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Decision Support Using Simulation for Customer-Driven Manufacturing System Design and Operations Planning

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1. Introduction

Agile, fast and flexible production networks are a must in today's global competition. The interrelations between manufacturing systems and processes are becoming more complex and the amount of data for decision making is growing. Manufacturing, engineering and production management decisions involve the consideration of multiple parameters. These often complex, interdependent factors and variables are too many for the human mind to cope with at one time. Agile production needs a management and evaluation tool for production changes, manufacturing system development, configuration and operations planning. A decision support system based on manufacturing simulation is one suitable solution.

Discrete Event Simulation (DES) has mainly been used as a production system analysis tool to evaluate new production system concepts, layout and control logic. Recent development has enhanced DES models for use 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. After a simulation model has been built, experiments are performed by 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.

A simulation-based Decision Support System (DSS) can be used to augment the tasks of planners and schedulers to run production more efficiently (Figure 1). Some of the benefits of implementing an operational simulation scheduling system include: less effort required to plan day-to-day scheduling, customer order due date conformance, synchronisation of flow through the plant, minimisation of set-ups/changeovers, early warnings of potential problems, checks of critical resources and materials, and, naturally, "what-if" scenario analysis for capacity planning.

Although dedicated software packages are currently available, there are limited examples of the use of simulation tools in the operational planning of manufacturing. This chapter also sheds light on development challenges and current development efforts to solve these challenges for this data and model-driven DSS. The major challenges are: 1) data integration, 2) automated simulation model creation and updates, and 3) visualisation of results for interactive and effective decision making.

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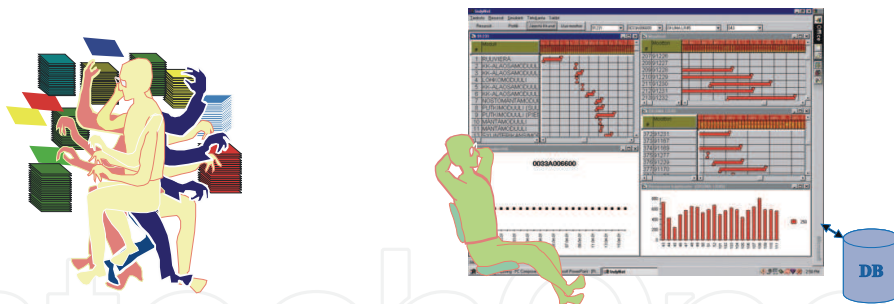


Fig. 1. Simulation and modelling-based system helps operators in daily operations planning.

The costs of integrating simulation systems with other manufacturing applications are high; there is always a need to transfer and share data between the simulation and other manufacturing software applications. Custom-built proprietary interfaces require extensive customisation and the current standardisation landscape for system integration is challenging. Development efforts to solve this problem are ongoing. Naturally, if managers are using a simulation model to plan operations, the model must be precise enough and kept up to date. There is a need for permanent, always on, synchronised factory models that can be created automatically on-demand from ERP and other data sources. Users need fast analysis and methods to perform “what-if” scenarios. Simulation results can provide suggestions for feasible and optimised finite scheduling, but the human in the loop will make the final decision. The users also need a visually effective user interface. Visual analytics provides visual and interactive tools for analytical reasoning and decision making from data. The basic idea is to combine the strengths of automatic data analysis with the visual perception and analysis capabilities of the human user. The use of simulation with an easy-to-use graphical user interface provides tools and methods for manufacturing scenario evaluation, scheduling optimisation, and production planning even for simulation non-experts. Some of the past case studies are described to illustrate the system solution. The benefits of simulation-based DSS in the customer-driven manufacturing domain and the suitable user groups are discussed.

1.1 Manufacturing system complexity

A manufacturing system is made up of entities (input and outputs), activities, resources and controls. It encompasses processes but also includes the resources and controls for carrying them out, as shown in Figure 2. Manufacturing system design involves a number of interrelated subjects, including tooling strategy, material handling systems, system size, process flow configuration, flexibility needed for future engineering changes or capacity adjustments, and space strategy.

There are many challenging factors: the need to boost system performance due to global competition and the growing complexity of both the manufacturing systems and products to be manufactured. The operations planning and capacity management of these complex manufacturing systems are indeed challenging. Productivity enhancement is also a major objective for manufacturing enterprises. Manufacturers are experiencing fluctuating market demand for their products, with ever shorter lead times and smaller but more frequent order quantities, accompanied by increasingly frequent changes in product specifications - even during manufacture. Product life cycles are shorter and it is becoming more difficult to forecast demand. All this requires agility and flexibility on the part of the factory, which runs counter to the built-in inertia and the gravitational force to ‘conduct business as usual’, combined with the limited ability of management to reconsider decisions almost ‘in real time’.

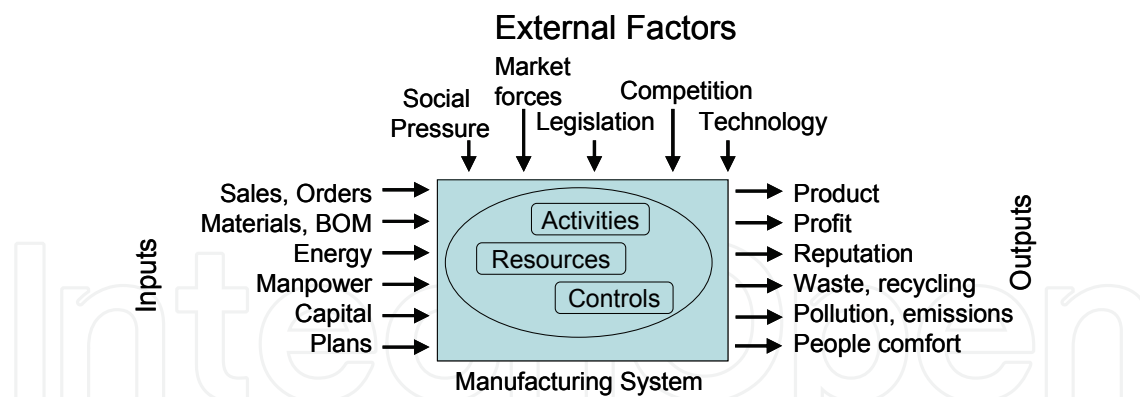


Fig. 2. Manufacturing system (modified from Harrel and Tumay, 1995).

1.2 Customer-driven manufacturing

Customers define the business. They want high-quality personalised products. Time-to-customer, punctuality and throughput time are important competitive factors in customer-driven manufacturing. The products are usually complex systems consisting of components that are manufactured in different factories, sometimes in different countries. The whole production network - including both component manufacturing and assembly - has to be flexible and able to react to changes in production capacity requirements.

Manufacturing is performed on the basis of customer orders. Each order can be unique, consisting of different components, and batch sizes vary. Naturally, the throughput times of the products may differ from one another. A new order is a 'disturbance' to the current situation in production. All this makes the design and management of production networks a complex task. One of the risks is the occurrence of dynamic bottlenecks, in which the demand for capacity in one particular operation suddenly turns out to be excessive and the resulting delays reverberate throughout the rest of the production system. The changing location of bottlenecks depends on the status of production resources, equipment, materials, human operators and orders in production.

Features of customer-driven manufacturing:

- Promises to the customer must be kept (always); Time, Quality and Cost
- Need for speed and flexibility due to dynamic global competition
- Order book shrinks while delivery times shorten
- 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 customisation.
- Assemble-to-Order (ATO): the customer order initiates the assembly from components and modules in stock. Customisation is based on customer requirements in assembly before delivery.
- Make-to-Order (MTO): the customer order initiates material purchases, component and module manufacturing and assembly of the product.
- Engineer-to-Order (ETO): customer specifications initiate the engineering process before material purchases are made and component manufacturing and assembly are started.

The deeper the order entry point is into the manufacturing process, the more challenging and complex the production planning. The case studies of operations planning provided in this chapter have features of ATO, MTO and ETO. In current global competition and in lean and agile manufacturing, material stocks are kept as small as possible, while expensive resource utilisation should be kept as high as possible. Production personnel must seek a balance between customer orders and limited resources. Every new order disturbs the current balance (Figure 3). The resources are equipment, machinery, human operators as well the material needed for the manufacturing operations.

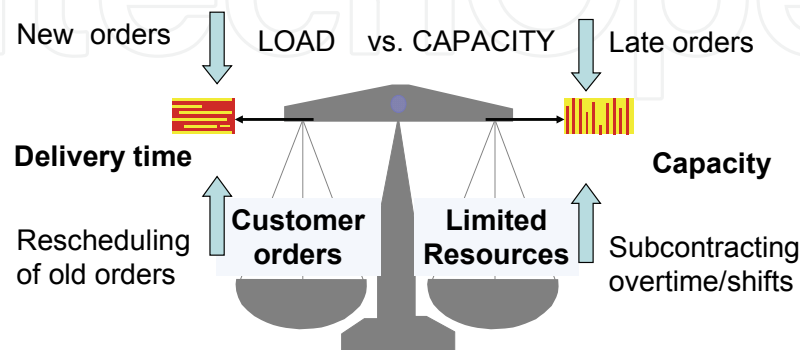


Fig. 3. Production balancing between orders and limited resources.

The accuracy of order date delivery promises is a key element in customer satisfaction. One of the important decisions in production planning is the scheduling and synchronisation of activities, resources and material flow. Old static production planning methods are not adequate; production planners need accurate and dynamic models of production, i.e. a simulation model using production network and real shop floor data in near real time.

In this complex world, the development of decision support for human operators and information management is a key asset in managing “better-faster-cheaper” competition. Simulation analysis with real data provides forecasts on the basis of the given input values. This gives production managers the time to react to potential problems and evaluate alternatives. A better balance between multiple parallel customer orders and finite resources can be found.

2. Decision support systems

A Decision Support System (DSS) is an interactive computer-based system or subsystem intended to help decision makers use communications technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions. Decision Support System is a general term for any computer application that enhances a person or group’s ability to make decisions. In general, Decision Support Systems are a class of computerised information systems that support decision-making activities. Five more specific DSS types include (Power 2009)

- Communications-Driven DSS,
- Data-Driven DSS,
- Document-Driven DSS,
- Knowledge-Driven DSS and
- Model-Driven DSS.

2.1 Decision making in production engineering and management

There are multiple decision-making aims in the manufacturing system domain. Strategic and tactical aims focus on the design or selection of a new manufacturing system or the improvement of the existing manufacturing system, and the planning time horizon is years or months (Figure 4). Operational aims, which involve the running of the existing system, have a much shorter time frame – days, hours or minutes to solve problems in manufacturing.

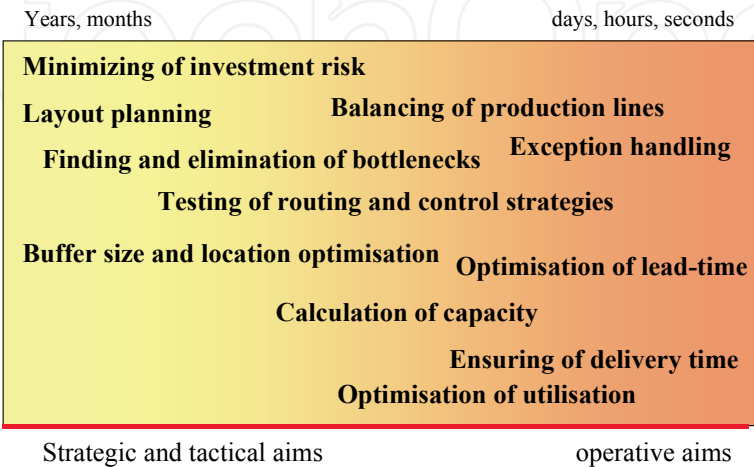


Fig. 4. The planning horizon and aims in production engineering and management.

The production engineering and management decision is typically based on the data and information available at the moment of the decision. Operators and managers can use all the quantitative data at their disposal, but they still have to distrust it and use their own intelligence and judgement. Production managers, sales and customer service engineers have traditionally made their decisions based on the following data, information and factors:

- Own intuition, long experience and asking the "experts"
- Use of tables and handbooks, given static information, order books, legacy systems, ERP
- Use of own calculations, spreadsheets and other static calculation methods
- Use of simulation and optimisation methods

There is a need for a quick response tool to evaluate alternatives and scenarios before strategic, tactical or operational decisions are made (see Figure 1). Optimisation and simulation modelling could be used to provide information for decision makers.

2.2 Visual analytics

Visual analytics provides visual and interactive tools for analytical reasoning and decision making from data. The basic idea is to combine the strengths of automatic data analysis with the visual perception and analysis capabilities of the human user. It is especially focused on situations where the huge amount of data and the complexity of the problem make automatic reasoning impossible without human interaction. It combines different data sources containing complex and heterogeneous data of various types and qualities. (Järvinen et al. 2009).

Visual analytics is a new and active research field that has its origins in U.S. national security. It is a multi-disciplinary research area, combining information visualisation

science, data mining, mathematical and statistical methods, data management, user interface techniques as well as human perception and cognition research. It can be applied in all areas where decisions need to be made on the basis of accumulated data. The manufacturing industry is one promising application area. All phases of the manufacturing process generate data, which is often stored in separate and heterogeneous data stores, and quick decision making on the basis of data is required to keep the production process effective.

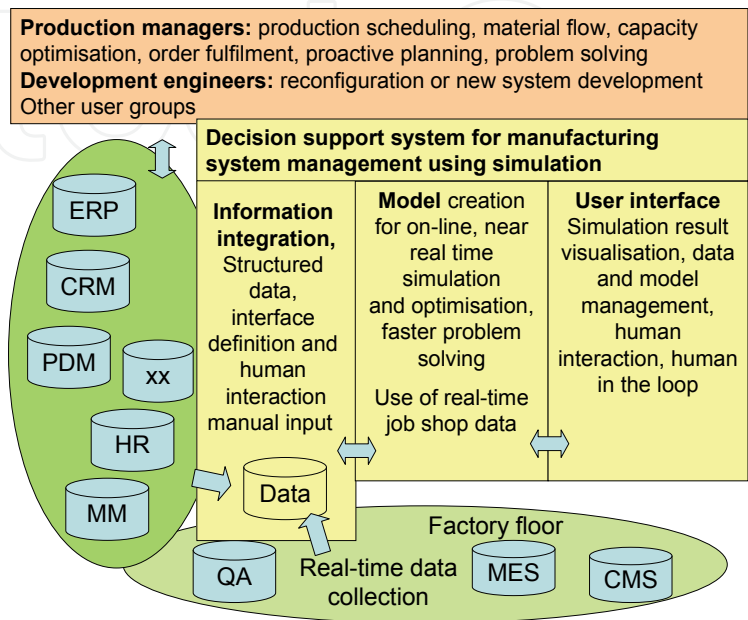


Fig. 5. Heterogeneous information systems (business, product and facility) as well as factory-floor software parallel to a simulation-based decision support system.

Manufacturing system operations planning is usually performed in a heterogeneous information system environment (see Figure 5). There are business-oriented systems like Enterprise Resource Planning (ERP) – or Manufacturing Resource Planning (MPRII) or Material Requirements Planning (MRP) – Customer Relationship Management (CRM), facility-related systems like Enterprise Asset Management (EAM) or Maintenance Management System (MMS) and Product Data Management systems (PDM). Systems potentially used on the factory floor include a Manufacturing Execution System (MES), job shop data acquisition systems, quality control system, individual machine control systems and so on. A dedicated decision support system for manufacturing operations planning does not replace those existing systems; they remain in place as parallel systems, serving as sources of information for decision making. Depending on the role of the decision support system user, he or she also has access to these other systems.

2.3 Use of discrete event simulation in the manufacturing life cycle

“Simulation is the imitation of the operation of the real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented”. (Banks et al. 1996)

Manufacturing simulation focuses on modelling the behaviour of manufacturing organisations, processes and systems. Traditionally simulation tools have been used in

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 6). The more accurate the model, with detailed process elements, the more complex it is to build, and the more data is needed. The following steps are found: concept creation, layout planning, production simulation, software development and operator training (Heilala et al. 2001, 2007). Naturally, there are a wide variety of simulation tools in the manufacturing domain.

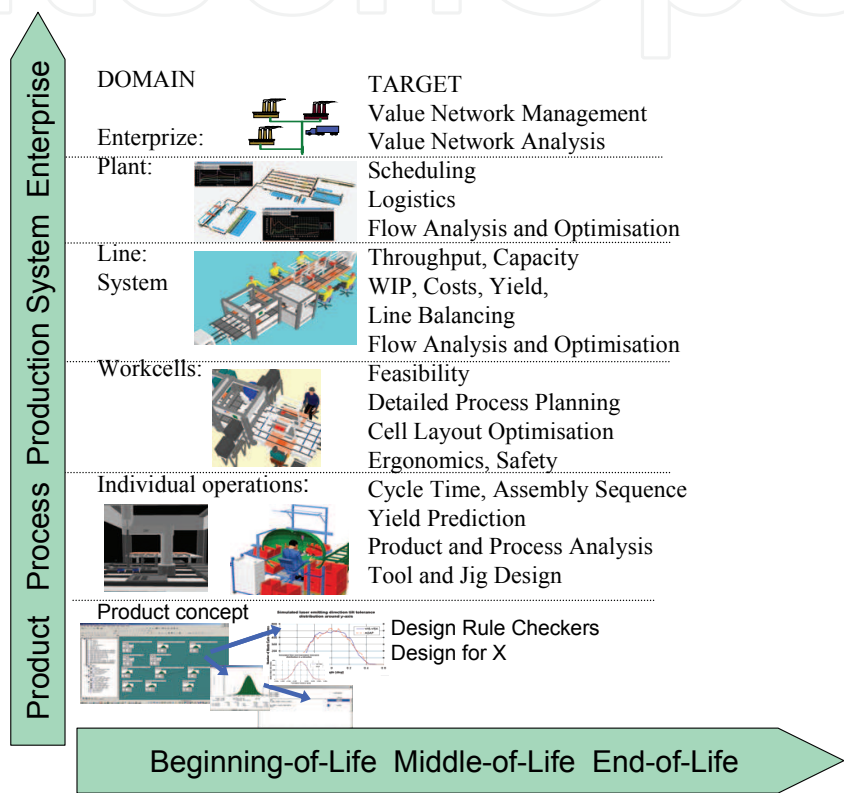


Fig. 6. Manufacturing systems modelling and simulation has many hierarchical levels and development aims, and can be used in different life cycle phases.

The use of discrete event simulation (DES) can be enhanced to also cover production operations planning as a decision support tool, as suggested by Thomson (1993). Table 1 summarises the use of discrete event simulation in manufacturing life cycle phases. The design and analysis of the system concept provide input for strategic decisions. Production planning with simulation provides input for operational decisions. Discrete event simulation methods are feasible for analysis of all types of discrete manufacturing systems, from project shops to automated production and assembly lines, and even all the way to the supply chain. A review on simulation-based real-time decision making for manufacturing automation systems is presented by Yoon and Shen (2006). Kádár et al. (2006) present how to use discrete event simulation for supporting production planning and scheduling decisions. In general, the annual Winter Simulation conference (<http://www.wintersim.org/>) is a good source for finding ongoing research and development results.

System life-cycle phase	What and how	Why
Concept creation, layout planning of cells, lines and factories.	2D and 3D visualisation, communication, animation, easy and fast modelling are needed.	Selling and developing ideas and concepts. Fast elimination of those that are unsuitable.
Production simulation, detailed development of the system, design optimisation.	Analysis of control principles, routing, buffer sizes, capacity, utilisation, throughput time, bottlenecks, etc. Data analysis, reports, multiple runs, stochastic values.	Investment insurance, strategic decision support 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 the 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 planning, short-term scheduling, operational and tactical capacity planning, order-book validation.

Table 1. Use of discrete event simulation in different manufacturing system life-cycle phases, based on Heilala et al. (2001, 2007).

2.4 Operational use

While some DES models are used for planning 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, effects of missing materials, and changes in operations. Having built a simulation and calculations model, experiments are then performed by 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 support planners and schedulers and thereby boost production efficiency (Figure 1).

It is important to recognise that normally simulation primarily serves as a decision support and evaluation tool for feasible scheduling and does not directly seek optimal solutions. Optimisation algorithms or scheduling rules can be embedded into the simulation model or the system could combine optimisation and simulation as presented by Appelqvist and Lehtonen (2005) and Vasudevan et al. (2008).

Potential uses of simulation-aided decision support for production planning are shown in Figure 7. In operations planning, a validated and tested simulation model is a must, as is having reliable data for analysis. The challenges of manufacturing system simulation and modelling are discussed later in the text.

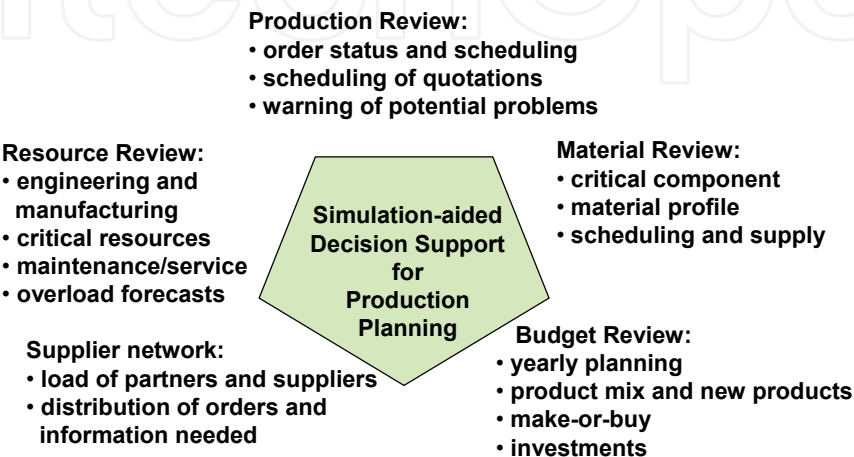


Fig. 7. Potential use of simulation-aided decision support for production planning.

2.5 Current status of simulation-aided operations planning

Simulation-based scheduling and planning tools are actively being developed. Commercial solutions exist; some of the latest examples have been presented by Hindle and Duffin (2006) and Vasudevan et al. (2008). The semiconductor and process industries have been leading the way. Clear reasons for this include expensive equipment, the need to keep equipment utilisation high and customer service. In the mechanical industry, there are limited examples of the use of simulation or optimisation tools in operational planning, the finite scheduling of manufacturing, despite the availability of dedicated software packages like Preactor (www.preactor.com), Asprova (www.asprova.com), and others made by simulation engineering offices, like Simul8-Planner (www.simul8-planner.com) and Delfoi Planner (www.delfoi.com/web/en_GB/). Commercial simulation software can potentially be used as a development platform.

The cheapest packages have fixed data structures and menus. This kind of Gantt chart scheduling software is targeted at users with simple production scheduling problems typical of small job shops. Open source softwares from a research institutes are available. Such software is usually targeted at simpler production scheduling problems or educational use. More information is available at the Production Scheduling Portal (www.productionscheduling.com).

The more advanced, customised solutions are expensive and their costs are not limited to the price of the software. The costs of integrating simulation systems with other manufacturing applications are high; there is always a need to transfer and share data between the simulation and other manufacturing software applications. Custom-built proprietary

interfaces are too costly, making it prohibitive for users to use simulation technology. Thus applications need to be customised extensively; due to the lack of standardisation, system integration is challenging. Naturally, if managers are using a simulation model to plan operations, the model must be precise enough and use accurate data.

Some of the benefits of implementing an operational simulation scheduling system include: less effort required to plan day-to-day scheduling, customer order due date conformance, synchronisation of the flow through the plant; minimisation of set-ups/changeovers, early warnings of potential problems, checks of critical resources and materials, and, of course, “what-if” scenario analysis for capacity planning.

2.6 User groups

An operational decision support system has many potential users (Table 2), from the operator on the production line to the plant manager. Present Factory Information System (FIS) capability is geared towards supporting operators and engineers, not planners, financial analysts, and upper management. Manufacturers have begun the transition from passive data monitoring to converting data to information, and they have not attempted proactive, operational and strategic decision making.

Different users require, or are allowed access to, different types of information, or the same information is presented differently. Users should be given enough information to enable them to make the decisions necessary to optimise the performance of their job function. One of the challenges is to provide the appropriate granularity of information needed by each class of user.

Organisational and operational level	User	Time frame	Data and information	Decision
Manufacturing Cell/Line	Supervisor Process Engineer Production Planners	Minutes/Hours/Shifts	Production line data, e.g. process data, equipment utilisation, material availability	Assignment of order to each line/machine, scheduling of orders.
Business Unit/Plant	Plant Manager Production Teams Customer service	Shifts/Days/Weeks	Summarised data from Cell/Line level e.g. production, subcontracting, materials	Determination of an order list, workload, scheduling of order book and forecasts
Enterprise	Upper Management	Days/Weeks/Months	Summarised data from Business Unit/Plant level	Make or buy, production mix, budget planning, game plans
Suppliers	OEMs Partners	Days/Weeks/Months	Supply data such as production numbers, due dates.	Production planning

Table 2. Decision and planning data at different organisational levels.

3. Developing a model-driven decision support system

3.1 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 & Leong 2001a; 2001b). Simulation modelling and analysis could help. Discrete event/material flow/factory simulation is used commonly in the manufacturing system design phase to evaluate the concept and optimise system solutions, sometimes also for training operators or selling ideas to potential customers, using a "virtual factory" as shown in this chapter.

The IMTI Modelling and Simulation for Affordable Manufacturing Roadmap (IMTI 2003) defines 75 top-level goals and 250 supporting requirements for research, development, and implementation of modelling 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 modelling 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:

5. **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.
6. **Emerging Grand Challenge 2: Development of real-time simulation based problem solving capability.** Permanent, always on, synchronised factory models, on-demand, automatically built factory models.
7. **Emerging Grand Challenge 3: True plug-and-play interoperability of simulations and supporting software within a specific application domain.**
8. **Big Challenge 4: Greater acceptance** of modelling and simulation within industry.

These challenges partially overlap. One other common challenge is input data collection and management as presented by Skoogh (2009). The following sections addresses these challenges and discusses selected public case studies carried out at VTT.

4. VTT system development

The VTT solution concept presented here is a hybrid decision support system solution. The industrial cases presented in this chapter use complex multi-criteria models, i.e. discrete manufacturing system simulation, to provide decision support. The solutions use data from existing manufacturing information systems and parameters provided by decision makers

to aid decision makers in analysing current and future production situations. Visualisation of the current and future factory-floor status is essential in decision making as well as interactive user-system communication for “what-if” scenario analysis. The system can be called a model-oriented or model-based decision support system (see Figure 1).

4.1 Past development

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

The basic concept is still the same. Although similarities can be found in the user interface, each of the pilots is unique. The past generic system environment is shown in Figures 8 and 9. Integration into other enterprise applications, like ERP or MRP, was done using formatted ASCII text files or CSV files. ASCII text transfer is a robust traditional method. SQL query has also been used. 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 incorporated tools for data management.

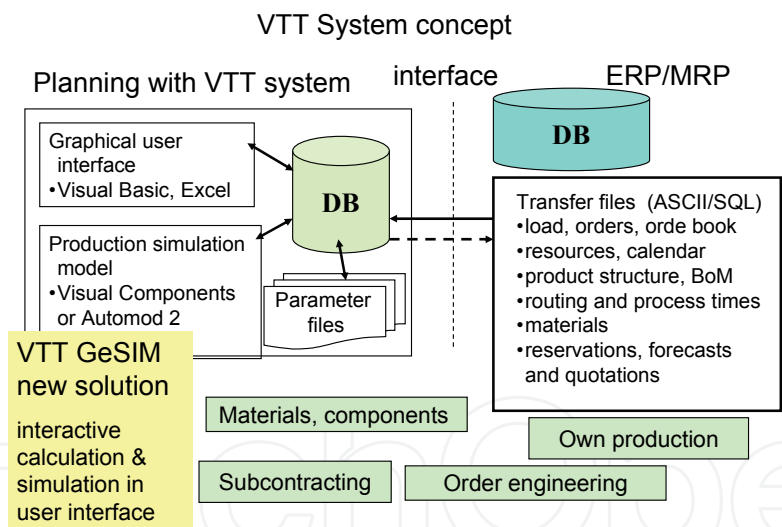


Fig. 8. Current VTT system concept for manufacturing operations planning

The analysis run in these pilot applications was a batch process (Figure 9). The target was to create a daily work list, short-term scheduling, capacity planning, order book creation and validation, and “what-if” scenarios in general. The length of a simulation run ranged from a single shift to a few weeks, months, or even years of simulated production time. It is important to note that there is a human in the loop; the user accepts or modifies the solution provided by the system.

The user interface consisted of graphics, bar and Gantt charts, and custom reports pointing out potential problem areas in production, such as resource overload, unnecessary waiting times or missing components and orders that would be late in the future. The status of work centres and customer orders could even be seen at the component level.

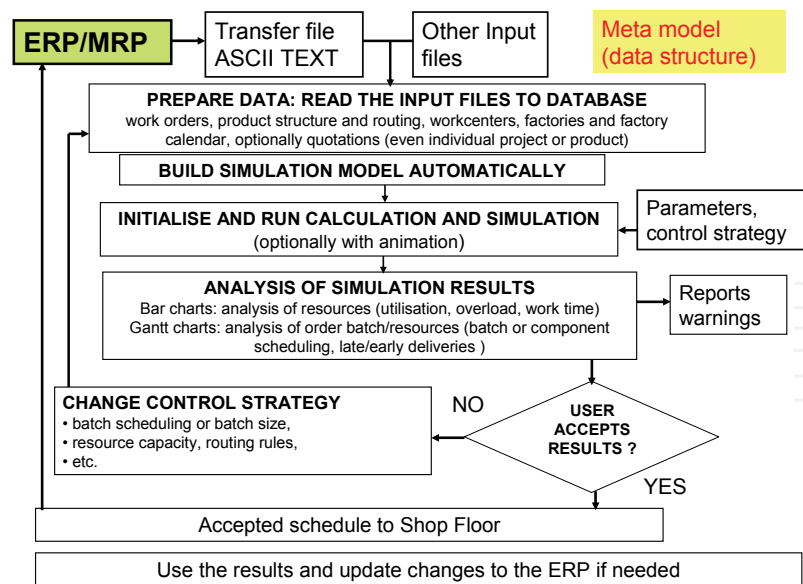


Fig. 9. Analysis workflow.

The graphical user interface (GUI) can have several windows. Scheduling changes could be done interactively, e.g. with a mouse and simple drag and drop. The first GUIs were based on MS Office tools, MS Excel and MS Project as reported 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; 2007).

The two first case studies, carried out in 1997-1999 (Heilala et al. 1999), a commercial simulation software Automod was used (www.automod.com). The run-time features were enhanced with C programming language algorithms. One of the main results was a generic and parametric model, which was automatically initialised and configured based on input data files.

Analysis of the process flow is shown in Figure 9. Optionally, a simple 3D animation of the simulation could have been used, but since more computer capacity would have been required for this, it was normally not used in daily operations planning. Production managers were satisfied with bar and Gantt chart type visualisation. 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, such as of machine breakdowns, by editing the input files or using the user-interface functionality. Later case studies, carried out in 1999-2001 (Heilala et al. 2001), studied also the potential to do simulation calculations directly in the graphical user interface and to also add new features for analysis. In addition, those early cases included the order engineering phase, and partly subcontracting of selected critical components.

4.2 Recent case studies

The latest public case studies have been presented at the Winter Simulation conference by Heilala et al. (2007). The industrial partners in the pilot cases were Sandvik Mining and Construction Oy (www.sandvik.com), a producer of rock drilling equipment, single and multi-boom mining and tunnelling jumbos and long-hole production drill rigs, and Raute Corporation (www.raute.com), a supplier of 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.

The industrial pilots had different aims and development platforms. The heavy machinery case, Sandvik, which involves the customer-driven manufacturing of mining equipment, is purely an operational simulation case with tools for production managers. It is based on an embedded simulation platform, VTT's proprietary GESIM (Generic Simulation). The Raute case involves plywood factory design and operational manufacturing simulation with simulation software based on the Visual Components 3DCreate®. Simulation development and modelling support the system sales process, equipment development, factory planning and later also operational 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 to make simulation as easy as possible. In both cases, generic development yielded improvements to the integration of manufacturing-related data from existing legacy systems, like ERP. Also, methods for automated model building were developed and advanced methods for simulation model management using a graphical user interface were studied. Simulation results must be presented in a visually effective way and some new ideas were evaluated in case studies. The development of tools and methods seeks to create easy-to-use, user-friendly solutions.

4.3 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 10). Data integration is partially generic using custom-built proprietary interfaces. Simulation data is fed from the ERP as text files in CSV format; this is a robust integration into the ERP system. Current ERP systems usually have output to Excel or text files and thus the VTT system concept 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 interaction as well as functions for planning production operations. It is easy to re-schedule orders as well as forecasts, and to add and delete orders. The user interface shows the factory status: all orders are displayed in the upper window, while the workload on a selected resource is in the middle window, including estimates of the selected subcontractor's workload and orders in the selected resource. Potential critical material shortages are displayed along with certain other warnings.

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

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 the 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 by enabling production managers to make better decisions.

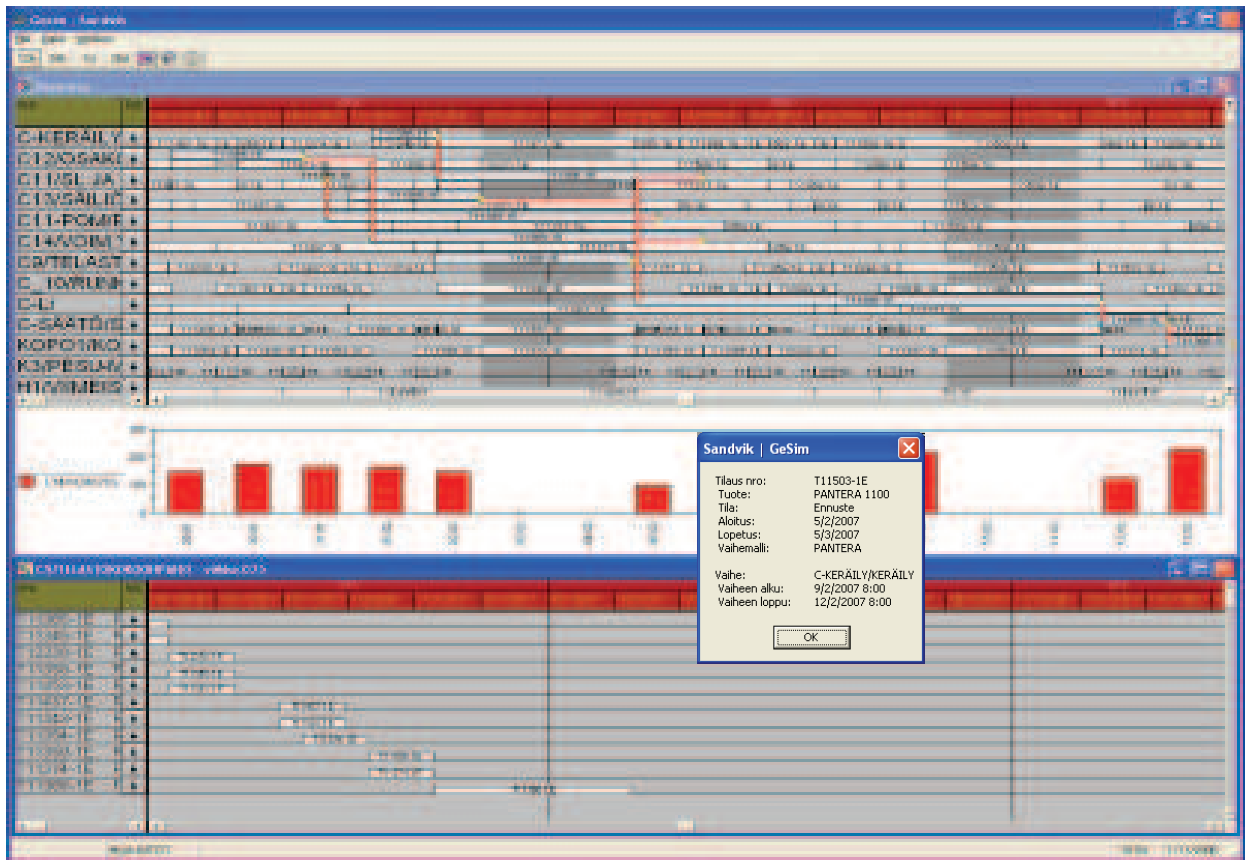


Fig. 10. User interface, case Sandvik. Upper windows shows all orders and the critical path of the selected order, middle windows shows manual working hour in the selected resource and lower windows shows orders in the same selected resource or process phase.

4.4 Plywood manufacturing - Raute

The Raute case study – implementation of a simulation tool for plywood factory planning using Raute equipment models and later for scheduling plywood mill operations. An initial implementation is available, shown in Figure 11.

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 was the creation of methods for simulation model building. Means of transferring simulation data from the database to the actual simulation model and controlling the simulation with an easy-to-use interface were developed. The automated model building functionality was developed with Visual Component software as well.

The developed methods have many potential uses. For instance, they can serve as a tool for sales engineering or factory design. Later the methods can be used for the planning and optimisation of day-to-day factory operations. The current version evaluates the work schedules of the ERP systems and compares them with simulation run results. The user interface has many functions that are not presented here. The tool that was developed is an add-on for Visual Components 3DCreate®.



Fig. 11. Raute case simulation, plywood factory with Raute equipments.

5. Application building guidelines

The tool concept created during the development projects can be adapted for different companies as described previously. The building of each application is still a project: that requires a resource commitment from both the developers and the end-user. Application set-up is simple within an enterprise if all its manufacturing information systems are the same; it is just a configuration task. This has been evaluated and tested in the past cases. A typical simulation project is described in many simulation textbooks, for example Banks et al. (1996). Now the aim is to create an integrated or embedded simulation application for manufacturing personnel. This project is more challenging. The application needs data from various other manufacturing information systems. Furthermore, the human aspect – user interaction with the planned system – must be carefully developed. Based on earlier development tasks at VTT, the guidelines from enterprise application integration (Linthicum, 2000), simulation project steps (Banks et al., 1996; Banks, 1998) and the user-centred design principle (Vilpola & Terho, 2008; ISO 13407 standard; Sears & Jacko, 2009), the following procedure for application building has been identified. These activities should be considered when approaching the development and implementation of operational simulation applications. The 10 steps in application building are (this is not a comprehensive list):

1. Defining the needs with the end-users
2. Defining the business processes and way of working
3. Specifying data and file structures, making sense of the data,
4. Collecting and creating data, interfacing
5. Specifying the graphical user interface, visualisation, user-centric design
6. Programming the graphical user interface
7. Implementing changes to the simulation and calculation model

8. Testing and validating the model and system
9. Integrating the application into the ERP or MRP system and other legacy systems
10. User training and documentation

The first steps are critical for successful implementation. These steps are required for requirements gathering. The input of the final end-user is necessary. Final end-user resources are also required in testing and system validation. This is an iterative and parallel development process.

Understanding the enterprise and problem domain, steps 1 and 2: This is one of the most complex and time-consuming parts of the process. Understanding the problem domain requires working with many organisation and department heads in order to get a handle on the structure and content of the various information systems, as well as to determine the business requirements of each organisation. This process is a basic requirements-gathering problem. It requires interfacing with paper, people, and systems to determine the information that will allow the problem to be defined correctly so that it can be analysed, modelled and refined.

Making sense of the data, steps 3 and 4: The data-level implementation comes down to understanding where the data exists, gathering information about the data, and applying business principles to determine which data flows where, and why. There are basic sub-steps that must be followed:

1. Identifying the data
2. Cataloguing the data
3. Building the enterprise manufacturing metadata models
4. Definition of interfaces between systems

User-centric development, step 5: The specification of the graphical user interface, simulation data management, effective visualisation and reporting as well user interaction with the system are challenging. The development team should apply user-centric design methodology (Vilpola & Terho, 2008; ISO 13407:1999 standard; Sears & Jacko, 2009). This means keeping the planned end-users in the development loop. User feedback is essential during development. The success of the system depends on how easy it is to use.

The other steps: The steps can be done parallel to simulation modelling and graphical user interface development. The development of the graphical user interface and adapting the simulation and calculation model is demanding as well and is based on the requirements collected in steps 1-5. The value of validation and testing must never be underestimated, as it usually takes a significant amount of time. The users must be able to rely on the data and information provided by the system.

6. Faster model building and rebuilding

6.1 Component-based simulation model creation

For the system sales process, the use of component-based simulation brings clear speed advantages to model building. But pre-engineered simulation components must be available. Model building centres on configuring a layout by selecting the right components to fulfil the process flow and setting the right parameters. In some VTT cases, Visual Components software is used as the development platform (www.visualcomponents.com). The selected software supports system modularity and reuse of existing simulation library elements. Similar development can be done with other object-oriented simulation software.

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, such as key performance indicators, capacity analyses and other decision-making parameters, for example system life cycle and other cost analyses. This is also the aim in one of the other industrial pilots of the recent development project, presented elsewhere Heilala et al. (2007b).

6.2 Database-driven model building

Automated model building from ERP data is also being developed and tested in the industrial pilot cases with different simulation software. Depending on the 3D visualisation needs, manual input from a simulation engineer might be required. In general, the model and simulation load can be initiated based on information such as:

- work orders (order book from ERP database), optional quotation book (from CRM or sales offices), production scheduling
- product structure and routing, standard phase times
- work centres and component factories, layout, equipment capability
- stock items, buffers, material supply
- factory calendar, holidays, absences, planned maintenance, etc.
- equipment availability, efficiency
- simulation parameters: depth of product structure, work order release rules
- optional what-if analysis (machine breakdowns) and new orders, others.

The other generic development point has been simulation data management. 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 interface incorporates tools to map the data fields of different source files to the simulation database data fields. Means of controlling the simulation with an easy-to-use interface and presenting the simulation results were also developed.

7. Potential in standardised neutral interfaces

The use of standardised structured manufacturing data in a neutral format (like XML) could clearly increase interoperability between the manufacturing information system and the simulation, and also speed up modelling and problem solving cycles.

The Core Manufacturing Simulation Data (CMSD) specification (SISO 2009) is intended to define a neutral format for the exchange of data between simulations and other manufacturing applications. The CMSD specification is being developed by NIST under the auspices of the Simulation Interoperability Standards Organisation (SISO). Over the last few years, several projects involving researchers from different industries have been undertaken where the draft CMSD specification (SISO 2006) is used to integrate manufacturing applications. Examples of these projects can be found in Kibira and McLean (2007), Johansson et al. (2007), McLean et al. (2007), Riddick and Lee (2008).

The CMSD specification was developed to address interoperability issues related to information definition and exchange as it provides a neutral framework for modelling manufacturing information, with an emphasis on the information needed for manufacturing simulations. Information coding and representation problems increase the time and effort required to construct simulations and limit the application of simulation technology in

manufacturing. Usually manufacturing simulation data is difficult to exchange between different simulation applications and other manufacturing applications. The Core Manufacturing Simulation Data specification is intended to be a neutral data format for addressing interoperability problems such as these. CMSD is defined as an information model using the Unified Modelling Language (UML) with a mapping to an exchangeable eXtensible Markup Language (XML) format.

The CMSD information model describes essential entities in the manufacturing domain and relationships between those entities needed to create manufacturing-oriented simulations. This specification facilitates the exchange of information between manufacturing-oriented simulations and other manufacturing applications such as process planning, scheduling, inventory management, production management, and plant layout. Six UML packages define manufacturing information (SISO 2009). These packages are:

- Layout
- Part Information
- Support
- Resource Information
- Production Operations
- Production Planning.

Leong et al. (2006) give a detailed description of these packages. The draft specification (SISO 2009) provides the complete specification of CMSD. The formal balloting process for this specification is slated to begin in late 2009.

Other standardisation activities also might be useful in the future. For instance, ISA-95 (www.isa.org or www.isa-95.com) is focusing on MES/ERP integration. MIMOSA (www.mimosa.org) is developing and encouraging the adoption of open information standards for operations and maintenance in manufacturing and facility environments. The MIMOSA open standard enables collaborative asset lifecycle management. The MTConnect Institute (www.mtconnect.org) is designing an open communication standard for interconnectability in the manufacturing arena. The MTConnect standard allows devices and systems to send out understandable information. Similarly, AutomationML (www.automationml.org) developed Automation Markup Language (AutomationML™) as an intermediate standardised format for the digital factory. All these standardisation efforts could help in getting real-time status information on manufacturing equipment.

8. Simulation result visualisation

Simulation analysis produces a great deal of numerical information consisting of tables, listings, and reports. It is difficult for a human decision maker 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 effective 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 is presented differently. For instance, a line supervisor and plant manager rely on different levels of data to base their 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 organisation; a manager

cannot afford to be “swimming in data” when making a quick decision. (Heilala et al., 2001; 2007)

The system gives, for example, a proposal for rescheduling production orders by showing late or early orders and overloaded components or resources. The user can change control and routing strategies and add resources to overloaded workplaces, either by adding more human operators, increasing working hours or using subcontracting. The user can reschedule orders, change batch sizes and so on with the visual interface and has the option of re-running the simulation to check the results.

9. Summary of VTT system constraints and benefits

The development of the method is still ongoing at VTT, as shown in Figure 12.

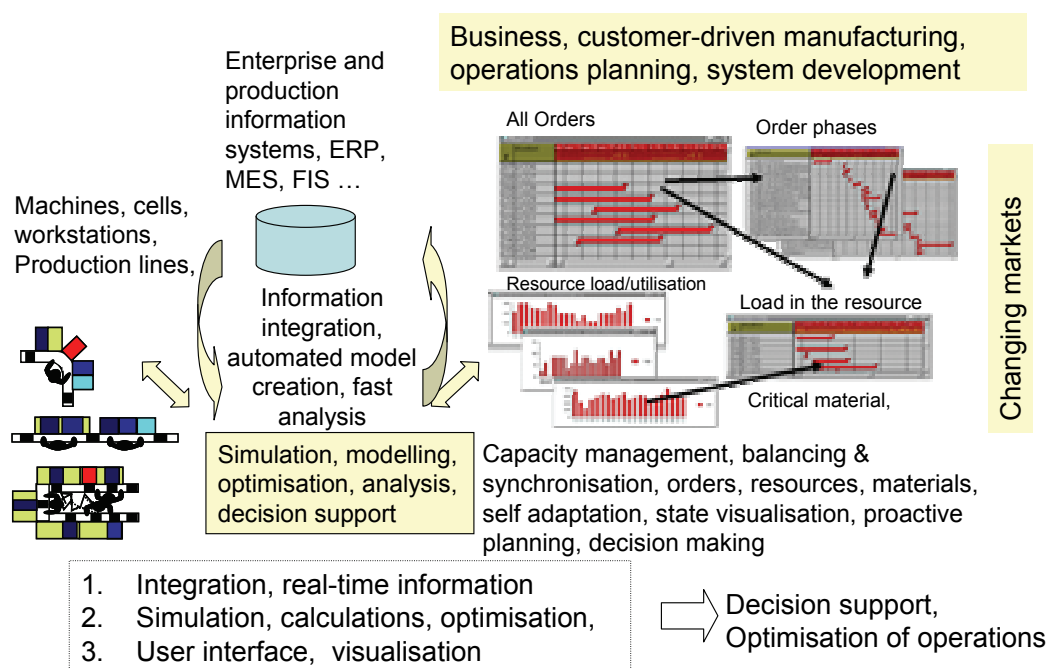


Fig. 12. Ongoing development efforts at VTT 2009-2010, improvements to use near real-time information, simulation and user interface development

The following list describes the features of the VTT solution:

- Independent system, analysis is done offline from the ERP/MRP database
- Batch process, no real-time integration to the ERP or MRP system, new iterations will use near real time factory status data
- Traditional information transfer, earlier ASCII text, CSV files or SQL query; XML-based methods are now also being studied
- Sensitive to quality of data, garbage in – garbage out, in the manner of all simulation and modelling
- Deterministic simulation model for speed, using standard operation times, no stochastic values used
- Visualisation of the order book, resource status, material availability
- Window to future events with given input, scenario, evaluation of alternatives, proactive planning

- Generic manufacturing system model, model updates and reconfiguration based on database information (some limitations)
- Decisions are made by the user

9.1 Real-time issues and data latency

The VTT solution presented here is not a real-time solution, as there is some data latency. Data latency is the characteristic of the data that defines how current the information needs to be (Linthicum, 2000).

- Real time: data is current, up-to-the second.
- Near time: data refers to information that is updated in set intervals rather than instantaneously.
- One time: data is typically updated only once or very rarely.

Some of the input files are “one time”: only the modifications to the parameters are updated. Some other input files are “near time”: analysis can either be started by the user or is performed automatically at selected intervals. The latest version seeks to use the following near real-time data from other manufacturing information systems: maintenance management data, machine utilisation data and real-time work flow management data. In some earlier iterations, reliable data was several days old, and the current situation was simulated.

9.2 Modelling issues

The simulation and calculation model used in the cases could either have capacity constraints or unlimited capacity depending on the objectives of the user. In the first case, capacity constraints, the analysis shows when the order will be ready and how late it will be; it can also pinpoint the reason for late completion, such as a shortage of material, overload in manufacturing resources, and so on. In the latter case, unlimited capacity, the analysis shows the amount of resources needed in order to keep the customer promise, and the managers have the option to add, for example, human operators to critical manufacturing phases. Typically manual labour -intensive final assembly can be analysed with unlimited capacity if it is easy to add human operators when and where necessary. The model also checks the critical materials, i.e. stock values and ordered components, and indicates whether materials might run out at a certain time in the future (see also Figure 7). Scheduling control strategies can be embedded directly into the simulation model or can be kept as a separate file, enabling users to adjust the parameters as necessary.

10. Summary and conclusion

The authors have developed several simulation-based decision support systems (DSS) for customer-driven manufacturing. Selected cases are presented here: DSS for sales engineers (Raute) and operations planning (Sandvik and Raute). Both presented cases use complex multi-criteria models to provide decision support. The solutions use data and parameters provided by decision makers to help analyse future production situations.

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 towards supporting 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. At present, manufacturing scenarios cannot be studied efficiently with the ERP system. Manufacturers have begun the transition from passive data monitoring to converting data to information, and must seek to engage in proactive, operational and strategic decision making in the future.

The developed tool is useful in customer-driven manufacturing because it adds features for production planners and capacity managers that were not provided by standard tools in the past. By integrating discrete event simulation and traditional production planning methods, it is possible to forecast the required workloads with given input values. The simulation model and the developed graphical user interface make it possible to visualise the occurrence of potential bottlenecks or other production problems and to take corrective actions. The load data for simulation, indicating the product, its parameters as well as 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 utilisation. Delivery days can be confirmed on the basis of the simulation model. Overload situations and unnecessary waiting time can be eliminated. The use of the tool is not limited only to operational planning; it is useful for strategic planning as well. The effects of additional equipment can be analysed.

Many other similar tools are available. One limiting factor for the wider use of the technology is the cost of data integration, the integration of the simulation model and other manufacturing information systems; in other words, the customisation cost is high. There is no commonly accepted data model standard. Neutral standardised interfaces are needed and efforts are ongoing to aid the integration and development of reusable simulation models and objects. These interfaces would make modelling easier and reduce the costs associated with both model construction and data exchange between simulations and other manufacturing software applications. This would make simulation technology more affordable and accessible to a wide range of industrial users. The authors used ASCII text files in the presented case studies, but perhaps in the future XML will provide a better solution.

The developed simulation tools can be adapted for new industrial fields and implemented for other enterprises. The developers must have a deep understanding of the processes of the field in question in order to be able to model the specific features of the industry. Naturally, modifications to the user interface and data interface are required. Both the end-user and system developer must commit development resources to the implementation project.

Simulation software has evolved and most of the current software is object oriented with a graphical windows-style user interface. At the same time, however, the complexity of manufacturing systems and products has increased. There are development needs in manufacturing system modelling and simulation: e.g. integration of different simulation and modelling 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 there is a need for real-time data coupling from the factory floor.

Another future aim could be hybrid methods – simulation, optimisation and other manufacturing information systems in an integrated application. These could be used by non-simulation experts, even online and in real-time on the factory floor (plug and simulate), enabling science-based system management.

Future development includes evaluation of the use of new optimisation parameters, such as energy consumption and other environmental aspects. The development of using environmental aspects in the system design phase has been presented by Heilala et al. (2008), Lind et al. (2009). The next step would be to use these parameters for production scheduling decisions as well.

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This book by In-Tech publishing helps the reader understand the power of informed decision making by covering a broad range of DSS (Decision Support Systems) applications in the fields of medical, environmental, transport and business. The expertise of the chapter writers spans an equally extensive spectrum of researchers from around the globe including universities in Canada, Mexico, Brazil and the United States, to institutes and universities in Italy, Germany, Poland, France, United Kingdom, Romania, Turkey and Ireland to as far east as Malaysia and Singapore and as far north as Finland. Decision Support Systems are not a new technology but they have evolved and developed with the ever demanding necessity to analyse a large number of options for decision makers (DM) for specific situations, where there is an increasing level of uncertainty about the problem at hand and where there is a high impact relative to the correct decisions to be made. DSS's offer decision makers a more stable solution to solving the semi-structured and unstructured problem. This is exactly what the reader will see in this book.

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