simulation, optimization algorithms and heuristics to support decision-making for complex production planning and scheduling problems. Riane et al. (2001) use linear programming and Appelqvist and Lehtonen (2002) use a search algorithm based on branch and bound for creating the preliminary schedule. In all cases simulation is used for evaluating the feasibility of the preliminary schedule, getting more precise start and end times for events and identifying potential problems. Musselman et al. (2002) point out that exact durations of events are usually not needed on the shop floor as long as there are no problems. The usefulness of simulations lies in detecting and preventing these problems before the detailed schedule reaches the shop floor.

In the case described in this article, simulation is used as a decision support tool in manual schedule creation. Our assumption when building the system was that simulation can be beneficial also in the situation where the preliminary schedule is created using human expertise.

## 5 CASE ALBANY INTERNATIONAL

Albany International Corp. designs, manufactures and markets paper machine clothing for each section of the paper machine. Albany is the world's largest producer of custom-designed engineered fabrics called paper machine clothing (PMC). Albany has facilities in 15 countries and net sales of $816 million in 2002. One of Albany's manufacturing sites is a paper machine dryer fabric manufacturing plant in Helsinki, Europe. The dryer fabrics go to the drying section of the paper machine. As paper machine widths are not standardized, neither are dryer fabric dimensions. In addition, the physical performance (e.g. permeability) is tailored to maximize performance of the particular paper machine. Paper mills tend to change dryer fabrics according to preventive maintenance schedules that are known months in advance but there also exists unforeseen replacement due to breakdowns and alike. Because of high cost of lost production in the paper machines, paper producers keep a spare dryer fabric nearby the machine for the event of corrective maintenance need. Fabric sales are handled through a sales force and agent network who quote delivery time based on current order book.

## 5.1 Production Environment

In weaving that is the first manufacturing stage, the type, density and dimensions of the dryer fabric are determined. In heat setting 1 the fabric permeability is finalized. At labor intensive seaming stage, seams are made to both ends of the fabric. Seams enable installation of the felt onto the paper machine. The routes of dryer fabrics and forming fabrics are identical from inspection onwards. After another heat setting, the fabrics are equipped with installation aids of customer's choosing and packaged. The manufacturing process flowchart is shown in figure 1.

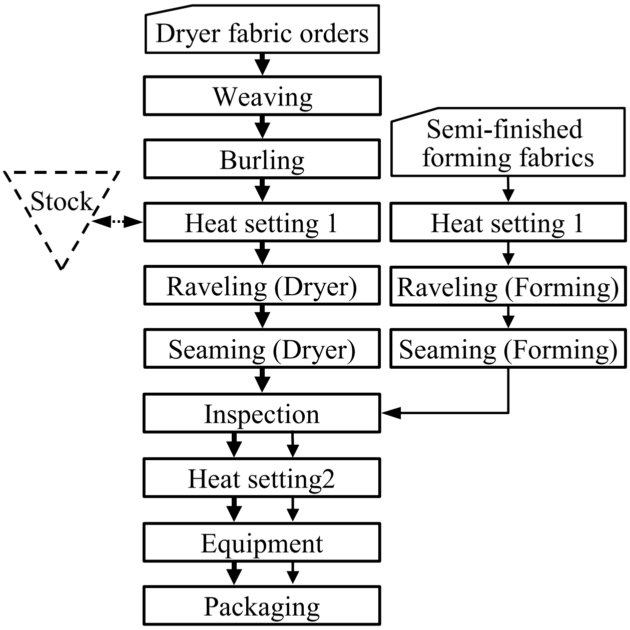

Figure 1: Process Flowchart

As figure 1 shows, the production environment resembles a flow-shop. It is, however, not a flow-shop, because some orders are manufactured (especially woven) in a specific machine. In addition, in heat setting 2 some of the orders can be alternatively treated with the heatsetting equipment dedicated mostly for heatsetting 1.

The fabrics are always weaved to the full width of the weaving machine. One woven fabric can contain several customer orders of same product quality and near delivery dates. These orders are positioned on the fabric so that the utilization of the woven fabric material is maximized in the same manner as in two-dimensional bin packing problem (Johnson, 1974). The leftovers of a woven fabric can be stocked in hope for a matching order in the future but the high degree of customer specificity makes stocking undesirable.

In the weaving department, there are such differences between weaving machines (like type and dimensions) that each machine is loaded individually. Materials consist of different types of wefts. A major part of the product range, however can be manufactured from one warp type and relatively few weft types. This means that materials planning is not in a key role.

There are three types of resources: machines, labor and space each of which needs to be considered. Resources are divided into classes but inside each class there are special requirements, i.e. the class is not homogenous under all circumstances. Examples are orders that must be processed in a particular machine and weft changes that only some workers inside labor class can perform. Another example is that one worker can simultaneously tend two weaving looms provided that they are next to each other.

Because of the wide variability in the product mix the load in different machines varies very much. For example, one specific machine accommodating some dimension in weaving can be temporarily bottleneck while a little later bottleneck can be seaming when fabrics are narrow and short or labor or even floor space to perform manual phases like raveling. The operative exceptions like machine breaks and labor absenteeism must be taken into account in scheduling. For rush orders due to unplanned fabric change at customer the ability for fast delivery as well as accurate capable-to-promise at such situations is important.

## 5.2 Manufacturing Objectives

In terms of manufacturing costs, labor, machines, and material are the main focus areas. The objectives are:

- Keeping promised due dates
- Maximizing throughput
- Minimizing WIP and throughput time
- Minimizing labor hours
- Minimizing the woven fabrics stock.

The scheduling problem at Albany is to form a schedule that will fulfill the objectives above given the set of hard and soft constraints. Main constraints for planning are resource capacity, labor calendar, machine maintenance calendar and warp changes that require labor from weaving.

## 6 SIMULATION-BASED SCHEDULING SOLUTION AT ALBANY INTERNATIONAL

In the year 2002, Albany International decided to cut the manufacturing throughput time by 50%. This was considered challenging but feasible. Up until then, the production scheduler had made schedules manually. The capacity planning was infinite and in weekly buckets with planned lead times. The share of processing time was 20% while the remaining 80% was queuing time. This resulted in both excess need for working hours and risk for unnecessary long delivery times (Tamminiemi, 2003). The management thought that the production schedulers needed better scheduling tools to realize the objective and that they were not available in the ERP system. The solution was a simulation-based finite scheduling application. Because the dryer fabrics are bulky and costly to handle while damage must be avoided, the key objective was throughput time reduction. Delfoi ltd. was selected for the solution provider. Delfoi Ltd. is the market leader in manufacturing simulation solutions and services in the Nordic countries (`www.delfoi.com`).

### 6.1 Simulation-Based Scheduling Workflow

The scheduling workflow with the simulation-based solution Delfoi Planner at Albany is illustrated in Figure 2. The first step is to download data from the ERP system. The data consists of the current work order situation at the factory floor (work in process status) and the orders in the order book. It is also possible to create orders in the Planner. These orders can be used for capable-to-promise as well as for capacity loading for product development test runs. The next step is to plan hourly labor calendar for each labor class. As the machine maintenance calendar is not kept in ERP, the machine constraints such as planned service breaks or possible exceptions and breakdowns are entered manually.

Figure 3 shows the screen for order release planning at weaving, the first processing stage for dryer fabrics. The first task in making the weaving plan is to combine customer orders so that stock pieces are avoided as much as possible. The existing stock pieces, of course, are also taken into account. Then weaving jobs are assigned to machines based on type and dimensions. The weaving plan thereby defines the order release for dryer fabrics. The weaving plan & order release planning is done by moving individual orders with drag-and-drop feature while the software takes care of the constraints and calculates manufacturing speed for that machine. It is also possible to select entire weaving jobs that may consist of several combined orders and drag-and-drop them to another machine or to a different order release time. For forming fabrics only the order release date is planned. Rush orders are assigned higher priority in order release planning.

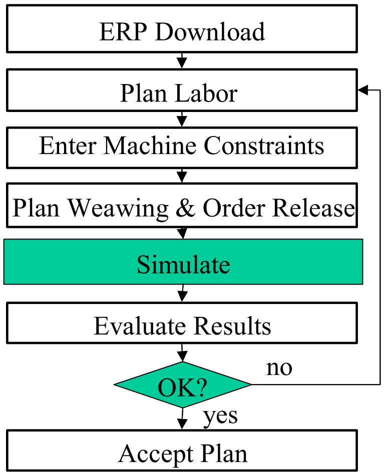

Figure 2: Scheduling Workflow in Planner

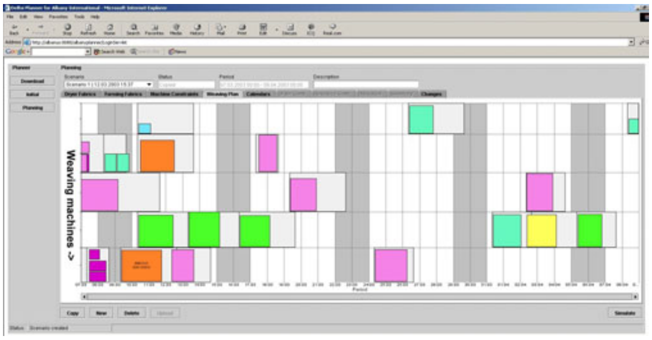

Figure 3: Weaving & Order Release Planning

After completing the planning stages, the production scheduler simulates the performance of the current plan. In the simulation, the flow of orders through production is controlled by earliest due date local sequencing rule, which is overridden only by the high-priority rush orders. The simulation model is deterministic, that is, there are no random elements in the calculation of event durations. The model contains a considerable amount of detail.

After simulating, the production scheduler can evaluate the performance from different perspectives including:

- summary of key performance indicators
- order Gantt chart that shows the throughput time of each order and highlights tardy orders
- resource Gantt-chart that shows finite loading plan of each resource (Figure 4)
- throughput time by order and manufacturing stage. It shows the sum of actual manufacturing time and the time the order had claimed a machine but was waiting for labor.

After evaluating the results, the production scheduler can decide either to go back to step two and make further changes to the existing plan or to accept the current plan.

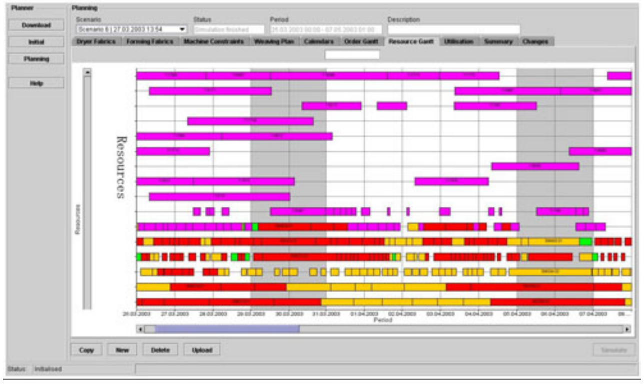

Figure 4: Resource Gantt

The Planner facilitates schedule implementation by keeping track of all the changes that the production scheduler has made. The plan is not uploaded to ERP as the operative implementation steps for the plan are manual. Request for additional labor is provided to supervisors for acceptance. The order release into the production currently takes place manually through printing work orders.

The Planner does not limit scheduling horizon length but in practice the visibility of the firm customer does. In practice, the horizon is – depending on the decision at hand – between two to four weeks.

### 6.2 Solution Architecture

The Planner is based on layered architecture (Figure 5) that separates applications, databases and browsing. The user uses it through a web browser such as Netscape or Internet Explorer from his planning workstation. First planning task is to download the work-in-process status and open orders with their parameters from the ERP system (MFG/Pro) to the Planner database. At present, the actual WIP status is download at night and hours from download to planning are simulated. The labor calendars are retrieved from the Excel sheets where they are maintained. When the scheduler launches simulation, the current plan is read from the Planner server database to Delmia QUEST® simulation software by using the middleware application Delfoi Integrator. QUEST® in turn writes events back to Planner database, from which they can be viewed with a web browser over intranet.

In the architecture of figure 5, simulation is the memory-resident calculation engine that provides fast enough schedule calculation. Tests show that five weeks of production can be simulated with animation in less than 1,5 minutes on a workstation with Intel P4 processor and 512 MB RAM memory (Tamminiemi, 2003). Database, on the other hand is a must in an operative solution, where high reliability is a necessity. Finally, the web-based architectural layer enables easy results sharing.

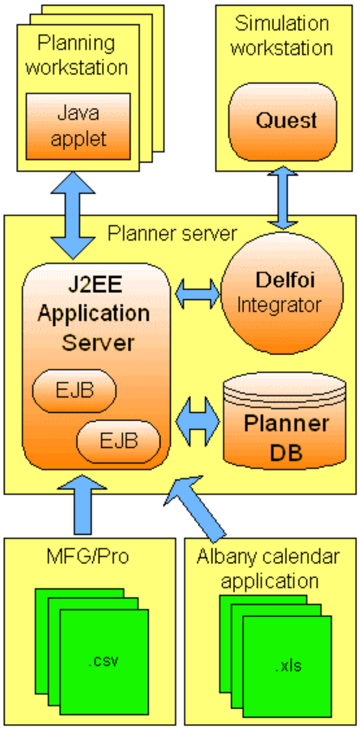

Figure 5: Scheduling Architecture at Albany

## 7 RESULTS AND CONCLUSIONS

The system was installed at Albany International, Helsinki, in the middle of March 2003. At the time of writing this paper, the test period is still ongoing and scheduled to end on 30th March. Therefore data on the results concerning the numerical project goals, a 50% reduction in throughput time and 3% reduction in material waste, are not yet available. According to Tamminiemi (2003) production schedules have used Planner 20 times during the test period so far. The usability has been excellent. The key improvement over the previous, manual/Excel-based procedure is greatly increased planning accuracy (Tamminiemi, 2003). He argues that this enables throughput time reduction as well as increased productivity in the labor intensive seaming stage. In terms of supporting the production schedulers' work, the key improvements are

- Greatly increased planning and replanning speed thanks to schedule performance feedback
- Ability to make multiple changes at a time
- Animation gives a feeling of the outcome of the plan on the shop floor
- Visual user interface for weaving planning shows stock pieces and material usage, thereby enabling more efficient plans. (Tamminiemi, 2003).

The application development project required two people form the vendor, Delfoi, for six months. From Albany the project required two man-months.

### 7.1 Why Was ERP-Supported Capacity Planning Augmented with Simulation-Based Finite Scheduling at Albany?

At Albany there are large variations in resource load of orders in the sense of leading to a moving bottleneck department and resource. All the three types of resource classes (machines, labor and space) must each be considered simultaneously with finite approach in order to get an accurate schedule that minimizes both labor and throughput time. This cannot be done in Albany's ERP system.

Another reason is the necessary level of detail in e.g. order-specific routing inside department and weaving plan that render capacity calculation at department level inaccurate and ERP-based solution cumbersome. Additionally, the rather industry-specific weaving plan necessitates some tailoring of the solution anyway.

The third reason is that the ability for re-scheduling due to operative exceptions like machine breaks and labor absenteeism require planning tools that are easy and fast. As the project key goal was throughput time reduction, an investment in advanced planning systems was considered worthwhile.

### 7.2 Why Was Simulation-Based Finite Scheduling Applied Instead of an Optimization Algorithm at Albany?

By definition, the optimal solution is the best. However, it can be argued that optimization-based approach is not necessarily the most economical. In Albany's production scheduling environment there are a number of tentative key enablers of a simulation-based solution.

Foremost is that production of dryer fabrics does not include any combining or assembly operations, so that the forward scheduling in standard simulation packages could be readily applied. Backward scheduling with simulation with standard packages has been reported (Watson et al., 1997), but it is not always a clear improvement (Jain and Chan, 1997).

Second, simple local sequencing rule together with priority class was considered adequate at Albany. More complex scheduling logic would mean more work on algorithm and leading, eventually, to a point when considerations of optimization run-time would dominate.

The key benefit of a simulation-based scheduling system comes not from optimal solution designed by experts. Instead, the key is feedback of the schedule performance to the expert human scheduler and his tools for improving it. Simulation-based system capitalizes this existing source of tacit knowledge without incurring the learning and costs of making it explicit. Albany's Helsinki plant, size and volumes are not so large that the savings in optimization approach would outweigh its inherent costs of making the current production schedulers' knowledge explicit. In similar environments, simulation-based scheduling systems could offer a viable alternative to optimization-based scheduling by giving a set of tools for the production scheduler to test and improve the schedule.

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