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PROCESS ACCOMPANYING SIMULATION – A GENERAL APPROACH FOR THE CONTINUOUS OPTIMIZATION OF MANUFACTURING SCHEDULES IN ELECTRONICS PRODUCTION

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ABSTRACT

The paper will present the successful realization of simulation based manufacturing planning and control in electronics production. The principle has been implemented in various applications as supplementary decision aid in connection with ERP systems. A theoretical model of virtual and real time explains relations between simulation and production planning. In all cases the discrete event simulator ROSI has been used, which provides comfortable functions for manufacturing models. Scenarios are being optimized by meta-heuristic methods like Genetic Algorithms. As real production and simulation are producing data in the same logical format, a comparison technique is being proposed that enables the observation of errors between reality and simulation, where simulation can be retriggered when the error is rising too high. In addition the adaptation of parameters is derived of this comparison. Examples clarify all contributions.

1 INTRODUCTION

Today's turbulent market situations require precise and fast predictions of manufacturing schedules, especially under changing conditions. Discrete event simulation is a very appropriate method to generate those predictions. The focus still lays on simulation studies that require an expert (Pinedo 1995).

ERP systems offer planning modules that often do not create realistic results for various reasons (Corell and Edson 1998). Our effort consists in bringing simulation into industrial environments for the use of every planning person and for repeated tasks in daily production planning – we call this and all the side effects around it process accompanying simulation. As ERP systems store most of the manufacturing relevant data, their databases serve as data deliverers for simulation models and simulation replaces scheduling routines. ERP, production data acquisition (PDA), and discrete event simulation (DES) form an unbreakable liaison for the continuous optimization of manufacturing schedules in our approach (Figure 1).

It is often recommended to split planning and control for each separate manufacturing unit with proprietary simulation models for better results. As ERP has the idea of centralized manufacturing control, we will only use parts of its data for each unit but keep connectivity functionality between units in ERP systems.

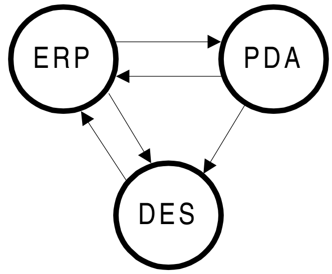

Figure 1: ERP, PDA, and DES

2 REAL AND VIRTUAL PROCESS – A TIME MODEL

We distinguish a planning and a production level. The production is a dynamic process that we can observe along the real time t_r. Planning itself is a virtual process that represents a section of the real process and runs along a virtual time t_v. In general the planning process takes less time than the represented section. That means the virtual process runs faster than the real process. As we imagine a relation between the age of a (discrete) event and the real time t_r of its occurrence we can construct a time model that consists of two axis: time t_r and age τ where $\tau = t_r - t_v$.

Every event exists in past, present and future. Figure 2 shows an example process by its events in a Gantt chart where the event structure keeps constant in different ages (past or future). The event lines have an angle of 45° to the real time axis because $\tau \sim t_r$ for $t_v = \text{const}$. Several observation tracks can be considered. A prediction method allows us to reflect the future events (with age $\tau < 0$) as discrete event simulation does.

We want simulation to produce an observation track (see Figure 2) that starts in past or at present and ends in future which allows us to control the future events of the real process. Along the real time axis we can observe the accelerated process that is like a projection of all intersections with event lines. Simulation models do never represent the exact future behavior of the real system, thus there is an error e in the prediction, where probably $e \sim |\tau|$.

3 ELECTRONICS PRODUCTION STRUCTURES

Electronics industry generally is determined by a high customer oriented structure and a high product variety. For this reason manufacturing often is more job shop like than a series production. Assembly hierarchies are flat, most of the assembled parts are bought from suppliers and assembled in the first technological steps where the number of technological steps is not negligible and different from product to product.

This implicates that organizational means do effect the production value rather than in a series production where manufacturing cells should be optimized in advance. Important objectives of organization are due date keeping and reduction of cycle time for lower capital commitment.

Machine group definition is a very rare phenomenon in electronics industry. In most cases the resources and the related standard time for a product are predefined in charts. In other cases processing time can be calculated from technological parameters. These conditions make it valuable to use discrete event simulation for repeated planning tasks.

4 INFORMATION SYSTEMS AND DATA FLOW

ERP systems are very common in electronics production. The diversity of those systems is as high as the product variety. The planning results of ERP systems for single production units often are not satisfying. This is caused by different reasons. One of them may be the centralized approach, another is the capacity based planning algorithm that does not consider many aspects. But what they have in

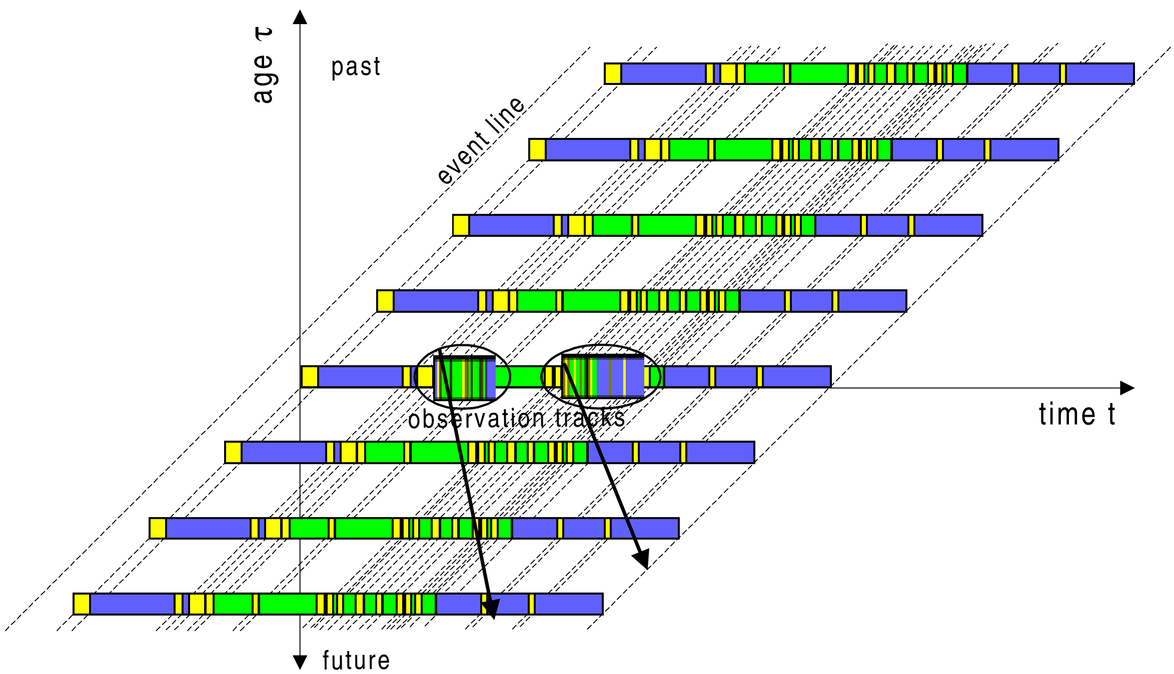

Figure 2: Time Model

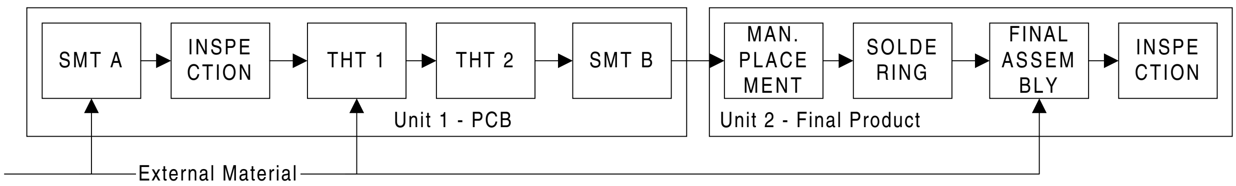

Figure 3: Example Product Technology

common is the available amount of data stored that is necessary for simulation models. If it is possible to extract the required information from ERP systems a first step for the automated model generation has been done. Databases generally form the basis for ERP systems and standard interfaces are accessible (Dangelmaier and Warnecke 1997; Kurbel 1995).

A second prerequisite is a production data acquisition (PDA) system to trace the current production state. Most of the ERP systems do include PDA, if not it is widespread to have a supplementary system that cooperates with ERP.

Other data or rules for simulation models can only be collected apart. We store necessary input or special strategies in additional databases or ERP database extensions where planner's view to things is kept and graphical user interfaces help to maintain the data. From ERP and/or additional databases we extract all data and form a simulation model. Figure 4 demonstrates the data flow. It has successfully been realized to mirror ERP data in the second layer as a complete planning tool with included simulation which is available as a simulation based planning software prototype. It simplifies the implementation of the principle because there is only an interface to ERP needed and in case of recurrence of the same ERP system the interface can be reused (i.e., SAP R/3).

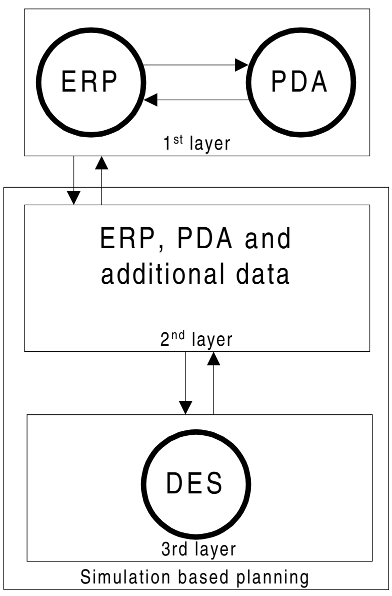

Figure 4: Data Flow in Simulation Based Planning

After simulation results are returned through the layers up to ERP and used for scheduling control. An example can be found in Werner, Kellner, Schenk, and Weigert (2002).

5 SIMULATOR

For all applications we have used the discrete event simulator ROSI designed at the Electronics Technology Laboratory. It is a very compact and powerful modeler for manufacturing applications. The object oriented structure offers many of the relevant features for models and simulation is very fast. Open programming interfaces allow the easy implementation of extra rules and strategies. The software construction permits the complete integration into existing systems and the execution without GUI which equals a simulation engine that is controlled from outside.

Access to the simulator is managed by an interpreter. All functions are controllable by commands and new procedures can be added by scripts. Database interfaces (or others) are available and are being used for parameter import to simulation models. For creation of models, analysis of simulation runs or statistics the GUI is very helpful (Weigert, Werner, and Hampel 2000).

6 MODELS AND SIMULATION

A simulator is used in daily production planning. Scenarios can be computed very fast by the simulation engine (typically a 2 to 5 week prediction in 1 to 5 seconds) and results are returned to the ERP system. Models are generated automatically, that means that a template model has been developed by a simulation expert that is only filled with ERP and extra parameters. The template model can be adapted in special cases to implement additional strategies.

The import routine collects all data from ERP and PDA and forms a new simulation model that exactly contains the production state of the modeled unit and the scheduling rules of the template model. A simulation run generates an event list that finally is returned to the controlling system together with other information and allocated to the manufacturing resources.

The following list gives a general overview over the most important data that has been considered in models:

- Resources (groups, machines, persons, operating resources, …)
- Alternative resources or technologies
- Product orders and parameters (amount, release dates, due dates, priority, …)
- Work charts (technologies) and parameters (technological restrictions, resources, setup and processing time, release dates, overlap, …)
- Product order network (dependencies between orders)
- Material (availability, availability dates, provision dates, …)
- PDA (current production state for each order and each resource)
- Shift system (shifts, shift combinations and validity intervals, …)
- Working calendar
- Maintenance intervals

- Flexible scheduling rules
- …

Planning responsibles can use the advantages of the simulation method without having any simulation skills. Models are preformed in the planner's world (ERP and ERP like data). Planning know-how has been transferred to the template model and is there available for the user. Not only production schedules but also just-in-time delivery control can be considered in the models (Reinhart 2001).

Different scenarios can be simulated "manually" by changing parameters. A better way to fit the required objectives is an automated optimization. As simulation is fast, runs can be repeated by automatic changes of input parameters (order sequences, priorities, strategies, …) and best solutions are offered for scheduling. This optimization loop is being practiced with a separate optimization tool that only generates new solutions by Genetic Algorithms and other meta-heuristic techniques. Each solution is evaluated by the simulator which calculates the objective values.

7 PROCESS ACCOMPANYING SIMULATION

The continuous use of simulation in parallel to the manufacturing process and its side effects has been called process accompanying simulation. The prediction error e of the simulation is one point that we focus on. The error is unknown at the instant of the simulation. The goal of the process accompanying simulation is to observe the error during the running production process and to act if the error between predicted and real process gets too high or even to improve the simulation model by learning from reality. We define two kinds of action: synchronization and adaptation.

Synchronization is the simple correction of the simulation model by translating the current production state into the model. That means a new simulation with online-data from PDA. This causes an error $e = 0$ because the model contains the same state as the production. During simulation the error can rise again. Comparison between predicted data and real data is only possible in the future after the synchronization. Figure 5 proposes a way of error analysis between real and simulated process.

Both real and simulated process produce dates. There is a start and an end date for each technological step. We distinguish a start error e_s and a duration error e_d. As simulation and production dates of technological steps correspond to each other, the absolute or the signed values of differences between their pass start dates (e_s) and durations (e_d) can be added to the error value e. Synchronization can be triggered periodically. Starting from last synchronization the error is observed and when it reaches a given maximum value the proposal for a new synchronization follows. Planning has to be updated because simulation and reality do not correspond anymore. Error dependent synchronization is the most appropriate method to keep previews and production in track.

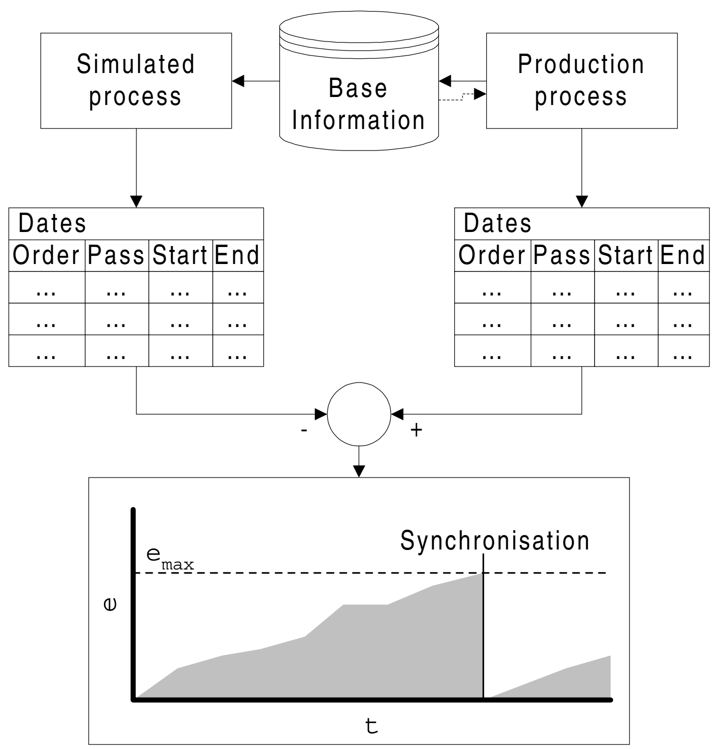

Figure 5: Error Analysis between Simulation and Reality

In industrial applications we have implemented the error observation in combination of simulation and PDA. Different forms of curves can be studied. A general statement is that the start date error (e_s) in most cases is higher than the duration error (e_d). The errors using absolute values are higher than in the case of using signed values where positive and negative differences partly balance each other. Figure 6 shows some example curves with real data. The left curves represent a normal run with frequent synchronizations (once or several times a day). In the middle term observation on the right side we have considered that there was no synchronization after July 1. The error would rise extremely in this case. The used work charts contain precise standard time. This causes the signed duration error to stay around the zero line.

The error may have different causes. On the one hand there are manual scheduling changes that can not be taken into account in a simulation or the scheduling rules are not correctly integrated in the simulation model. These are logical errors, which are hard to find out (partly observed by e_s). On the other hand there are parameter uncertainties in the base data, especially processing time parameters (e_d). Now it is possible to extract information from PDA for base data updates. Real durations of processing steps can be determined from start and end dates by statistical methods. The longer the real process is running, the more parameters can be corrected. The simulation will get better results with updated base data and the error will rise less in future. Adaptations should be linked to synchronizations. Although algorithms for this method have been designed and tested, adaptations are not executed yet.

The time model presented (see Figure 2) is able to clarify the synchronization and adaptation in form of a static process model where synchronization and/or adaptation always take place along the real time axis. Putting the error e in past and future into the third dimension we obtain an error mountain as a theoretical experiment (Figure 7).

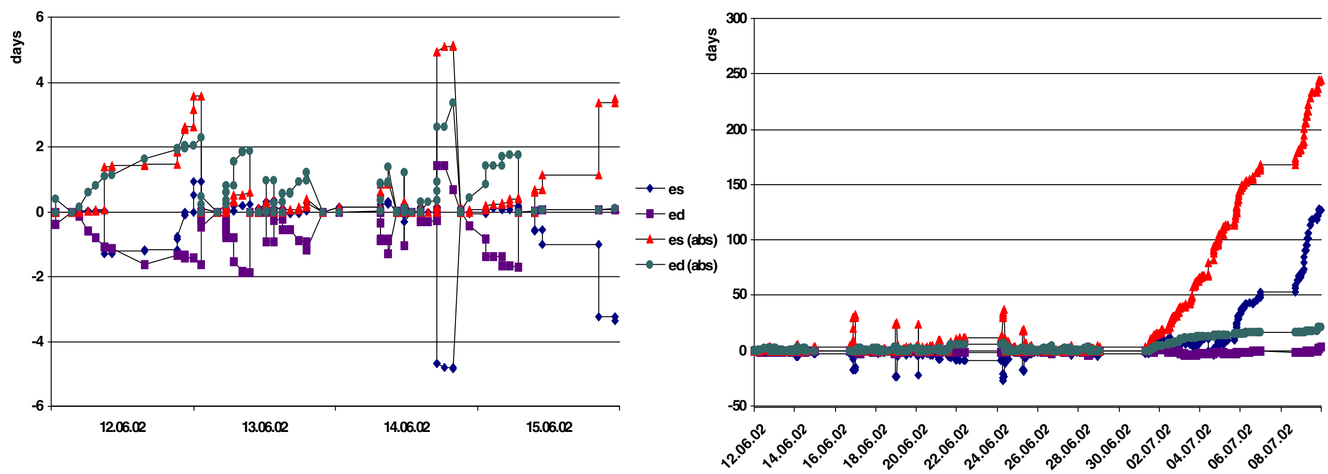

Figure 6: Continuous Error Observation between Simulation and Reality – Industrial Example Data

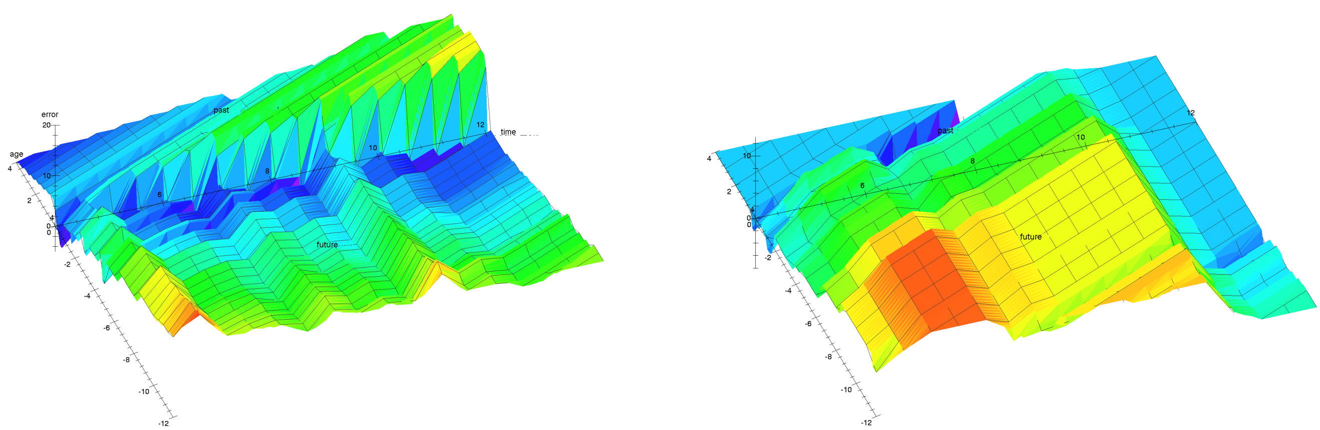

Figure 7: Synchronization and Adaptation – A Static Process Model

8 CONCLUSION

Daily application of discrete event simulation for planning results in better predictions and fulfillment of objectives. Real production and simulation are compared, this gives information about validity of simulation runs.

Simulation fills the lack between ERP and planning requirements without simulation skills for the user. Separate units have the authority over their own planning strategies in certain limits, which are given by supply and due dates from other units. By breaking the complete manufacturing into fractals, planning within units and over all units is getting more flexible and precise.

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