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Component-based 3D Simulation Platform for Production Planning and Process Control

Anlagen-basierte 3D-Simulationsplattform zur Produktionsplanung und Fertigungssteuerung

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Abstract: The use of 2D and 3D Simulation tools to analyse and improve material flow, logistic and production processes is nowadays commonly accepted standard practice for many companies. This article focuses on further extending the application area by introducing simulation processes to the shop floor and re-using available models for production order scheduling, line monitoring and cost optimisation. The challenge of this approach is to design an integrated Simulation and Scheduling Framework based on best-of-breed simulation and optimisation technologies.

1 Introduction

Globalisation and the associated pressures on costs has increased considerably from the last century and most production companies, especially small and medium size enterprises "SMEs", are forced to adapt, continually, most often through better production flexibility and efficiency. The result is that many successful SME businesses share the common attribute of a lean manufacturing processe with an integrated, flexible and affordable IT-System.

Unfortunately planning and scheduling remains one area where production schedules are still derived manually and based on planner experience and self-made tools. This approach usually results in a very non-optimised solution and the potential is lost to increase throughput and deliver-on-time more frequently. Also, manually based solutions limit the information flow between the ERP level and shop floor management, placing an increased burden on the coordination between departments.

In contrast, large manufacturing enterprises utilise technologies based on industrial simulation toolkits and mathematical based optimisation algorithms to support shop floor production planning. SMEs on the other hand, apply industrial simulation and optimisation techniques on a very limited scale, mainly in the areas of logistic and material flow analysis, layout planning and process validation. The main reasons advanced planning and simulation technologies are not extensively utilised in SMEs is attributable to the high tool cost and expertise required to handle their complexity. However, there is one exception where simulation tools are finding a niche in daily SME operations, and that is in the sales department. Cost effective layout proposal tools built on a 3D simulation platform are being used with equipment model libraries generated from the company's existing 3D CAD data.

The application of 3D simulation models in sales is starting to promote the concept of a "Virtual Factory" for SMEs, paving the way for extensive reuse of the simulation rich data throughout other areas in the organisation: especially the planning department. The reuse of the simulation data for production planning is further supported by availability of low cost and powerful workstations for the task.

2 Current Techniques and Tools

Currently SME companies are managing their production facilities using different IT applications. In most cases the applications have grown organically based on specific user needs. As a result, many of the IT sub-systems within one company evolve with duplicate functionalities. The end result is a confusing IT landscape where it is unclear which sub-system can and should deliver the required services, or where new functionality should be developed.

Missing from the SME IT portfolio is an integrating architecture where functionalities are available through one common interface. Efforts have been focused on ERP (Enterprise Resource Planning) systems but there is little connection to the shop floor, especially in the areas of planning and optimisation. In the last couple of years a clear need has emerged for the research and development of improved ERP support tools for production.

The target for most ERP suppliers will be to add planning, scheduling and monitoring functionality to their Applications. These applications are commonly referred to in larger enterprises as APS (Advanced Planning and Scheduling) tools. To support an integrated solution for the SME with full Product Life Cycle Management the APS applications, PLM and PDM tools must all interface to the a connected master database.

The most common vertical integration within the IT infrastructure is between ERP, APS and MES (Manufacturing Execution Systems) applications as depicted in the following diagram as shown in figure 1.

In today's manufacturing environment simulation techniques are used to reduce risk mainly in the planning phase for "green field" production plants or the reorganisation of an existing facility.

The areas where the simulation techniques are applied fall into one of the following categories:

- Material flow logistics
- Work cell and layout planning
- Process optimisation

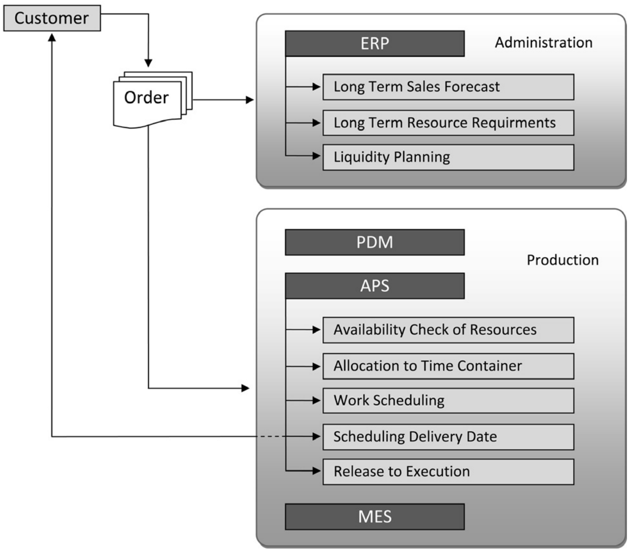


Figure 1: *Vertical Integration of Administration and Production Systems*

Both 2D and 3D industrial software packages are available for these types of tasks and the derived models are often very detailed and rich in process information. In many cases the logistics function and physical detail is so close to the finally implemented system an opportunity exists to take advantage of the high level of process detail to reuse the models to support the end-users daily processes. However most companies apply simulation models for a specific task with little reuse in other business areas, and the opportunity is lost. Other business areas can include: embedding the 3D model within the line controller software for monitoring purposes; or reuse as a tool for production scheduling, for example.

The reuse of the data rich simulation models for operative short term scheduling can be of particular interest to line builders and modular equipment suppliers who already use complete machine model libraries to create a working 3D simulation layout model for pre-sales. These types of companies, would be able to extend the use of the pre-sales models and provide a scheduling tool as an option for every turn-key production system delivered: to help their customers get the best out of the production system.

The research and development challenge is to achieve an integrated simulation based scheduling tool that combines appropriate technologies together in a user friendly package that has good ERP connectivity.

2.1 Selected Tools

Tools from Dualis IT Solution and Visual Components were selected for the pilot project of this study.

Visual Components is a Finish software development company based in Helsinki focusing on the development of a 3D simulation toolkit. The discrete event based software products 3DCreate, 3DRealize and 3DVideo can be used for material flow and logistic simulation as well as robot simulation within the same platform. The component based product family allows customers to import design department CAD data and add in simulation behaviour. The result is an application specific customer equipment library that can be used for different planning operations.

DUALIS IT Solution is a provider of innovative simulation, optimisation and production scheduling solutions in Germany. Dualis has over 200 worldwide customers who have been able to improve and optimise their production processes with tools based on specialised mathematical algorithms for optimisation. Dualis develops techniques for solving real world optimisation and scheduling problems in the Automotive, Packaging, Automation Assembly and Logistics industries. Dualis' latest software development is an optimisation based short term scheduling architecture for small and medium sized companies in the production planning area. The architecture has a planner and constraint based solver algorithm for optimising several, and often conflicting, production goals based on a system with finite resources and capacity.

SMEs using the planning optimisation architecture are able to automatically generate production plans that target specific production goals. The availability of the short term planning solution fills the missing information and lack of scheduling gap commonly found in current commercial MES and ERP systems.

2.2 Core Technologies Simulation, ERP, and APS

The VDI directive #3633 (VDI 1996) defines simulation as: "Simulation is the model based emulation of a dynamic process in order to receive results that can be transferred to the real system".

In general the creation of a simulation model considers the input and output data required for different modelling phases. When a model is completed and the validation step satisfactorily completed the user is able to perform defined experiments on the model. Validation is not always easy, and the most accurate data based on available shop floor information is usually found in an ERP system.

Many definitions exist for ERP systems but generally they are considered as a company wide information and organisation platform. ERP suppliers provide tools and add-on modules to administer essential business data, organise and analyse business processes, and allocate and optimise company resources. The modules available with different ERP systems tend to belong to control, administration, human resources (HR Planning), financial planning, and production planning

From the above areas there is a noticeable need for further development in production planning modules to handle customer specific order and production scheduling optimisation needs. Current ERP systems are not able to model production processes close enough and with the right level of detail. Dynamic production restrictions or planning resources such as employees with special qualifications are not considered. The inability to react to daily changes in the process, and material resource planning and order scheduling based on the infinite capacity of production resources, does not deliver optimised schedules (Kurbel 2006).

Therefore, APS systems have been in demand by planners to help plan more exactly with more detail for better results. APS systems implement new techniques for production planning and control, and as part of an MES-System (fig. 1) they have much better possibilities to model production system parameters and constraints and perform multi-resource planning of production resources, employees and tools. In addition most APS systems implement activity based costing for resources and orders by utilising a detailed process models. The cost considerations directly influence the planning results from the high performance optimisation algorithms and solvers now included in most APS-tools.

APS systems also support testing of different planning scenarios, also known as the “What-if” simulation procedure. The user has a lot more adjustment possibilities within the tools to meet changing production demands, similarly to the simulation approach.

The challenge is to provide a flexible platform which can be easily adjusted to changing parameters and conditions. Modern platforms should provide simple routines or visualisation to update process model parameters.

3 Component Based Simulation Scheduling Solution

The ST “short-term” Scheduler is the name given to the component based scheduling concept designed by the project partners. The ST Scheduler is a tool in response to the need for improved scheduling solutions at the production level. It combines material flow simulation and short term production scheduling into one platform that is integrated to ERP- and MES-systems.

The first step in the definition of the ST Scheduler, was too identify a clear structure for the new platform’s architecture. The architecture would need to support existing simulation and scheduling applications and interfaces to leading data systems. As the required simulation and scheduling technologies are commercially available the main thrust of the definition process was towards customer and end user needs. In order to achieve the target of a more efficient scheduling solution which fits the needs of different customers and processes there must be clear understanding and definition of the existing operational processes (Geiger 1992).

3.1 ST Scheduler Architecture

The architecture for the ST Scheduler was based on a requirements analysis that identified: data maintenance, modelling, simulation and optimisation, planning and scheduling, and a Graphical User Interface as the main functions required

A brief description of each module outlining its main functions follows. The module based architecture fitted the ST Scheduler well as it supported new module extensions for additional customer needs and requests (fig. 2).

Since the ST Scheduler is still in its first development stage it was anticipated that necessary changes and adaptations in future customer projects were quite likely. The modular platform is also an advantage from the software development side because the task of each module is clearly specified and delegated so that development bugs are easier to track and repair.

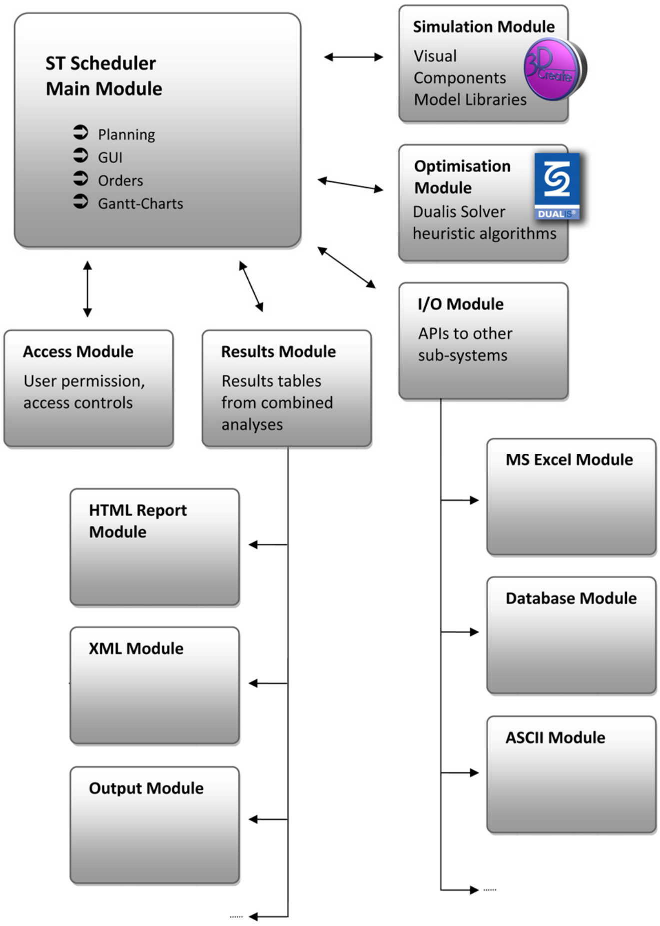


Figure2: *Modular ST Scheduler Architecture*

3.1.1 Main Module

The main module deals with the optimisation process, tracking the scheduling process, as well as administrating and editing the master and order data imported from the ERP-System. Additionally the user can view the optimised production plan as a Gantt chart. The main module also controls the user access and permission levels to other modules.

3.1.2 Process Module

Constraints and parameters are set through the user interface for the 3D production model when it is loaded into the 3DWindow. At the same time, order information is retrieved from an ERP-System and loaded into the Process Module and graphically depicted as 3D order icons at the beginning of the production lines in the model. A manual over-ride lets the user adjust order information pertaining to delivery times and quantities, and orders can be split and re-assigned to other production lines as determined by the production manager. When the simulation commences the orders are processed based on the physical queuing order at each assembly line and the specific process times of machines available.

3.1.3 Optimisation Module

The optimisation module allows the user to start the automatic planning and scheduling routines using mathematical based algorithms. After finishing an optimisation run, the results are accessed through the process and analysis module where the schedule quality can be ascertained. The need for powerful algorithms becomes clear by examining, for an example, even just a small operative scheduling problem, as outlined in the next section.

3.1.4 I/O Module

The data import and export between systems is organised by the I/O Module. It prepares the data exchange and converts incoming data into the main module format. In order for connection flexibility with different ERP-systems the ST Scheduler platform will provide this text file in a supported API format. An SQL database already supports data consistency which is an important requirement for communications to master data storage systems.

3.1.5 Analysis module

Similar to the I/O module the analysis module prepares data from the process module for further use. A report generator lets the user select the information and scenarios to be stored and visualised in prepared result tables.

3.1.6 User access permission module

It is important that a planning and scheduling solution controls different levels of access to the planning and scheduling functions. The ST Scheduler platform includes an easy to handle user access permission configuration to identify each user's read and write access permissions.

3.2 Component Based Scheduler Benefits

The benefits offered by the ST Planner in comparison to current short term planning options available with today's ERP- or MES-Systems, can be listed in terms of the general benefits from simulation and optimisation as well as the operative scheduling benefit for the end –user (Fishman 2001).

The general benefits from using simulation and optimisation technologies in the scheduler architecture are expected to be (Zell 1992):

- Trying "what-if" scenarios on the virtual production system without any real term consequences such as production loss and interruptions.
- Fast scenario testing and future prediction capability for planning purposes

- Better understanding of the production system
- Cost effective validation of new ideas or strategies
- Faster analyses and results
- Modelling of complex systems and networks
- Fast and flexible adaptation to changing production system environment
- optimised production schedules

4 Pilot Plant Implementation

A pilot platform implementation to demonstrate the potential of the "component based" simulation and scheduling architecture was developed for an application in the Surface Mount Technology industry.

Based on the architecture description and the available software tools for 3D simulation and optimisation by Visual Components and DUALIS, the ST Scheduler prototype was developed over a six month period by both partners.

4.1 Project Implementation Workflow

The example customer was an electronics manufacturing supplier (EMS) who sells capacity in "turn key" production facilities around the world. For them it is very important to have fast planning and scheduling capabilities for pending manufacturing contracts. The starting point began with the specification and completion of a customer specific reusable component based simulation library. The first use-case for the customer was to have a planning department capable of accurately remodelling any of their worldwide production facilities. For layout and concept validation the process units were modelled with a high level of detail. In addition to physical geometric parameters, process times, failure distributions and shift models, the user can also edit individual machine operation costs and layout constraints such as electricity and air consumption (fig. 3). The equipment library was validated by manually defining work orders and studying their progress through the simulation model based on routing rules. The load analysis on the modelled production system was based on an order pool from real production data that included a weekly schedule of 10 to 15 products in batches of 5.000 to 20.000 pieces. As input data for the simulation run, .each order included up to 8 different work steps with defined setup and processing times.

After verification and validation of the simulation library the next step was to integrate the components with a flexible database using MS SQL Server 2005 to connect to ERP-System master data. Finally the user interface of the ST Scheduler was prepared so that the production planner can load the required production system model into the 3D world, import and edit order information and execute manual planning procedures by placing the production orders in front of the schematically represented assembly lines (fig. 4).

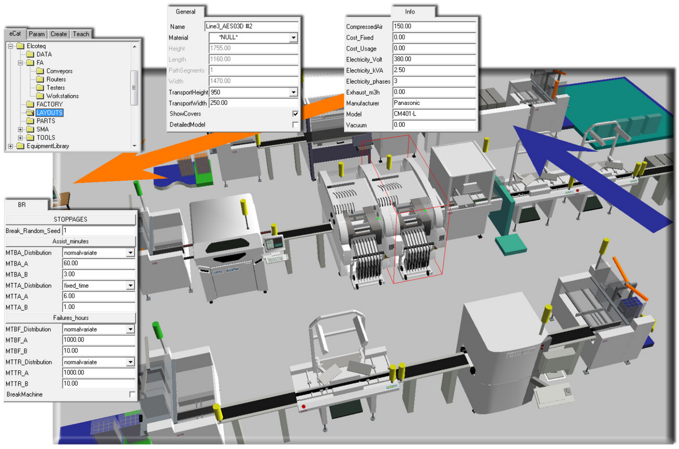
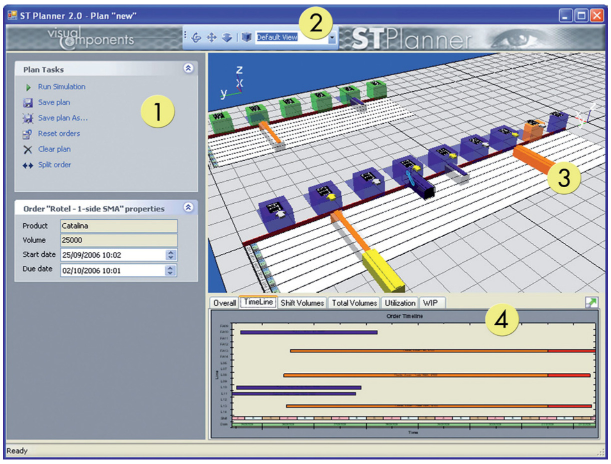


Figure 3: *Component based Layout Planning and Simulation Capability*



1. *Task property panel*
2. *Navigation Toolbar*
3. *3D view panel*
4. *The Reporting panel*

Figure 4: *User Interface of the ST Scheduler Simulation and Scheduling Solution*

The optimisation module was implemented during the validation and test phase. The integrated planning algorithm works with forward and backwards planning techniques. The inputs for the scheduling task were the production orders with workflow procedures and production constraints, as well as production and resource costs. The outcome is displayed in an integrated Gantt chart, and several comparison tables are available to view the results of the planning process.

The optimisation uses a cost function based on different weights set by the planner. The lowest cost option is usually the best solution calculated by the solver algorithms, however the planner can evaluate different solutions also with a higher overall cost function. The decision which plan is finally chosen is depending on the daily production situation and the specific weighting of the single optimisation targets. The optimisation mechanism also includes an adaptive learning system that improves the optimisation process by noting the plans which were selected as the best. Comparison between manually derived schedules with the results reached from the integrated scheduling solution; showed better planning is achieved with the automatic planning approach: even for just small scheduling tasks.

4.2 Conclusion and Vision

A more detailed validation of the "component based" ST Scheduler architecture will be available as more successful project implementations are completed. Although not all modules of the anticipated architecture have been completed several benefits have been observed for end-users:

- 50-80% reduction in facility planning times with the use of a plug-and-play architecture for equipment libraries.
- 10-15% reduction in setup times using a "solver" optimised order sequencing.
- 10-15% more on-time deliveries

A reaffirming signal from the market indicating potential acceptance, is the number of new SME customers requesting similar functionality. The component based fits well with SMEs who are always seeking to lower the total cost of ownership of software purchases with modular and widely applicable solutions for their whole organisation. Future development plans include the incorporation of an online real-time production monitoring system.

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