VALIDATING THE PRODUCTION WEEKLY PLAN BY SCHEDULING SIMULATION

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KEYWORDS

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ABSTRACT

Large Corporate and Small and Medium Enterprises are still going through deep innovation and re-engineering processes. Organisation should became leaner and more efficient.
Even planning and scheduling should be integrated in order to yield feasible and robust plan in an automatic way by continuous planning, from forecasting to daily line load.
We present a framework for weekly plan validation with respect to all the production constraints based on scheduling simulation and apply it in a real case involving the world-wide leader in Medication Delivery market.

INTRODUCTION

A strong need exists in large, medium and small enterprises for exact validation of the plan issued by the Logistic personnel. Effective validation should lead to a feasible plan, acceptable for Production personnel.
In order to reach this goal validating the weekly plan is required with respect to all the relevant production constraints. This validation process usually starts during (weekly) meetings involving both Logistic and Production Departments and requires three time consuming stages: revision, modification and approval.
Automatically performing this process is desired in order to make more efficient the process and more reliable the plan.
Simulation should be used as a support for performing this task, especially dealing with complex manufacturing system: since simulation accurately describes the process and its constraints [Carson and Maria 1997], it allows to perform the validation of the plan according to the feasibility and reliability requirements previously mentioned.
In order to fully validate a weekly plan, the low resolution plan provided by the Logistic Department should be detailed by scheduling the required products and quantities with respect to the corresponding due dates [Pinedo2002], production rate, availability of personnel and tools, WIP level and physical and logical constraints [Peterson 1998]. The scheduling process is expected to yield the allocation of each single item on one of the allowed machines, with time resolution around minutes or even lower, depending on the degree of automation. Otherwise, production personnel could be obliged to modify the schedule according to the production constraints. In the latter case, a new adjusted schedule is delivered and communications issues arise. Limiting at the minimal level the modification of the plan once it has been delivered by the Logistic Department is crucial: the inferior bound for unexpected variations of the plan are due to inherent stochastic ness of the production process, such as equipment breakdowns.
Thus, starting from a list of requirements a detailed job allocation should be performed. This is just a matter of scheduling.
As a result, the weekly plan validation should be performed by simulation, since all the relevant constraints should be considered in order to avoid any subsequent modification of the plan, and the simulation model should be integrated by scheduling algorithms, in order to detail the weekly plan at an operations level as required by simulation.
With respect to the knowledge of the Authors, no simulation framework have been presented, explicitly addressing this topic.

SCHEDULING SIMULATION

The idea of scheduling simulation, as presented in this paper, has a twofold aim:

- firstly, to answer to the specific requirements of Companies for a new paradigm of planning system allowed to provide monthly/weekly plan validated at finite capacity with respect to all the deterministic constraints that affect operations;
- secondly, to support cost-reduction strategies by technology, especially referring to internet-working, largely distributed supply chains, remote planning and spreading of industrial plants world-wide.

This view results in a clear statements:

to be able to reproduce manufacturing operations and scheduling process everywhere, in a reliable and robust manner, respecting the physical and logical constraints typical of the production process, progressively making leaner and more efficient the enterprise organisation.

The proposed approach is based on the desire to emulate the real scheduling process and operations management. Scheduling simulation can be used as a tool aimed to support the planning activities, in order to maximise

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customer satisfaction, minimise back orders, and reduce the production costs.

With more details, we propose to run the weekly plan (the timeframe mainly depends on the manufactured products) by a simulator of the production process, minimising the scheduling operation performed before simulation starting and introducing routines for job allocation during the simulation run. We call these procedures Delegate Functions (DFs).

On the basis of the weekly plan, operations are simulated since a situation of decision is detected. With respect to common scheduling approaches [Pinedo 2002], a decision is an assignment of a independent variable (according with the adopted scheduling approach it could be either a binary or multi-values variable).

When alternatives should be evaluated and compared, a specific DF runs in order to determine the best choice on the basis of the actual conditions of machineries and resources. The expected evolution of the production system is sometimes considered in order to fit medium term requirements and to avoid bottlenecks.

This is a key successful factor in scheduling simulation according with the well known issues due to continuous rescheduling and subsequent schedule instability [Herrmann et al.].

DFs are therefore suitable for short-medium term scheduling and most common dispatching: they play a key role in the optimisation of the Gantt and in the validation process of the medium-term plan.

DFs can be in different forms:

- algorithms belonging to Artificial Computation: a huge number of scientific papers that have been written highlight the synergy between simulation and Artificial Computation;
- Autonomous Agents: Agent-Directed Simulation is today considered a promising field [Oren 2001] and large interest has been shown in the simulation paradigm explicitly involving agents;
- any heuristic, expert or hybrid algorithm, simple or complex, with respect to the requirements of the specific application.

WEEKLY PLANNING: A COMMON INDUSTRIAL FRAMEWORK

Largely adopted framework for manufacturing production planning involves three main stages: demand forecasting, master planning and weekly (or daily) rolling review of the plan [Peterson et al. 1998]. Demand forecasting [Beroldo et al. 2002] yields an aggregate prevision over a medium-long term with respect to the quantities of each product family to be likely requested. Forecasting is usually performed at multi-site level (MSL) and its output is provided to the MSL Master Production Scheduling (MPS) [Bernocco et al. 2003a]. Requested quantities for each single plant over a medium-long term are then used for determining the weekly master plan [Aloi et al. 2002]. It takes into account also the production plan, and other important considerations as backorders, availability of material, availability of capacity, management policy and goals [Proud 1999].

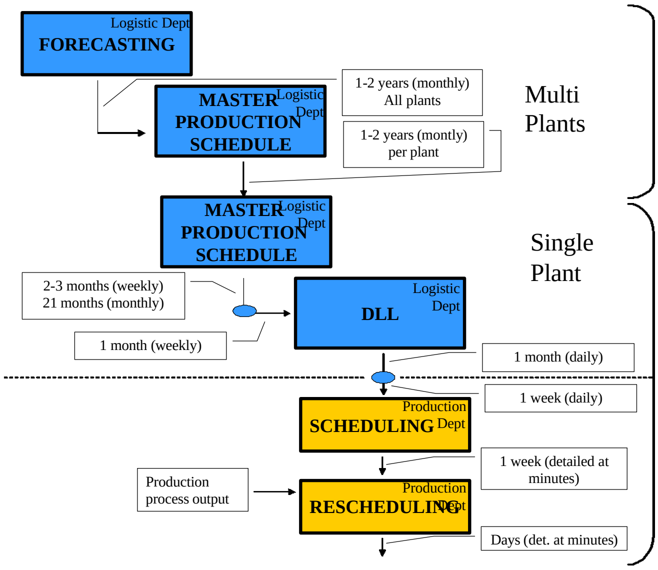

Figure 1: Common Planning Framework

A CASE STUDY: BAXTER-BIEFFE MEDITAL

Baxter-Bieffe Medital production process for Clear-Flex bags is compounded by four phases: solution mixing, bag filling, sterilisation and packing. Figure 2 offers a simplified view of the departments, where mixing, filling and sterilisation are performed. They are: i) the tank room - phase 1; ii) the filling machines - phase 2; iii) the sterilisation and the unloading stations - phase 3.

Even if the production rate over each phase depends on the size, the vessels can be considered as the bottleneck of the whole process almost for every code.

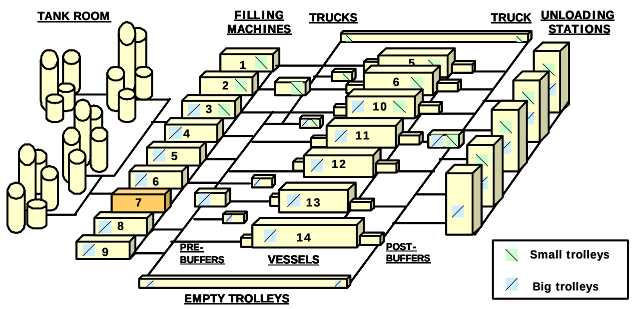

Figure 2: Schematic Baxter Planning Framework

Planning Process "As Is"

From a single-plant prospective, planners receive a list of codes (i.e. products) to be produced, detailed in terms of inventory position (i.e. a measure of the product demand that can be satisfied by actual stock, expressed in terms of weeks) and grouped by product size.

Since the production rate depends on the size to be manufactured, grouping by size leads to product clusters based on the corresponding manufacturing performance.

On the basis of the experience of the production personnel with respect to the sterilisation phase and the corresponding knowledge base collected over the years, an evaluation process takes place in order to roughly estimate the capacity of the process according to the codes to be manufactured. This is a sort of Rough-Cut Capacity Planning (RCCP) procedure [Lee Berry 1997]. In this way, a first, basic allocation of the (grouped) codes is derived in accordance with the capacity constraints of the bottleneck production phase. It is called campaign allocation, since a campaign is a job that prescribes the manufacturing of fixed size products.

Scheduling Process "As Is"

Moreover, a scheduling process takes place in order to optimise the performance (i.e. respecting logistic priority based on stock levels and the total set-up time) over the filling phase. During this phase, production personnel considers the most relevant constraints at mixing level. The performance of the sterilisation phase has been previously considered by the RCCP.

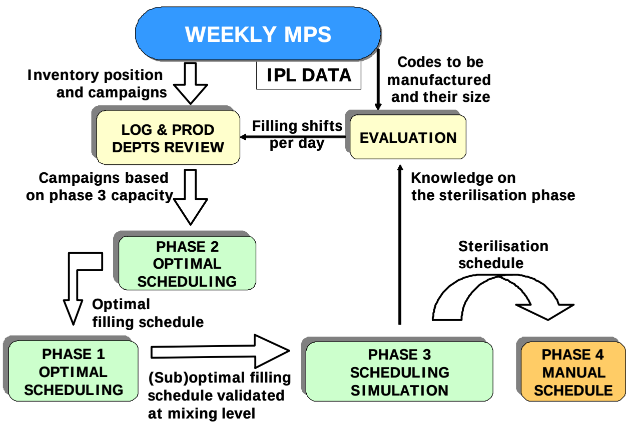

Figure 3: Schematic Baxter Planning Framework "To Be"

Picture "To Be"

The goal of the re-organisation process and introduction of the system for daily line load can be summarised as follow: realise the automatic validation of weekly plan with high resolution and taking into consideration all the constraints. This result has been achieved by the implementation of a mixture of scheduling techniques and simulation.

A scheduling system based on both heuristics and combinatorial optimisation has been developed for phase 2 daily allocation. An hybrid scheduler, based on if-then rules and heuristics has been designed and implemented in order to perform the tank allocation. A scheduling simulator performs the allocation of the sterilisation tasks onto the vessels.

The weekly plan (expressed in terms of inventory positions and campaigns) is compared with the capacity constraint resulting from the evaluation of the production manager. The resulting new campaigns are then processed by the scheduler of phase 2 in order to determine the optimal job allocation over the filling phase.

The resulting schedule is used as input for the mixing scheduler: it performs a capacity check backward allocating the formulas to be used by the filling machines.

In case of low capacity, the tank allocator shows the unfeasible codes and their position: in this way the planner can remove the corresponding job or modify its position in input of the filling scheduler. Then he re-runs the two scheduling systems until a feasible Gantt is reached.

Since the obtained sequence can be considered sub-optimal, with respect to phase 2 (adjustments due to phase 1 capacity constraints affect optimality of the Gantt), it only remains to validate the Gantt over the sterilisation phase.

Nevertheless this task is not trivial. It can be performed in two ways:

1. by common forward scheduling approaches;
2. by scheduling simulation.

Common scheduling approaches result not appropriate in this case since routing and trolleys selection should be rigorously taken into account and are dynamically changing. It means that the constraints cannot be stated at the beginning, but they largely depends on the specific allocation. Moreover if the system does not consider them the validation cannot be considered reliable and optimised; on the other side, no common scheduling paradigm exists that perform this evaluation in a changeable environment.

In this mind, a discrete event simulator that self-schedules the jobs has been designed, tested and implemented.

SIMULATION OBJECTS

Trolley: the trolley is the product unit considered in the process. The goal of the production process is indeed to fill trolleys respecting the production schedule as most as possible, to sterilize them in the vessels, and finally to discard them, minimising wastes of time. The trolley can be of two types: small or big. Each trolley can contain a different number of bags, depending on the type of the bag and the dimensions of the trolley.

Bag: it is not really an object in the simulator. The bags are identified by a trolley, which has an attribute reporting the ids of the corresponding bags. The most important features of a bag are the cycle time (i.e. the production rate in terms of second per item) and the batch number.

Filling Machines: it is the machine which fills the trolley with bags. Each machine has a Gantt which contains information about the daily or weekly production. Loading a trolley, the filling machine print on it some relevant data:

- the batch number;
- the cycle time;
- the run number (which is a progressive number different for each filling machine).

Vessel: it is the machine which sterilizes the trolleys. Each vessel can sterilize only certain trolleys, depending on their size and on their cycle reference. The vessel receives the trolleys from its pre-buffer, and after the sterilization job is completed, it discards the trolleys on a post-buffer.

Unload station: it is a station where human resources unloads the trolleys. When a trolley is discarded, it is brought to the return-rail.

Pre-buffer: it is a pre-buffer which collects trolleys which can be sterilized together until the sterilization batch is complete. It is a FIFO queue.

Post-buffer: it is the post-buffer which contains the trolleys sterilized until it is discarded. It is a FIFO queue.
Off-line buffer: it is a buffer which can contain trolleys after they have been produced, before they are brought to a pre-buffer, or empty trolley where the return-rail is near full or full. It is a LIFO queue.
Return rail: it is a buffer for empty trolleys. After they are discarded on the unload stations, they are brought to the return-rail. When they are needed, they are brought to filling machines. If the rail is full or near full, some of them are brought onto off-line buffers. It is a FIFO queue.
Wagon: it is used to move trolleys from the return rails to filling machines or to off-line buffers, or from filling machines to pre-buffers or off-line buffers.
Discard-wagon: it is used to move trolleys from the post-buffers to return-rails or to unload stations, or from unload station to return-rails.

BAXTER SCHEDULING SIMULATOR

In case of Baxter-Bieffe Medital production process, seven main decision should be taken. We summarise them by the questions that rise during the simulation (Table 1).

Table 1. Decision Points in Baxter Scheduling Simulation

Question/decision	Class
Pre-buffer or off-line buffer?	Optimisation
Which vessel?	Routing
Minimal number of empty trolleys?	Inventory Mngm
Incomplete sterilisation batch?	Routing
Small or big trolley?	Assignment
Which post buffer?	Routing
Which vessel with respect to the ending time?	Optimisation

The principle of the scheduling simulator developed for Baxter-Bieffe Medital is based on two kinds of decision-making procedures:

1. heuristics;
2. replication (or cloning).

The use of heuristics allows to take decision during the simulation. This is not novel [Bernocco et al. 2003], but it is integrated in a framework where simulation yields a Gantt (i.e. a schedule) for a phase of the production process. For instance, this is the case of the minimal number of empty trolley. In this case a heuristic typical of the inventory management problem has been successfully adopted, that is based on the principle of re-order point [Arnold and Chapman 2001].
On the other side, the replication is realised in those cases where no heuristics can support this decision since it would require prediction. Replication is indeed based on the exploration of the alternatives in an exhaustive way. It is realised by cloning the simulator that generates the situation of decision. A simulation manager is thus introduced in the software architecture in order to implement this procedure. The concept of replication takes its origin from Branch and Bound [Pinedo 2002] and is here applied jointly with simulation in order to yield a scheduling process.

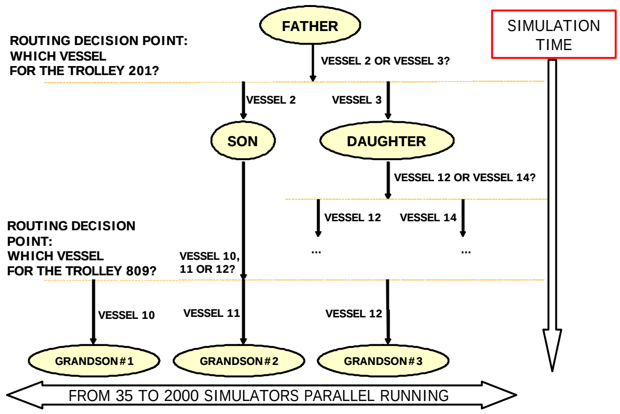

Figure 4: Replication Concept in Scheduling Simulation

EXPONENTIAL GROWTH

The main problem we found using replication was the exponential growth of the number of the simulators. Indeed, considering that the average transportation time is almost 15 second, and considering that usually one third of the total movements is due to full trolleys towards a destination to be selected (i.e. a decision), we have a replication every 45 seconds for each wagon.
We had 2 wagons, so one duplication every 22,5 seconds. We can thus say that we have 8 duplication every 3 minutes. In this way we can estimate 160 duplications every hour. Considering that the number of destination varies from 1 to 5, we can further estimate that we had a replication of 2 simulators each time. So the number of plants in an hour could reach 2160!
For solving this problem we followed two ways:

1. the limitations of the plants growth;
2. the cutting of the search tree.

With respect to the limitations of the plants growth, by using heuristic and gating techniques we cut some alternatives that are unlikely to be promising.
With respect to the cutting of the tree, since the number of running simulator dramatically increases each time that a decision should be taken, we decide to bound the number of them by a threshold fixed a-priori. In this mind, when a decision point is reached and several plants are generated by replication, some simulator should be destroyed in order to not exceed the threshold.
The simulator to be eliminated have been selected by some metrics combined by a weighted sum in order to obtain a fitness function [Goldberg and Deb 2001].
They are:

i) the number of trolleys sterilized;
ii) the number of trolleys produced;

iii) the number of trolleys discarded;
iv) the number of working vessel;
v) the number of empty trolley.

Nevertheless the rigorous application of this principle would result not effective since the simulator that have been just created do not significantly differ. As a result a second parameter should be introduced. This is the *minimal life time*, i.e. the minimal time during which a simulator cannot be destroyed even if its fitness is lower than others'.

Notice that this further parameter lead to strongly exceed the threshold on the number of parallel simulators.

RESULTS AND CONCLUSIONS

Performance Evaluation

Fixing the threshold for the number of plants to 50 and the minimal life time to 1 minute, a real week can be simulated in 2-3 minutes, depending on the pc, with up to 2000 simulators parallel running. Table 2 and Figure 5 show the results obtained with a AMD1800 with 512Mb Ram. About 772184 events have been processed in average (5 runs).

Table 2. Time per Event, Including Replication

Event	Time [s]
EndProduction	111,59
EndDiscarding	22,11
GiveTrolley	17,84
GiveTrolleyToARail	9,70
GiveEmptyTrolleyToABuffer	5,44
Total	182,95

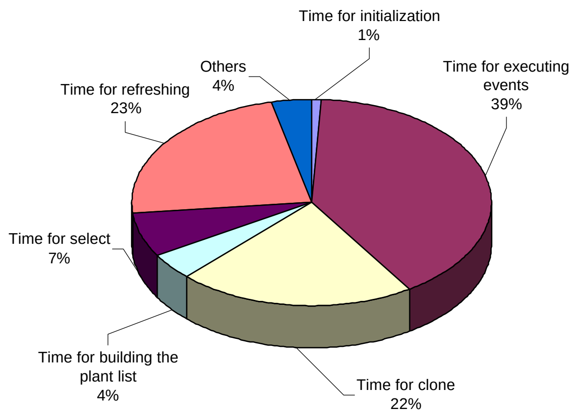

Figure 5: Times per Tasks [% of the Total CPU Time]

Scheduling Performance

The implementation of the presented system (tank allocator, filling scheduler, scheduling simulator) led to successfully results.

The performance has been measured by:

1. the opinion of practitioners within the verification and validation process;
2. comparing the "as is" scheduling approach versus the scheduling simulator: the number of unloaded trolleys has been increased in average of +2.74 %;
3. comparing the whole planning system versus the "as is" planning and scheduling procedures (this process should be completed during the last months of 2003). Preliminary results showed an overall improvement of the performance that is between 5% and 10%.

Baxter is interested in the continuation and extension of this project Europe-wide.

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