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MODELING AND SIMULATION FOR CUSTOMER DRIVEN MANUFACTURING SYSTEM DESIGN AND OPERATIONS PLANNING

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ABSTRACT

Agility, speed and flexibility in production networks are required in today's global competition in the flat world. The accuracy of order date delivery promises is a key element in customer satisfaction. Agile production needs a management and evaluation tool for production changes. Discrete event simulation, DES, has mainly been used as a production system analysis tool, to evaluate new production system concepts, layout and control logic. DES can be used for operational planning as well, as shown in the paper. The simulation analysis gives a forecast of the future with given input values, thus production managers have time to react to potential problems and evaluate alternatives. A balance between multiple parallel customer orders and finite resources can be found. The authors are developing a system design evaluation method and also a decision support system for production managers. Two case studies with different approaches are described in the paper.

1 INTRODUCTION

Manufacturing simulation focuses on modeling the behavior of manufacturing organizations, processes and systems. Traditionally, simulation tools have been used in production system planning and design. Simulation models live as long as there is a need for strategic planning. Once the system has been implemented, the model loses its value and is set aside until other strategic decisions have to be made. Today, simulation models are used in all the different system levels and phases of the manufacturing system life cycle (see Figure 1). The following steps are found: concept creation, layout planning, production simulation, software development and operator training (Heilala et al. 2001). Naturally there is wide variety of simulation tools in the manufacturing domain. The use of discrete event simulation, DES, can be enhanced also to cover production operations planning (Thomson 1993) as a decision support tool (see also Table 1). Simulation based scheduling and planners are actively being developed. Commercial solutions exist, one of the latest examples having been presented by Hindle and Duffin (2006).

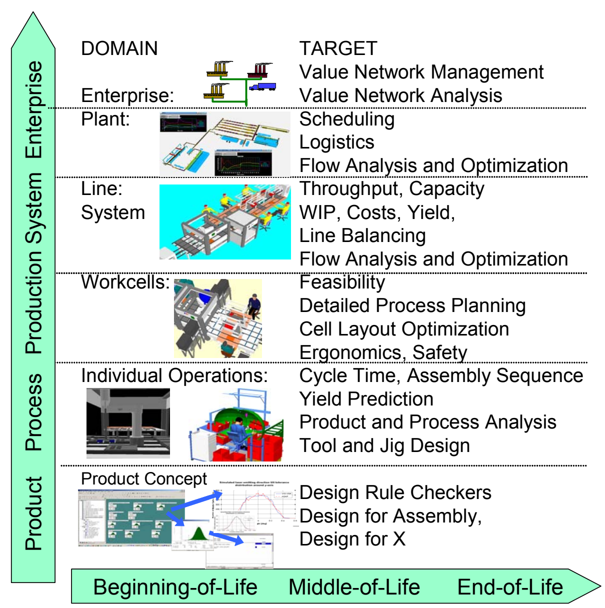

Figure 1: Manufacturing systems modeling and simulation

Table 1: Use of discrete event simulation in different manufacturing system life-cycle phases, based on (Heilala 2001)

System life-cycle phase	What and How	Why
Concept creation, layout planning of cells, lines and factories	Visualization 2D and 3D, communication, animation, easy and fast modelling needed.	Selling and development of ideas and concepts, fast elimination of unsuitable one.
Production simulation, detail level development of the system, design optimization.	Analysis of control principles, routing, buffer sizes, capacity, utilization, throughput-time, bottlenecks, etc. Data analysis, reports, multiple runs, stochastic, .	Investment insurance, strategic decisions and detailed evaluation of alternatives. Simulation model is an intelligent document of the system.
Control software development, debugging and validation.	Control software debugging and validation against virtual system, emulation. Real-time integration with validated simulation model and control software.	Debugging and testing of control system, shortening the development time, faster system installation, off-line control system development.
Training of operators, ramp-up and installation of system.	Training with virtual model and control software. Emulation, integration of validated simulation model and control software.	Experience for operators, normal use and exceptions, faster ramp-up.
Operational use, problem solving in exceptions, validation of production plans.	Simulation tools for production managers. Data integration, easy to use graphical user interface, fast analysis, embedded simulation.	Decision support for operations, short term scheduling, operative and tactical capacity planning, order-book validation.

1.1 Operational Use of DES

While some DES models are used to plan and design, other models are used in the day-to-day operational production planning of manufacturing facilities. These "as built"' models provide manufacturers with the ability to evaluate the capacity of the system for new orders, unforeseen events such as equipment downtime, and changes in operations. Having built a simulation model, experiments are then performed changing the input parameters and predicting the response. Experimentation is normally carried out by asking 'what-if' questions and using the model to predict the likely outcome. Some operations models also provide schedules that manufacturers can use to run their facilities. Simulation can complement other planning and scheduling systems to validate plans and confirm schedules. Before taking a new order from a customer, a simulation model can show when the order will be completed and how taking the new order will affect other orders in the facility. Simulation can be used to augment the tasks of planners and schedulers to run the production more efficiently. It is important to recognize that simulation is primarily a decision support tool and does not directly seek optimal solutions.

Traditionally, production managers, sales and customer service engineers have made decisions based on the following data, information and factors:

- Own intuition and long experience
- Asking the ”experts”
- Use of tables and handbook, given static information, order books, legacy systems, ERP, and
- Use of own calculations, spreadsheet and other static calculation methods.

The decision is based on the data and information available at the time. The operators and managers can use all the quantitative data they have, but they still have to distrust it and use their own intelligence and judgment. There is a need for a quick response tool to evaluate alternatives and scenarios before decisions are made. Optimization and simulation modeling could be used to provide information for decision makers.

1.2 Customer Driven Manufacturing

The best benefits of operative use of simulation can be gained in customer driven manufacturing. Time-to-customer, punctuality and throughput time are important competitive factors in make-to-order manufacturing. The products are usually complex systems consisting of components, which are manufactured in different factories, sometimes in different countries. Manufacturing is performed on the basis of customer orders and each order can be unique. Naturally, the throughput times of the products may differ from one another. The production systems have to be flexible and able to react to changes in production capacity requirements.

Features of customer driven manufacturing:

- Promises to the customer must be kept (always)
- Need for speed and flexibility, because of dynamic global competition
- Order book is shrinking while delivery times are getting shorter
- Outsourcing, supply and value networks
- Productivity improvements from supply chain management and coordination.

The order entry point defines the customers' influence on the features of the product:

- **Make-to-Stock, MTS**, the customer selects a product from stock and the product is shipped to the customer, no customization.
- **Assemble-to-Order, ATO,** the customer order initiates the assemby from components and modules in stock, customization based on customer requirements in assembly before delivery.
- **Make-to-Order, MTO**, the customer order initiates the material purchase, component and module manufacturing and assembly of the product.
- **Engineer-to-Order, ETO**, the customer specification initiates the engineering required before starting material purchase, component manufacturing and assembly.

The deeper the order entry point is into the manufacturing process, the more challenging is the production planning. The case studies in operation planning shown in the paper have features of ATO and MTO. In current global competition and in lean and agile manufacturing, material stocks are kept as small as possible, while expensive resources utilization should be kept as high as possible. Production personnel must seek a balance between customer orders and limited resources, and every new order disturbs the current balance (Figure 2).

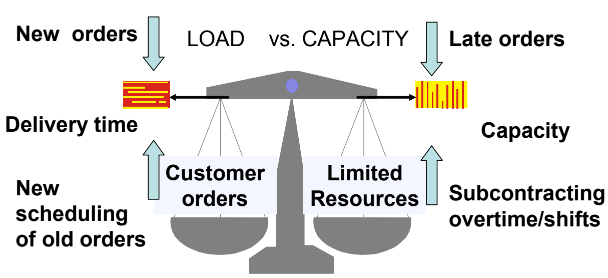

Figure 2: Production balancing

1.3 Challenges and Research Needs

Manufacturing systems, processes and data are growing and becoming more complex. Manufacturing engineering and production management decisions involve the consideration of many interdependent factors and variables. These often complex, interdependent factors and variables are probably too many for the human mind to cope with at one time (McLean and Leong 2001a; Mclean and Loeng 2001b; SISO 2004). Simulation modeling and analysis could help. Discrete event/material flow/factory simulation is used commonly in the manufacturing system design phase to evaluate the concept and optimize system solutions, sometimes also for training operators or selling ideas to potential customers, using a "virtual factory" as shown in the second case study.

The IMTI Modeling and Simulation for Affordable Manufacturing Roadmap (IMTI 2003) defines 75 top-level goals and 250 supporting requirements for research, development, and implementation of modeling and simulation technologies and capabilities. Subsequent processing has distilled these needs into four focused, high-level goals:

1. **Automated Model Generation** – Develop techniques to enable automated generation and management of models at various levels of abstraction for multiple domains.
2. **Automated Model-Based Process Planning** – Provide the capability to automatically generate manufacturing process plans based on product, process, and enterprise models, with integrated tools to evaluate the producibility of features, resources, and repeatability.
3. **Interoperable Unit Process Models** – Develop a shared base of robust, validated models for all materials and manufacturing processes to enable fast, accurate modeling simulation of any combination of processing steps.
4. **Scalable Life-Cycle Models** – Provide the capability to create and apply scalable product life-cycle models in every phase of the life cycle and across all tiers of the supply chain.

Another list of challenges (Fowler and Rose, 2004) identifies the following:

Grandest Challenge 1: An order-of-magnitude *reduction in problem solving cycles*. The simulation process for manufacturing systems analysis, model design, model development and deployment.

Emerging Grand Challenge 2: Development of *real-time simulation based problem solving* capability. Permanent, always on, synchronized factory models, on-demand, automatically built factory models.

Emerging Grand Challenge 3: True plug-and-play *interoperability* of simulations and supporting software within a specific application domain.

Big Challenge 4: Greater *acceptance* of modeling and simulation within industry.

1.4 Current status on Operative Planning

The semiconductor and process industries have been leading the way. In the mechanical industry, there are limited examples of the use of simulation tools in operational planning of manufacturing, despite the availability of dedicated software packages like Preactor <www.preactor.com>, Asprova <www.asprova.com>, Simul8-Planner <www.simul8-planner.com> and others made by simulation engineering offices. A limited number of the packages is based on optimization, like Dualis-It solutions <http://www.dualis-it.de>.

The following provides an indication of some of the benefits of implementing an operative simulation scheduling system: reduced planning effort for the day-to-day scheduling, customer order due date conformance, synchronization of the flow through the plant; minimization of set-ups/changeovers, early warnings of a potential problem, check of critical resources and materials, and naturally "What-if" scenario analysis for capacity planning.

The cheapest packages cost less than 1000 € a license, they have fixed data structures and menus. This Gantt-chart scheduling software is targeted for users with simple production scheduling problems typical of small job shops. The more advanced, customized solutions are much more expensive.

The costs of integrating simulation systems with other manufacturing applications are high; there is always a need to transfer and share data between simulation and other manufacturing software applications. Custom-built proprietary interfaces are too costly and make it prohibitive for users to use simulation technology (SISO 2004). Thus applications need a lot of customization; due to the lack of standardization, system integration is challenging. Naturally the model must be precise enough if managers are using simulation model to plan operations.

2 SYSTEM DEVELOPMENT

The ongoing development of the project MS2Value – "Modeling and Simulation of Manufacturing Systems for Value Networks" is helping to resolve the following challenges: model building speed, simulation based problem solving, on-demand automatically built factory models, plug-and-play interoperability of simulation, and the supporting software. The project is also developing advanced cost modeling integrated with simulation, Programmable Logic Controller (PLC) code validation, distributed simulation using High Level Architecture (HLA), and value network analysis.

2.1 Past Developments

The earlier development of some applied research projects has been discussed elsewhere (Heilala et al. 1999; Heilala et al. 2001). The development aims then and now have been very similar: to increase customer order delivery accuracy, capacity planning and synchronization of manufacturing tasks in customer driven manufacturing. The developed functional prototype tools increased the production network agility in fast changing environments; this was evaluated by users, but actual research into the benefits of using the systems was not carried out. Past industrial pilot cases were from mechanical, heavy mechanical and electronic industries.

The basic concept is still the same. Similarities can be found in the user interface, but each of the pilots is unique. The past generic system environment is shown in Figures 3 and 4. Integration into other enterprise applications, like ERP or MRP, was done using formatted ASCII text files. ASCII text transfer is a robust traditional method.

The number of input and parameter files depended on the enterprise IT system structure. The parameter file could be created and updated using spreadsheets or a simple text editor. The user interface also had tools for data management. An analysis run in these pilot applications was a batch process (Figure 4). The targeted use was to create a daily work-list, short term scheduling, capacity planning, order book creation and validation and in general "What-if" scenarios. The length of a simulation run was from one shift to a few weeks, months, or even years of simulated production time.

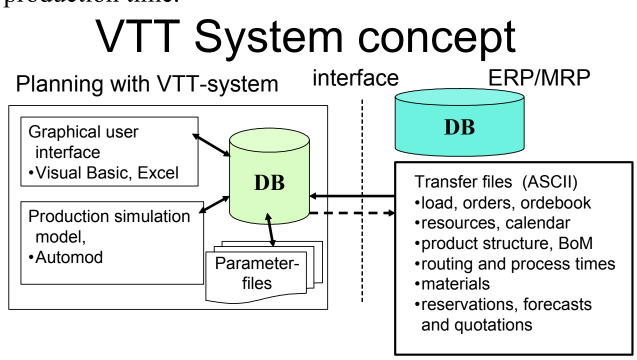

Figure 3: An early system concept

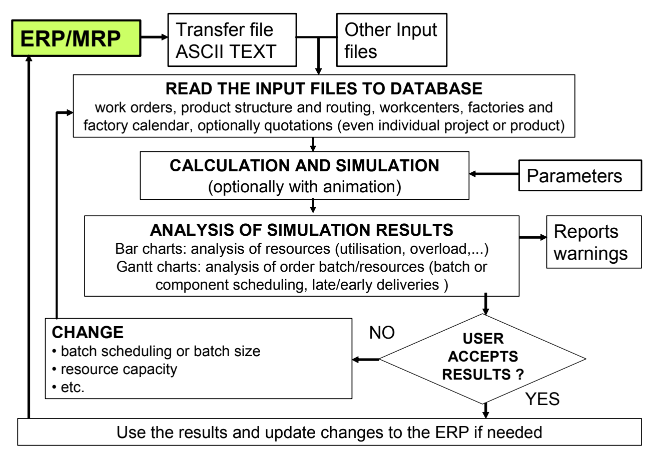

Figure 4: Analysis workflow

The user interface consisted of graphics, bar and Gantt-charts and custom reports pointing out the potential problem areas in production, like overload in resources or components and orders that would be late in the future. The status of work centers and customer orders could even be seen at the component level.

The graphical user interface, GUI, had several windows. The scheduling changes could be done interactively, e.g. with a mouse and simple drag and drop. The GUI could be based on MS-Office tools, MS-Excel and MS-Project as shown by Heilala et al. (1999), but there were limitations. In later cases the user interfaces were programmed using Visual Basic and some OCX libraries (Heilala et al. 2001).

In the two first case studies, carried out in 1997-1999, a commercial simulation software run-time license was used, called Automod <www.automod.com>. Analysis of the process flow is shown in Figure 4. Optionally, a simple 3D animation of the simulation could have been used, but since it needs more calculation capacity, it was normally not used in daily operation planning. Production managers were satisfied with bar and Gantt-chart type visualization. It is important to note that the user approved all the changes and he or she had control of the decision. The user could initiate an optional what-if analysis, machine breakdowns and others by editing the input files using the user-interface functionality.

Some of the past functional prototypes are no longer in use due to changes in the ERP platform; there would have been a need to customize the data interfaces, and naturally the key personnel changes in the companies had their own effect. However, several other similar developments carried out at VTT are still in use; the authors at VTT continued the development with new industrial partners.

2.2 Faster Model Building and Re-Building

The use of component based simulation clearly brings speed advantages to model building, especially if pre-engineered simulation components exist. Model building centers on configuring a layout, by selecting the right components to fulfill the process flow and setting the right parameters. The software selected here as the development platform is from Visual Components <www.visualcomponents.com>. The software supports modularity at different levels (see Figures 5 and 6).

The use of a simulation model can shorten the sales cycle of the production system — especially if the model can be created during the sales meeting and it creates additional information during the meeting, like system life cycle and other cost analysis. This is also the aim in one of the other industrial pilots of the MS2Value project, presented elsewhere (Heilala, et al 2007).

Automated model building from ERP data is also being developed and tested in two industrial pilot cases with different simulation software. The other generic development point has been in simulation data management. The simulation data is exported in both pilot cases from ERP and potentially some other manufacturing information system as formatted ASCII text and CSV files. The user interfaces has tools to map different source files data fields to simulation database data fields. There is also development on how to control simulation with an easy-to-use interface, and on how to present simulation results.

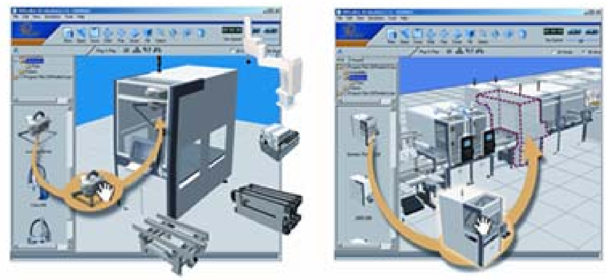

Figure 5: Component based simulation model building

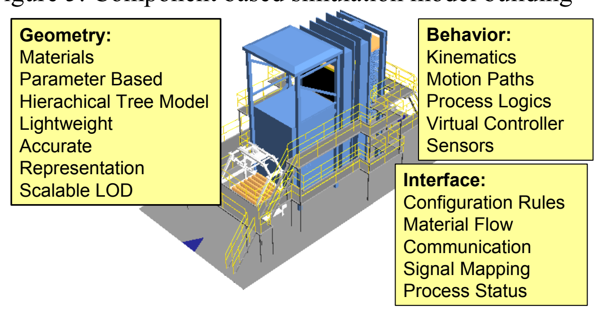

Figure 6: Properties of simulation components

2.3 Simulation Result Visualization

Simulation analysis produces lots of numerical information consisting of tables, listings, and reports. For a human decision-maker it is difficult to locate the relevant pieces of information. That is why normal operational users and production managers need tools for data mining. In addition, the simulation results have to be presented in a visually attractive way to speed up and improve the way the results will be understood.

Different users require, or are allowed access to, different types of information or the same information presented differently. For instance, a line supervisor and plant manager rely on different levels of data upon which to base business decisions — too little or too much data and its utility is diminished if not lost. Time is an important factor in defining how much and what kind of data should be aggregated for the upper levels of the organization; a manager can not afford to be “swimming in data” when making a quick decision. Ultimately, users should be given enough information to enable them to make the decisions necessary to optimize the performance of their job function. One of the challenges is to provide the appropriate granularity of information needed by each class of user (Heilala et al. 2001)

The system gives, for example, a proposal for rescheduling of production orders by showing late or early orders and components or resources that are overloaded. The user can add resources to overloaded workplaces, either more human operators or add working hours or use subcontracting. The user can re-schedule orders with the visual interface and has the option to re-run the simulation to check the results.

3 R&D ON CASE STUDIES

Industrial partners in the pilot cases are: Sandvik Mining and Construction Oy <www.sandvik.com>, a producer of rock drilling equipment, single and multi-boom mining and tunneling jumbos and long-hole production drill rigs (see Figure 7). Raute Corporation <www.raute.com> supplies a complete range of machinery, systems and technology for the production of plywood and veneer including log handling, peeling, drying, veneer handling, plywood layup and pressing, panel handling and automation and control (see Figure 8).

Figure 7: Underground multi boom mining jumbo.

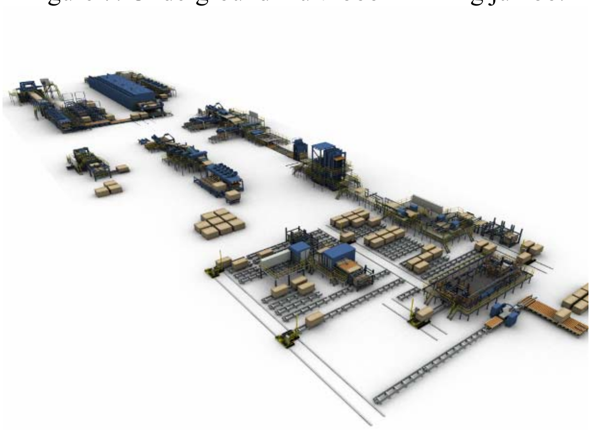

Figure. 8: Typical plywood factory

The end user case studies were defined in 2005-2006 and currently there are functional prototypes for demonstration and validation. The industrial pilots have different aims and development platforms. The heavy machinery case, Sandvik, which involves customer driven manufacturing of mining equipment, is purely an operative simulation case with tools for production managers. It is based on an embedded simulation platform, VTT proprietary GESIM (Generic Simulation). Raute is the plywood factory design and operative manufacturing simulation case, with Visual Components 3DCreate® component based simulation software. Simulation development and modeling supports the system sales process, equipment development, factory planning and later also operative planning at the real plywood factory.

In the use of simulation methods for operations planning and scheduling, the key issue is getting the correct analysis data for simulation as easy as possible. The generic development in both cases is in the improvements to integration of manufacturing-related data from existing legacy systems, like ERP. Also methods for automated model building are being developed and advanced methods for simulation model management using a graphical user interface have been studied. Simulation results must be presented in a visually attractive way and some new ideas are being evaluated in case studies. The development of tools and methods is aiming towards easy-to-use, user-friendly solutions.

3.1 Heavy Mechanical Industry - Sandvik

An initial implementation of the Sandvik case study includes a graphical user interface (GUI) with simulation capabilities for production managers (Figure 9). Data integration is partially generic using custom-built proprietary interfaces. Simulation data is fed from the ERP as text files; this is a robust integration into the ERP system and can be adapted to a new ERP system if needed. A simulation engine and calculations are embedded in the user interface and there is no 3D factory model. Simulation results are shown with a windows style graphical user interface, bar and Gantt charts. The simulation system is parametric; adding resource data to the ERP also adds resources automatically to the simulation model when data is read into the system.

The current GESIM-Sandvik solution has a wide range of functionalities. A wealth of information is readily available through pop-up windows with mouse clicks and functions for production operation planning. It is easy to reschedule orders, as well as forecasts, and add and delete orders. The user interface shows the factory status, all orders in the upper window, workload on a selected resource the middle window, including estimation of the selected subcontractor's workload, and orders in the selected resource. The potential critical material shortages, are shown and some other warnings as well.

Final assembly production is a flow line type, and products are moved to the next workplace at predefined time intervals. Since each order can have a different configuration, the workload on workplaces varies. The solution here is to adjust number of human operators in the workpalces. Simulation analysis shows the need for workers, or actually worktime needed in each process phase.

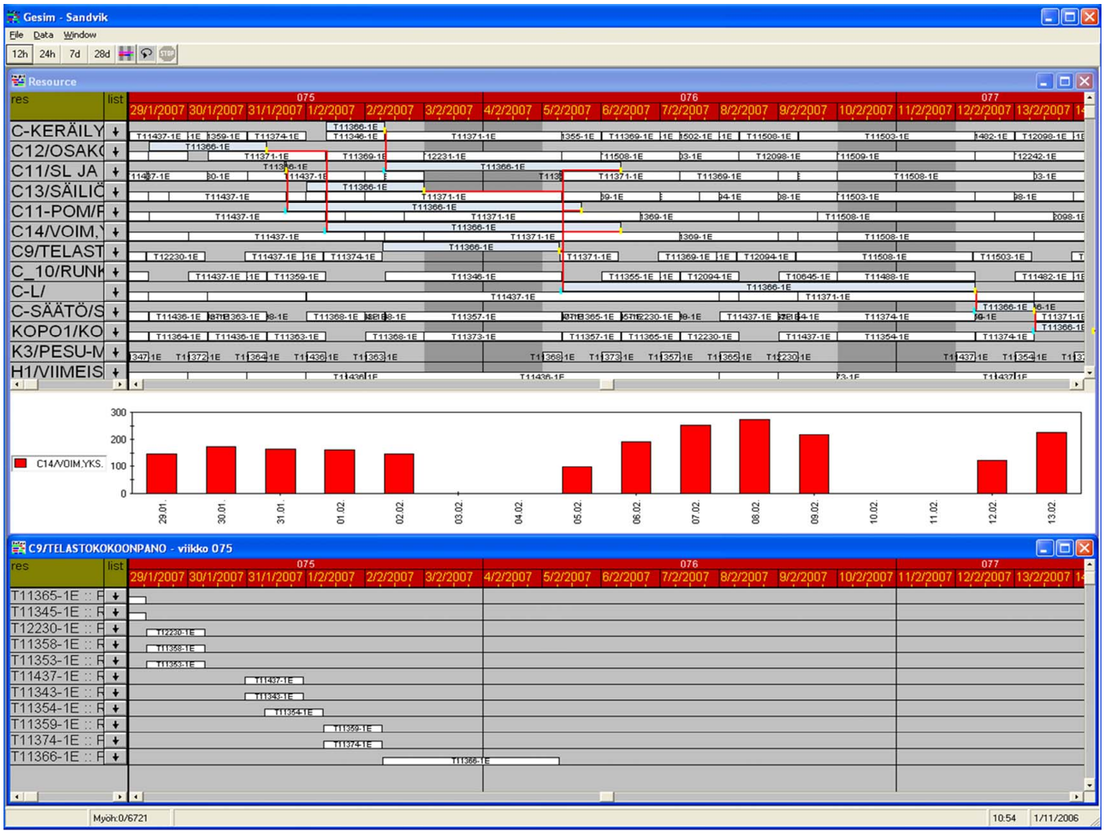

Figure 9: User interface, Sandvik

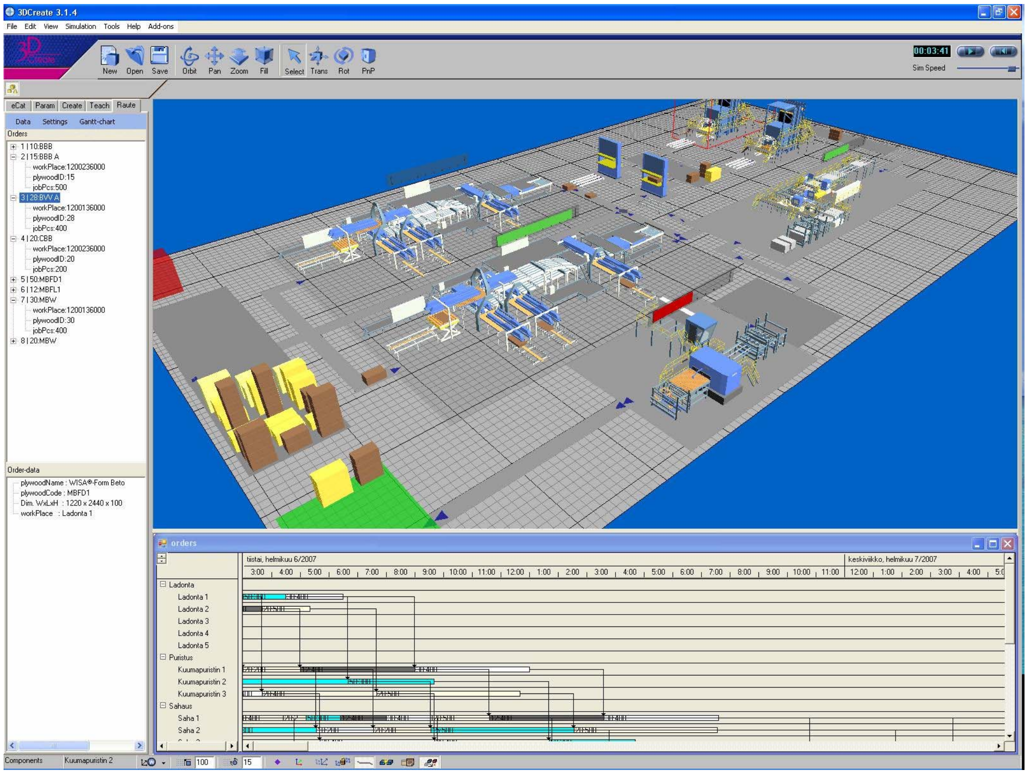

Figure 10: Raute case simulation

There are several potential user groups in the company, but the principal planned users are production managers and production line foremen. Information flow is from the ERP system to simulation. The evaluated and selected scenario must be entered manually into the ERP system, so the user is in control. The simulation tool helps in the planning of dynamic operations since production managers are able to make better decisions.

3.2 Plywood Manufacturing – Raute

The Raute case study — implementation of a simulation tool for planning of the plywood factory and later for scheduling of plywood mill operations — is currently under development. An initial implementation is available, shown in Figure 10. The 3D factory simulation provides information on equipment and storage status. Some additional information can be shown using a Gantt-chart type window. Depending on which windows are made active through the software user interface, other interactive menus will be opened.

The first development focus has been in the creation of methods for simulation model building. There is development on how to transfer simulation data from the database to the actual simulation model, and on how to control simulation with an easy-to-use interface. The automated model building functionality is also being developed with Visual Component software as well. It will be a specific plywood factory case with Raute equipment.

Potential uses for the development are many, like a tool for sales engineering or factory design. Later the developed methods can be used for the planning and optimization of day-to-day factory operations. The current developed version evaluates work schedules of the ERP systems and compares them with simulation run results. There are many functions of the user interface that are not presented here. Actual development is an add-on created for Visual Components 3DReate®.

4 ANALYSIS OF CASE STUDIES

The authors have developed a decision support system for sales engineers (Raute) and operation planning (Sandvik and Raute). Decision Support Systems (DSS) are interactive computer-based systems intended to help decision-makers use data and models to identify and solve problems and to make decisions. The DSS framework has five major categories (Power, 2007): Communications-Driven, Data-Driven, Document-Driven, Knowledge-Driven and Model-Driven DSS. The solution concept presented here is a hybrid solution.

Both presented cases use complex multi-criteria models to provide decision support. The solutions use data and parameters provided by decision-makers to help analyze a production situation. The system can be called model-oriented or model-based decision support systems.

An operational decision support system has many potential users, from the operator on the production line to the plant manager and even upper management. Present Factory Information System (FIS) capability is geared to support operators and engineers, not planners, financial analysts, and upper management. ERP or MRP systems have other limitations, they are usually based on static resource models, with unlimited capacity. Currently manufacturing scenarios can not be studied efficiently with the ERP system. Manufacturers have begun the transition from passive data monitoring to conversion of data to information and must attempt proactive, operational and strategic decision making in the future.

There are other similar tools available; one limiting factor for wider use of the technology is the cost of data integration, integration of the simulation model and other manufacturing information system, in other words the customization cost is high. There is no commonly accepted data model standard. The authors used ASCII text files in the presented cases studies, but perhaps in the future XML will provide a better solution. At present the limiting factor is on the ERP side, as it does not provide XML output.

4.1 Potential in Standardized Neutral Interfaces

The use of standardized structured manufacturing data in a neutral format (like XML) could clearly increase interoperability between manufacturing information system and simulation and also speed up modeling. There are currently activities in SISO, Simulation Interoperability Standards Organization, CMSD Product Development Group to create Core Manufacturing Simulation Data Information Model, (CMSDIM) to standardize job shop simulation data model (SISO 2004). The data elements of the current data model are called: Organizations, Calendars, Resources, Skill-definitions, Setup-definitions, Operation-definitions, Maintenance-definitions, Layout, Parts, Bills-of-materials, Inventory, Procurements, Process-plans, Work, Schedules, Revisions, Time-sheets, Probability-distributions, References, and Units-of-measurement (SISO 2006).

In the future this development could help to lower integration cost, if the SISO CMSD standard will be accepted by the industry, simulation software and other manufacturing information system providers.

5 DISCUSSION

The development presented here offers all functionality to lengthen a simulation model's life cycle and its benefit in day-to-day planning and control. The developed methods and tools shown here are useful in customer driven manufacturing by adding features for the production planners and capacity managers, which the standard tools in the past did not provide. By integrating discrete event simulation and traditional production planning methods, it is possible to forecast the required workloads with given input values.

The load data for simulation, indicating the product, its parameters and required quantities and delivery dates, will be obtained from marketing offices and ERP systems, so both orders and quotations can be used. Simulation gives the users a window to the future and information for decision making. It becomes possible to adjust work queues and orders and to achieve a balanced rate of resource utilization. Delivery days can be confirmed on the basis of the simulation model. Overload situations and unnecessary waiting time can be eliminated. By using the simulation model and a developed graphical user interface it is possible to visualize the occurrence of potential bottlenecks or other production problems and to take corrective actions.

Future development includes evaluation of the use of optimization techniques, rule based scheduling or genetic algorithms or linear, integer or mixed programming. The optimization could be used to search for some feasible solutions and with simulation the solutions could be tested and verified.

Neutral standardized interfaces are needed to aid integration and development of reusable simulation models and objects. These interfaces would make modeling easier and reduce the costs associated with both model construction and data exchange between simulation and other manufacturing software applications. This would make simulation technology more affordable and accessible to a wide range of industrial users.

The developed simulation tools can be adapted for new industrial fields and be implemented for other enterprises. The developers must have a deep understanding of the industrial field processes to be able to model the specific features of the industry and naturally modifications to the user interface and data interface are required. An implementation project needs development resources from both the end-user and system developer.

There has been progress in simulation software and most of the current software is object oriented with a graphical windows style user interface. At the same time, however, the complexity in manufacturing systems and products has increased. There are development needs in manufacturing system modeling and simulation: e.g. integration of different simulation and modeling methods – use of multi-disciplinary simulation with different abstraction levels. A simulation model and a manufacturing system life cycle should be combined, and the model should be a virtual, concurrently evolving digital image of the real system. Thus a need for real-time data coupling from the factory floor exists – even it was not expressed in the presented case studies.

A future aim could also be hybrid methods — simulation, optimization and other manufacturing information systems in an embedded application. These could be used by non-simulation experts, even on-line and real-time on the factory floor (plug and simulate), enabling science-based system management.

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