Use of simulation in manufacturing and logistics systems planning

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ABSTRACT

This presentation covers different phases of the manufacturing system life cycle. Starting from conceptual system design to planning of operations. Material handling and logistic are the key factors in modern networking manufacturing. The author proposes use of discrete event simulation as a system design and operation-planning tool. Traditionally simulation tools have been used in the system planning and design; today the simulation models are used in all the different phases of manufacturing system life cycle. This paper presents two case studies. First case shows a modular semiautomatic assembly system planning using simulation. Second case presents a simulation tool developed for operations planning, management of production capacity and decision helping for planning of operations.

1 Introduction

Product life cycles are getting shorter and customers want variations. Production system flexibility is the key factor and systems are getting more complex (Figure 1).

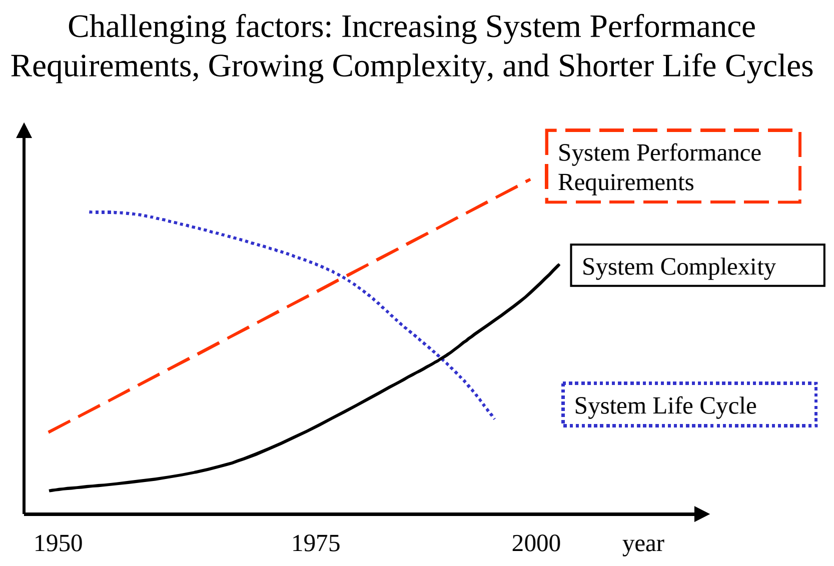

Figure 1. Challenging factors

Time-to-market is critical; this means faster manufacturing system designs and faster ramp-up processes. Production simulation and virtual manufacturing tools are valuable in shortening the design steps, Figure 2. Virtual production system speeds also the production ramp-up, because the operators know better the planned system and can study the parameters and features of the new system before anything is installed to the factory floor.

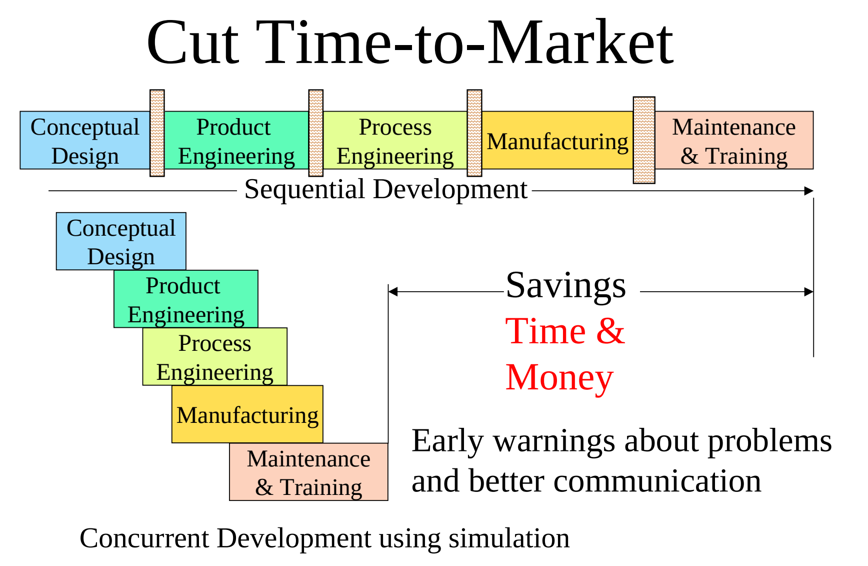

Figure 2. Digital manufacturing tools

Manufacturing system design involves a number of interrelated subjects, e.g., tooling strategy, material-handling system, system size, process flow configuration, flexibility needed for future engineering changes or capacity adjustment and space strategy. Manufacturing process design is critical area. Material handling is another area that deserves intensive study. Although this function does not add value to the product, it facilitates production process flow. The right kind of parts should be delivered in the right quantity to the right place at the right time in the right manner.

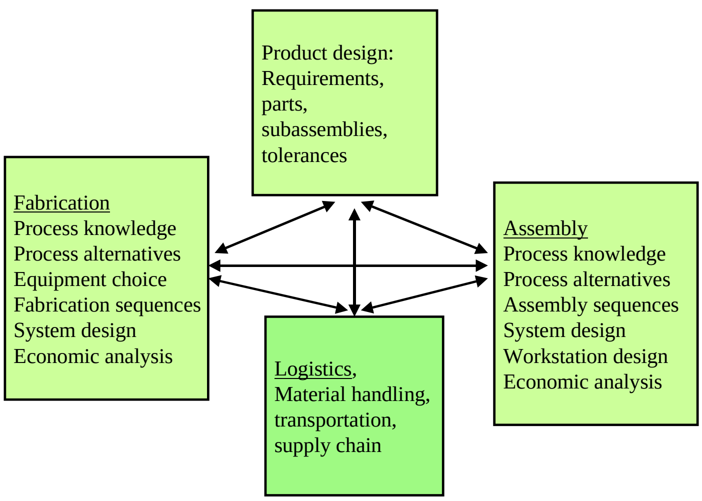

Figure 3. Connections between product design, fabrication, assembly and logistic system

Time-to-customer, punctuality and throughput time, are important competition 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 components may differ from one another. The production systems have to be flexible and able to react to changing production capacity requirements. All this makes planning and management of production networks a complex task.

2 Definition Of Simulation

Since the 1950s computer simulation has been used to tackle a range of business problems leading to improvements in efficiency reduced costs and increased profitability. Simulation studies have been carried out in most business sectors, including manufacturing and service industries as well as in the public sector. A simulation is a model that mimics reality; well-known examples are flight simulators and business games.

"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 is draw inferences concerning the operating characteristics of the real system that is represented". [Banks J et al 1996]

There are many types of simulation. Simulation model can have several dimensions [Law and Kelton 1991]:

- Static Simulation Models, time plays no role (particular time or steady state) Monte Carlo simulation
- Dynamic Simulation Models, model represents a system as it evolves over time
- Deterministic Simulation Models, no probabilistic (i.e. random) components
- Stochastic Simulation Models, at least one random input component
- Continuous Simulation Models, usually in process industry
- Discrete Simulation Models

Discrete event simulation involves the modeling of a system as it progresses through time and is particularly useful for modeling queuing systems. There are many examples of queuing systems: manufacturing systems, banks, fast food restaurants, airports and the list goes on.

A major facet of discrete event simulation is its ability to model random events based on standard and non-standard distributions and to predict the complex interactions between these events. For instance, the 'knock-on' effects of a machine breakdown on a production line can be modeled.

Having built a simulation model (normally on a computer), 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. It is important to recognize that simulation is primarily a decision support tool and does not directly seek optimum solutions.

The focus of this presentation is in dynamic discrete event simulation. Discrete event simulation is used for wide range of application, which are summarized in eight categories [Robinson, 1994]:

- Facilities planning – when designing a new facility, simulation is used to check that it performs correctly.
- Obtaining the best use of current facilities – potential solutions could be tested and identified.
- Developing methods of control – more than just physical equipment, for example experimenting with different control-logic as MRPII or kanban.
- Material handling – experiments can be performed to control the flow of materials to find for example bottlenecks.
- Examining the logistics of change – to minimize interruptions simulation can be used to examine the logistics of change.
- Company modeling – high-level model showing for example the flows of resources and information between sites.
- Operational planning – simulation can be used in day-to-day planning and scheduling.
- Training operations staff – supervisors and operators are trained in the operation of the facility.

A special use of simulation in manufacturing, particularly in automated systems, has been in the area of hardware emulation. As an emulator, simulation takes inputs from the actual control system (programmable controllers, microcomputers, etc.), mimics the behavior that would take place in the actual system, and then provides feedback signals to the control system. The control system is plugged into the model instead of the actual system. Simulation is used to test and debug the actual control system before any hardware has been installed. [Harrell and Tumay, 1995]

3 Modeling Of Manufacturing And Logistic Systems

Modeling of manufacturing system requires an understanding of the types of manufacturing systems that exits and the objectives and issues associated with each type of system. Types of manufacturing systems as defined by Harrell and Tumay (1995) include, but are not limited to:

1. Project shop
2. Job shop
3. Cellular manufacturing
4. Flexible manufacturing systems
5. Batch flow shop
6. Line flow systems (production and assembly lines, transfer lines)

Manufacturing and material handling systems can be arbitrarily complex and difficult to understand. Some of the characteristics needed for modeling are listed in Table 1 and 2. The number of possible combinations of input variables can be overwhelming when trying to perform experimentation. Other methods of analysis, such as spreadsheet models or linear programs, may not capture all the intricacies of process interaction, downtime, queuing, and other phenomena observed in the actual system.

Table 1. Characteristics of a manufacturing system model

Manufacturing System parameters	
Physical layout	Product • Product flow, routing and resources needed • Bill of materials

Labor
• Shift schedules
• Job duties and certifications
	Production schedules
	• Make-to-stock
	• Make-to-order
	  • Customer order
	  • Line items and quantities

Equipment
• Rates and capacities
• Breakdowns
  • Time to failure, MTTF
  • Time to repair, MTTR
  • Resources needed for repair
	Production control
	• Assignment of jobs to work areas
	• Task selection of workcenters
	• Routing decisions

Maintenance • PM schedule • Time and resource required • Tooling and fixtures	Suppliers • Ordering • Receipt and storage • Delivery to workcenters
Workcenters • Processing • Assembly • Disassembly	Storage • Suppliers • Spare parts • Work-in-process (WIP)
	Final goods • Packing and shipping • Order consolidation • Paperwork • Loading trailers

Table 2. Characteristics of a material handling model

Material Handling parameters	
Conveyors • Accumulating • Non-accumulating • Indexing and other special purpose • Fixed window or random spacing • Power and free	Storage systems • Pallet storage • Case storage • Small part storage • Oversize items • Rack storage or block stacked • Automated storage and retrieval systems (AS/RS) with storage -retrieval machines
Transporters • Unconstrained vehicles, Fork Lifts • Guided vehicles, AGV • Bridge cranes and other overhead lifts	

3.1 Analysis Of Manufacturing System

There are several ways to study the system as shown in Figure 4. In some cases even experiments with real system could be feasible [Law and Kelton 1991].

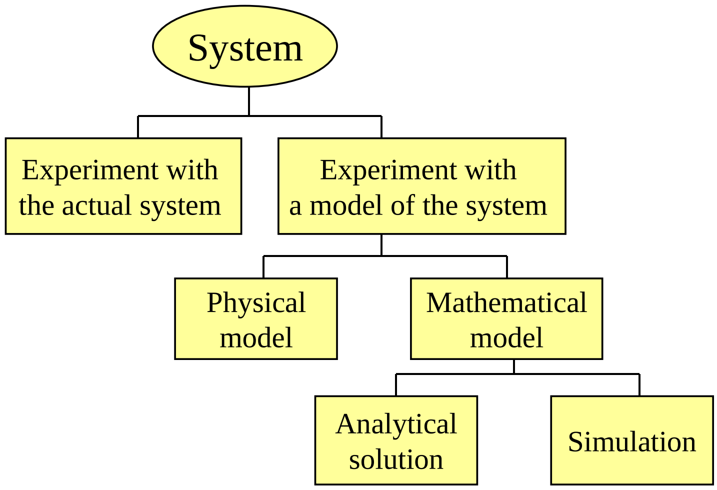

Figure 4. Ways to study a system

In the Table 3, there is listed some commends for using simulation instead of the other analysis methods.

Table 3. Simulation benefits over real system experimentation or mathematical modeling.

Benefits over real life experimentation	Benefits over mathematical modeling	Managerial benefits includes
Cost, repeatability, control over the time base, legality and safety	dynamic and transient effects, non-standard distributions, interaction of random events	fosters creative attitudes, promotes total solutions, makes people think, communicating good ideas

4 Simulation Tools

Simulation models can be build with general programming language such as FORTRAN or C/C++. Some routines can be found from the literature [Law and Kelton, 1991]

Currently there are several commercial simulation tools available. These tools can be divided into three basic classes: general-purpose simulation language, simulation front-ends and simulators. The general-purpose simulation language requires the user to be a proficient programmer as well as competent simulationist. The simulation front-ends are essentially interface programs between the user and the simulation language being used. The simulators of today utilize constructs and terminology common to the manufacturing community, and offer graphical presentation and animation.

The discrete event simulators are well suited for the simulation of a manufacturing system. Simulators can reduce the time required to develop a simulation model and they may exceed the capabilities of the average manufacturing engineer, thus requiring a dedicated programmer/analyst. There are often specialized situations and scenarios that are outside the available set of modeling constructs (i.e., objects), where the user must often resort to more intensive programming to complete the model. Recent development in simulator packages, especially in the ability to define submodels (reusable model segments), provide them with the flexibility to meet the needs of the development effort. The newest versions of simulator packages have a graphical user interface (GUI), and the use of a mouse in model building is an advantage. The computer platform is usually PC Windows/NT or a graphical Unix workstation.

Information about some simulators can be found from the following web addresses, note that there are also other simulators or simulation languages on the market:

Automod / Autosched	http://www.autosim.com
Promodel	http://www.promodel.com
Areena	http://www.sm.com
Factor/AIM	http://www.pritsker.com http://www.symix.com
Witness	http://www.lanner.com
TaylorII	http://www.taylorii.com
TaylorED	http://www.taylor-ed.com
Micro Saint	http://www.madboulder.com
Quest	http://www.deneb.com, http://www.tdm.fi,
Simple ++	http://www.aesop.de http://www.tecnomatix.com
Extend	http://www.imaginethatinc.com/
MODSIM III	http://www.modsim.com/

4.1 Rapid Modeling

The need for rapid model development is challenging because production systems are in a constant state of flux due to fluctuations in demands, annual design changes, and the introduction of new processing technologies. The ever-changing design process requires frequent, rapid (i.e., a few days or weeks) evaluation of system changes ranging from simple parameter modifications (i.e., new cycle times) to total line configuration. A model developer must be able to create accurate, realistic models in a short space of time. The second challenge faced by the simulationist is that there are a number of groups in the enterprise that could benefit from the information available from simulation models.

Thus there is a need to speed up simulation projects. One of the challenges is the shortening of the modeling time as described above. There are different ways to speed up simulation modeling:

1. *Reference Models*: A complete set of model structures together with a description, how these structures apply and how they can be adapted to a given problem. A reference model is not an ideal solution used as a measure, but a typical structure for a special type of problem.

2. *Simulation module library*. Hierarchical modeling allows the user to save whole models as clusters, groups that can be deleted, moved, or scaled as a single object. Groups or clusters can then make up sections of a larger, complex model. Groups, i.e. submodels can be pre-engineered, standardized solutions, Figure 5.
3. *Application Solution Templates (AST).* Industry-specific templates allow customization of the software so the user can automatically start up with specific icon libraries, functions, element terminology, element types, and other industry-specific settings. AST can be a highly graphical, easy-to-use simulation system that allows rapid modeling of manufacturing systems. AST could be, for example, a spreadsheet-like interface to fill in the needed information.
4. *The integration with other software tools*, like CAD, spreadsheets and databases. It is important to be able to use existing information stored in computers.

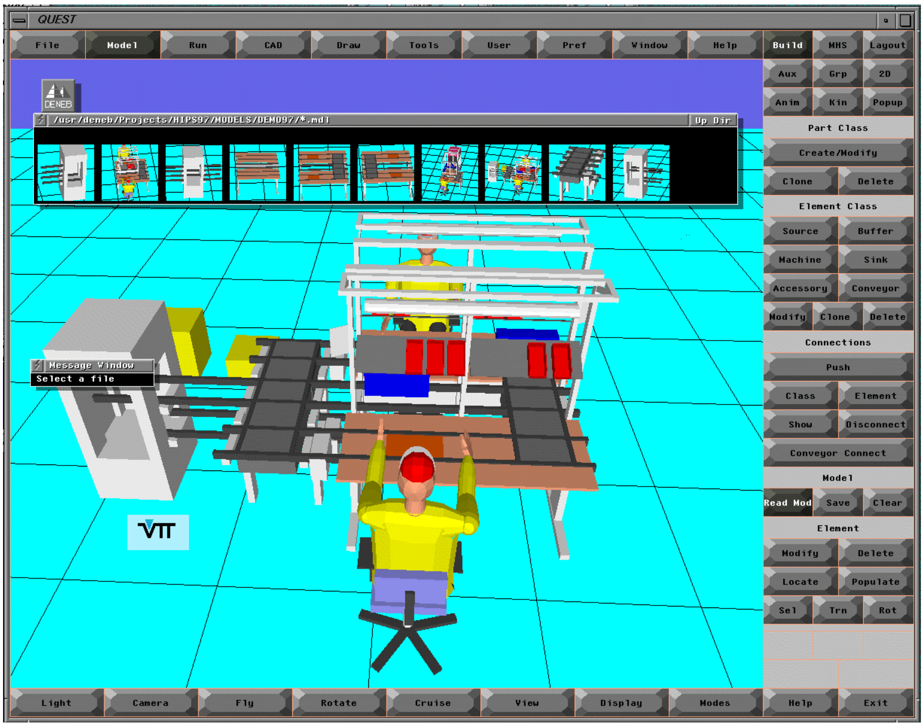

Figure 5. Example of simulation library [Heilala, Montonen 1998].

The best result is gained by combining all four ways presented here. Reference model, application solution templates, standardized library elements and integration to the other software.

The other method to speed up simulation analysis is to build as generic model as possible. The model building, programming of the model is more demanding, but the simulation analysist, user can modify the model characteristics with preprogrammed parameters without the simulation engineer. A model could be build based on the information from input files. Example of this flexible, parametric model building is presented in the second case.

4.2 Scale and Scope of Simulation

Simulation is useful in different levels of enterprise, Figure 6. The machine or human level is continuos simulation with high level of detail and the focus is in process and equipment design. For production line level both continuous and discrete event simulation is used, the process studies give cycle times used for process and material flow analysis. From cell to enterprise level discrete event simulation is the right tool and the focus is in the material flow.

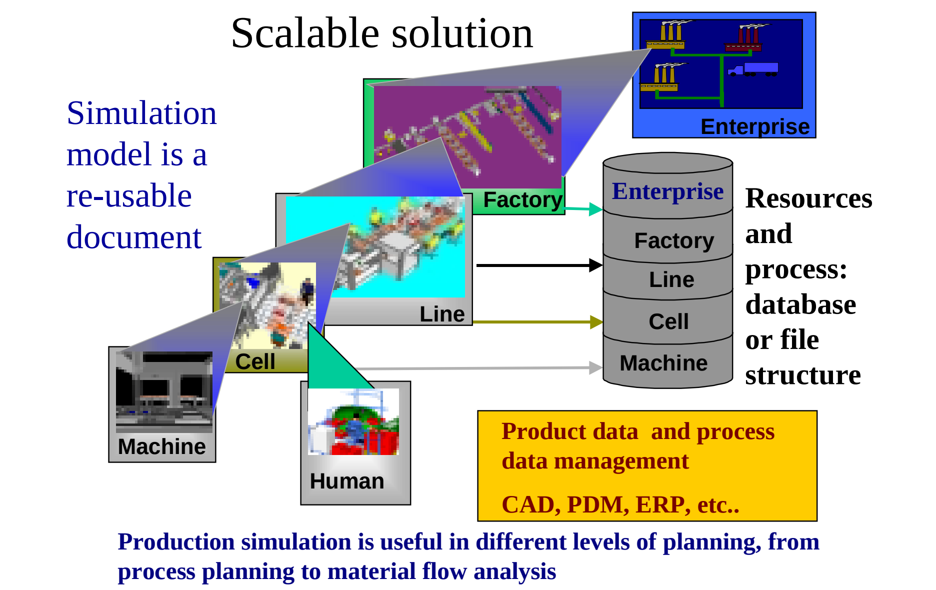

Figure 6. Simulation in all levels of manufacturing.

4.3 Simulation Project

A simulation project is described in Figure 7, [Banks et. al. 1996]. Set of steps guide a model builder in a thorough and sound simulation study. Following steps should be present in any simulation study [Shannon, 1998]:

1. Problem Definition. Clearly defining the goals of the study so that we know the purpose, i.e. why are we studying this problem and what questions do we hope to answer?
2. Project Planning. Being sure that we have sufficient and appropriate personnel, management support, computer hardware and software resources to do the job.
3. System Definition. Determining the boundaries and restrictions to be used in defining the system (or process) and investigating how the system works.
4. Conceptual Model Formulation. Developing a preliminary model either graphically (e.g. block diagram or process flow chart) or in pseudo-code to define the components, descriptive variables, and interactions (logic) that constitute the system.
5. Preliminary Experimental Design. Selecting the measures of effectiveness to be used, the factors to be varied, and the levels of those factors to be

investigated, i.e. what data need to be gathered from the model, in what form, and to what extent.

6. Input Data preparation. Identifying and collecting the input data needed by the model.
7. Model Translation. Formulating the model in an appropriate simulation language.
8. Verification and Validation. Confirming that the model operates the way the analyst intended (debugging) and that the output of the model is believable and representative of the output of the real system.
9. Final Experimental Design. Designing an experiment that will yield the desired information and determining how each of the test runs specified in the experimental design is to be executed (length of simulation run, warm-up periods, number of replications)
10. Experimentation. Executing the simulation to generate the desired data and to perform sensitivity analysis.
11. Analysis and Interpretation. Drawing inferences from the data generated by the simulation runs.
12. Implementation and Documentation. Reporting the results, putting the results to use, recording the findings, and documenting the model and its use.

There are three aspects to the model content that need to be considered:

- The experimental factors (inputs)
- The scope and level of the model
- The reports (outputs or responses)

There are three decisions to be taken when experimental factors are being considered:

- Identify the factors
- Determine the range of values that the factors are likely to take
- Decide upon the method of data entry for changing the factor values
    - The simulation model code
    - Menu-driven options
    - Datafiles
    - Third party software such as spreadsheets and databases

There are three stages in identifying the reports that a model should give:

- Identify the values to be reported
- Determine the method of reporting
- Decide how the reports should be viewed

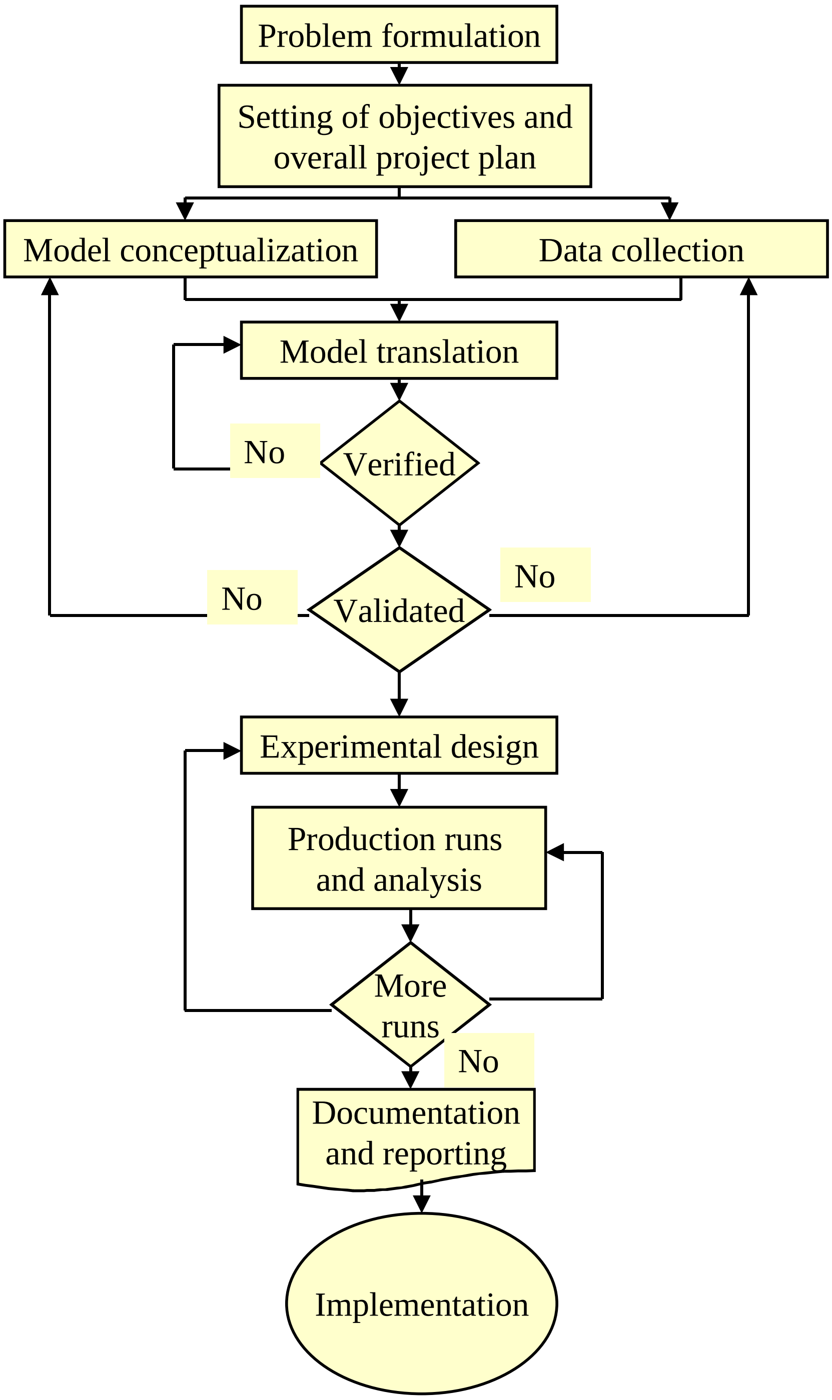

Figure 7. Simulation project

Tabular reports are very general. Table could be anything from just one figure to a large array of numbers. The table can present the information, results in different ways. Graphical reports are very useful in presenting information. (Table 4.)

Visualization and animation during simulation runs are also ways to point out the problem areas. The modern manufacturing simulators can produce VRML and avi or mpeg files as a report.

Table 4. Reporting the results.

Tabular reports	Graphical reports
• Cumulative total and percentage • Mean and standard deviation • Median and quartiles • Mode • Minimum and maximum • Statistical tests	• Time series • Histograms • Gantt charts • Pie charts • Scatter diagrams

Before starting simulation model building the designs must been "frozen" for analysis. The Figure 8 shows what kind of information is needed for model building. In manufacturing systems, all starts from the product, product structure and process information. The input is also the production mix and forecasts of volumes.

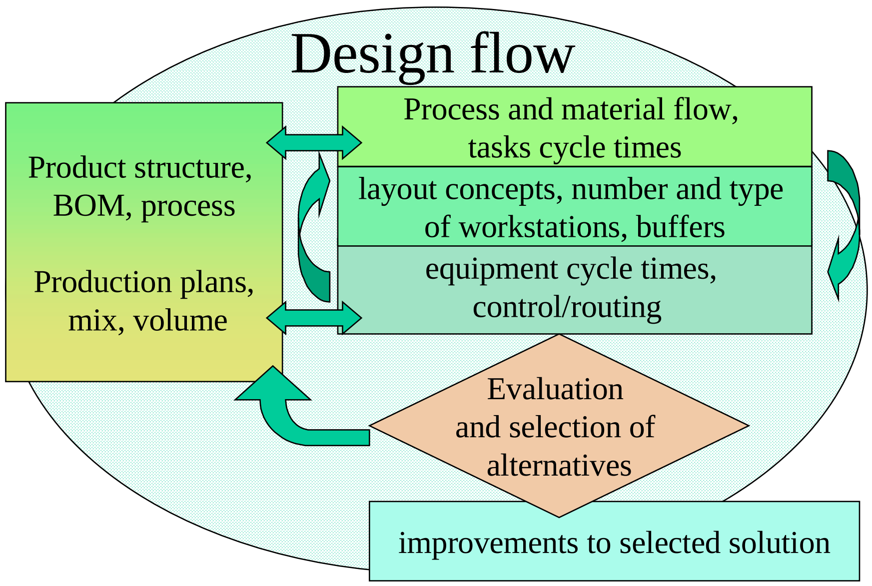

Figure 8. System design flow, simulation is the analysis tools for evaluating

4.4 Many Uses Of Simulation

In the manufacturing system life cycle following steps can be found: concept creation, layout planning, production simulation, software development, operator training and potentially operational use of the simulation model in decision support for managers. The use of simulation model can shorten the sales cycle of production system.

- Layout and concept creation (3D, animation)
  - visualization, communication

    - cell, lines, factories
- Production simulation (data, analysis, reports)
    - control principles, routing, buffer sizes, capacity, utilization, throughput-time, bottlenecks, etc
- Software development (emulation, system integration)
- Training of operators (emulation, VR)
- Operational use of simulation (Data, speed, integration)

4.4.1 Layout Planning And Concept Creation

3D visualization tools are needed to improve communication in concurrent engineering teams. In this step the facility floor space needs and production principle is verified. Logistic solutions can be evaluated also. Quick modeling is a benefit here.

4.4.2 Production Simulation

The aims usually are to test and verify plans, check the material flow routing and control principle, verify the buffer size and location and search for bottlenecks. The data should be real production data if available, or data from similar products or variants in the same product family. This is an iterative analysis, the engineers should return back to cell level studies, if some parameters need some more detail study, for example cycle time need to be shorter. One of the main requirements here is validated simulation model. Flexible, parametric model building is advantage.

4.4.3 Software Development

The simulation model can emulate the real system. With emulation the lower level software, i.e. PLC code can be tested and also upper level MES (Manufacturing Execution System) software. The real programs that will be used in the real system can be tested with real data if available. The virtual system, simulation model replaces in this case the planned system before anything is build to the factory floor. One of the main requirements here is validated simulation model and integration of software.

4.4.4 Training Of Operators

The emulation and simulation model is great tool for training of operators; the system parameters can be studied with simulation model. The software training with the real data can be done and this speeds up the ramp-up phase. If the control software has been integrated with the simulation model. The operators have the same user interface as in the real life and the simulation gives a holistic view to the manufacturing system.

4.4.5 Operational Use

While some models are used to plan and design, other models are used in the day-to-day operation 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. 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 operation with better efficiency.

Some of the operational uses of simulation models are [Thomson, 1993]:

- Emulation of real time control systems
- Real time display
- Real time forecasting
- Scheduling

4.5 Goals And Metrics For Simulation Project

The simulation projects must have clear goals and metrics. The aim is to identify problem areas and quantify system performance:

- Throughput under average and peak loads
- Utilization of resources, labor and machine
- Bottlenecks and choke points
- Queuing at work locations
- Queuing and delays caused by material handling devices and systems
- WIP storage needs
- Staffing requirements
- Effectiveness of scheduling system
- Effectiveness of control system

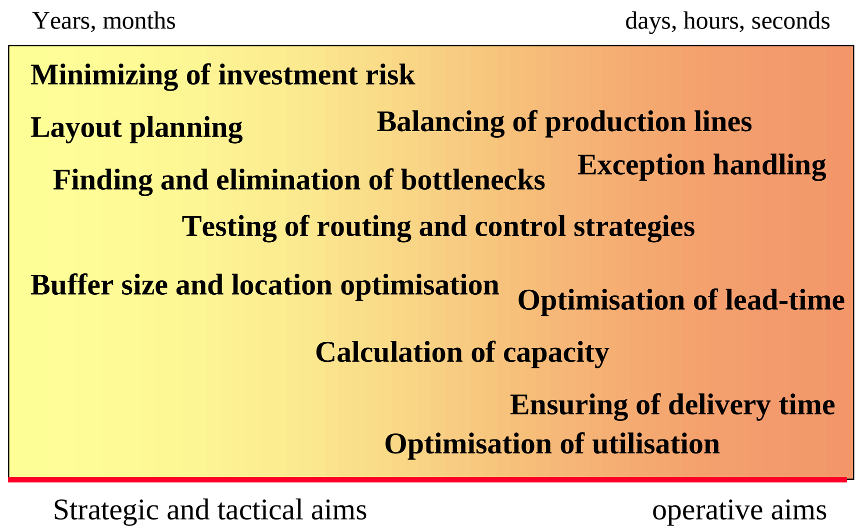

Figure 9. The planning horizon is short for operative aims

In the operative use one of the most challenging is the exception handling. The target is maximize the utilization, minimize production lead times and ensure on time delivery. Some of the other aims can found from Figure 9.

4.6 Advantages and Disadvantages of Simulation

In the Table 5, there is list of advantages and disadvantages of simulation. Most of the topics have been presented earlier in this article.

Table 5. Advantages and disadvantages of simulation

Advantages:	Disadvantages
• Choose correctly • Compress and expand time • Understand why • Explore possibilities • Diagnose problems • Identify constrains • Develop understanding • Visualize the plan • Build consensus • Prepare for change • Invest wisely • Train the team • Specify requirements	• Model building requires special training • Simulation results may be difficult to interpret • Simulation modeling and analysis can be time consuming and expensive • Simulation may use inappropriately

4.7 When Simulation Should Not Be Used

Simulation modeling has become an essential tool for many types of industrial systems; for analyzing anticipated performance, for validating a design, for demonstrating and visualization the operation, for testing hypotheses, and many other uses. A question that is often overlooked should be asked: Is the simulation modeling the right tool for the problem?

Here are 10 rules for determining when the technique is not appropriate or may not lead to a successful outcome [Banks J. 1998].

1. The problem can be solved using commonsense analysis
2. The problem can be solved analytically
3. It easier to change or perform direct experiments on the real system
4. The cost of the simulation exceeds possible savings
5. Proper resources are not available for the project
6. There isn’t enough time for the model results to be useful
7. There are no data – not even estimates
8. The model cannot be verified or validated
9. Project expectations cannot be met
10. System behavior is too complex or cannot be defined

4.8 Two different areas

As show earlier simulation has two areas of use:

- System development (a new system or a development of an existing system)
- Operational controls (controlling or optimizing the present system)

The requirement for management or operational use of the simulation is that there is a validated simulation model. If the system is large, some simplifications must be done; otherwise the computational task is too big. The next chapters present an example of both cases, assembly system development and management of production capacity.

5 Assembly System Design Using Simulation

5.1 Design and Analysis Of Assembly Line

In the modern manufacturing systems the engineers are combining automated and manual tasks and often operation process cycle times are not balanced. There are different variants and even different product families in the same assembly line. The lot size varies from order to order. Bottleneck location is changing dynamically, from one resource to another.

For an assembly line with multiple operations, local storage is often required for smooth production flow. The material handling system must combine workstations with short cycle time and workstations with long cycle-time. System balancing and material transfer system elements are the key issue while keeping the utilization of the whole line and individual workstation as high as possible.

From a workstation point of view, the time interval between successive arrivals should kept below the operation process time. For an automated workstation, a major concern is workstation failure. For a long feeding cycle, some workstation idle time is inevitable. On the other hand, if the cycle is short, the operator must respond to incoming work quickly and therefore, the quality of work may deteriorate.

In the manual assembly cycle time is variable and workpiece misses may occur. A miss means extra waiting time for next arrival and extra handling effort for the missing piece. If the missing workpieces are re-introduced into the conveyor line, either the conveyor or workstation must have intelligence to identify the right workpiece for the right operation.

Possibility to route different products and variants through same system by changing routing parameters is an advantage, but makes the system very complex. Because of the flexibility is needed in production the conveyor system can be the bottleneck. Balancing of the individual assembly tasks is important as well as buffers in the system. This makes the conveyor and routing system very complex and computer tools are needed in the design and control.

5.2 Analysis Method

Material flow analysis in a conveyor system could be done using different approaches. One analysis views a workpiece on a conveyor as a vehicle on a highway and traffic-engineering principles are applied directly. The second approach treats material flow on a conveyor as flow in a network. By solving a maximal flow problem, the capacity of the conveyor can be analyzed. The third approach is to assess a conveyor system using a stochastic model; for example a queuing model may be employed. The author prefers using the material flow simulation, DES (Discrete Event Simulation). DES is an analysis tool in the design of buffer places and sizes, to test and verify different routing and control principles.

5.3 Modular Semiautomatic Assembly System

The core of the assembly system consists of manual and automatic workstations. The workstations are the basic modules of the system, which can be configured, in different layouts according to the production needs. In addition to the workstations, the assembly hardware consists of a transfer system based on conveyor modules. The pallets are intelligent, as they are equipped with escort memories containing routing and product information.

The hardware components of the assembly system have own local, independent intelligent control. The module control unit can control actuators and motors by reading the sensor system and information on the intelligent pallet. The pallet is guided on the conveyors of the workstation module or another transfer system module according the routing information.

The flexible material flow gives the worker the freedom to perform the task at his own pace. The workstation modules have buffer places for the product pallets and the work is done off-line. The workers are not tied to the main material flow. If a particular workstation is jammed, or the buffer places in the workstation are full, or the worker is having a break, the automatic transfer system carries the product pallet further. The pallet tries to find another suitable workstation, or it returns to the starting point for a new attempt. This feature of the conveyor system is called the 'active buffer'.

An important element of the system is physical and logical flexibility. Physical flexibility is achieved by changing the number of assembly stations or by modifying their features. Logical flexibility stems from of the use of the intelligent pallets. As a result the material flow is very flexible, and multiple tasks can be carried out in one workstation. That not only reduces the occurrence of repetitive strain injuries, but also produces dramatic gains in throughput. It is also possible to divide tasks so that they are performed in a linked set of workstations, enabling automation of monotonous tasks.

Information is an important tool for workers organized in teams. In addition to taking care of the production control, the information system delivers product specific information to workers. The integration of the information flows enables small batch sizes and rapid product changes.

5.4 Simulation of the Assembly System

One of most sophisticated computer factories in Europe is shown in Figure 10. The customers can get the PC computer they specify in 24 hour. The production logistics and information delivery to the assembly operators are the key factors for paperless production and thus the production technology is enabling lot size one. The automated material handling frees the operators to do value added tasks.

The end-user wanted to check plans before signing the contract with the system supplier. The system vendor gave equipment parameters and system layout; the end-user gave real production data for simulation. During the simulation studies some changes were done to the conveyor system. For the system vendor, GWS Systems Oy, Finland, this case was the biggest turnkey assembly system delivery. More information can be found from [Heilala, Voho, 1997].

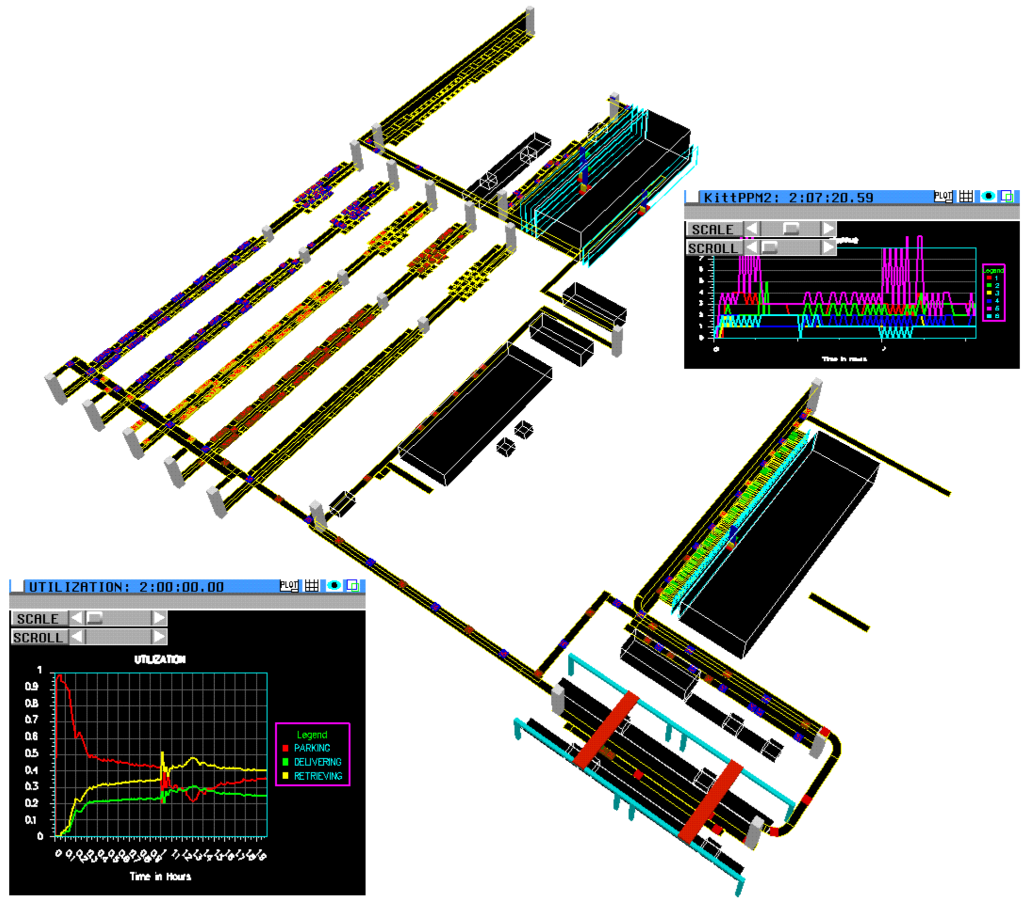

Figure 10. Simulation model of computer factory

Some parameters in the assembly system analysis using simulation:

- material and pallet flow, line balance, utilization
- Throughput time, capacity, bottlenecks buffers, etc.

6 Simulation Based Operations Planning In Make-To-Order Manufacturing

Traditional production planning tools are not enough in the fast changing market. There is a need for an operational decision support tool. Enterprises want to control the supply chains in the global manufacturing network by synchronization of the production network. The aims are to increase the punctuality of customer order delivery and shorten the throughput time of customer orders. Also, users want speed up customer order negotiation and order book creation, and make more accurate delivery date estimates in the quotation phase.

In make-to-order manufacturing the production systems have to be flexible and able to react to changing production capacity requirements. Each order can be different, consisting different component and there are changes in batch size, a new order is a 'disturbance' to the production. All this makes 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 through the rest of the production system. The changing location of bottleneck depends on the status of production resources and orders in production.

More information is found from [Heilala et. al. 1998, Heilala 1999, Heilala et. al. 1999]

6.1 Development of Embedded Simulation Tool

The aim is to increase customer order delivery accuracy in make-to-order manufacturing. By using the simulation model and a developed graphical user interface it is possible to visualize the occurrence of potential bottlenecks and take corrective actions. Simulation gives the production managers a window to the future. 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 and overload situations can be eliminated.

6.2 Building A Window To The Future Using Simulation

The occurrence of dynamic bottlenecks may be prevented by a skilful use of simulation models. By integrating discrete event simulation and traditional production planning methods, it is possible to forecast the required workloads. By using the simulation model it is possible to visualize the occurrence of potential bottlenecks in production and take corrective action. The load data for simulation, indicating the product, its parameters as well as required quantities and delivery dates will be obtained from marketing offices, orders and quotations. 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 dates can be confirmed on the basis of the simulation model and overload situations can be eliminated.

6.3 Development Goals

The development had three goals: flexible simulation model building, integration of input and output files to and from the other applications and ease of use for final end-users. The tools created enable flexible model building and the simulation model can be modified by changing input files. There is some limitation in the size of the model still, but usually no programming or simulation specialists are needed. The developers and end-users wanted to build as flexible a tool as possible. The concept is also a cost-effective solution, the recommended platform is Windows NT, but it can run under Windows 95. The users need only a run-time version of the simulation software.

The tool concept created during the development project can be adapted for different companies. Some of the changes are done automatically by changing the input files, which are in ASCII-text format. The model and load are created, based on, for example, the following information:

- workorders (order book from enterprise resource planning (ERP) database), optional quotation book (from sales offices), production scheduling,
- product structure and routing,
- workcenters and component factories, layout.

- factory calendar, holidays, absence, maintenance, etc.
- simulation parameters: depth of product structure, workorder release rules,
- optional what-if analysis, (machine breakdowns) and others.

6.3.1 Graphical User Interface For Data Mining Is Needed

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 capacity 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.

The user interface will consist of graphics, bar and Gantt-charts and custom problem reports pointing out the potential problem areas in production. Optionally 3D animation of the simulation can be used. The status of workcenters and customer orders can be seen even at the component level. In fact the development of the graphical user interface was more demanding task than the building of the simulation model itself.

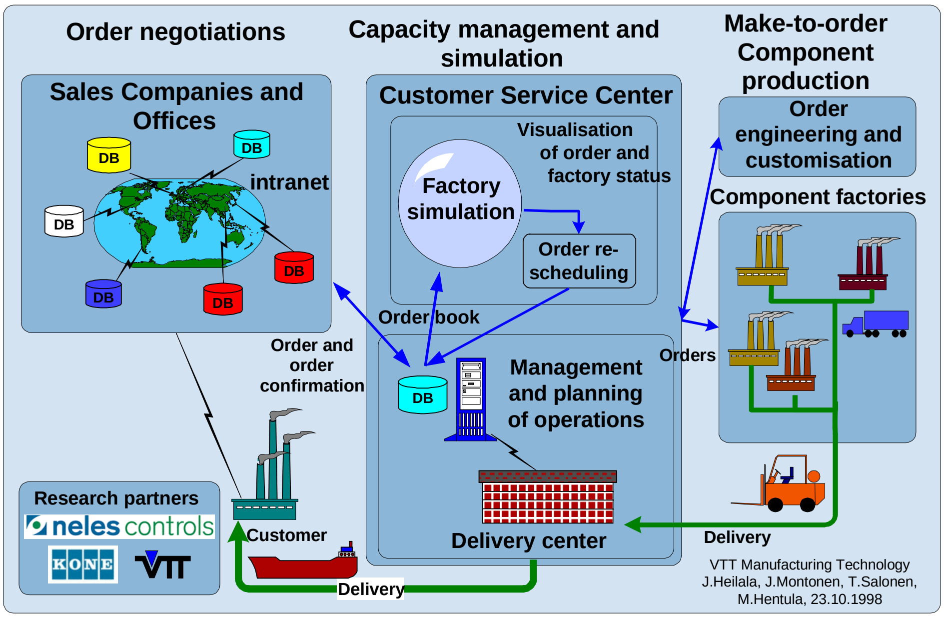

Figure 11. Simulation tool for production capacity management

6.4 Case Studies

Modern simulation techniques as described earlier are being developed and applied by VTT Manufacturing Technology in co-operation with Finnish industry. The system environment is shown in Figure 11.

6.4.1 Pilot Companies

Neles Automation specializes in automated valves and flow control systems for pulp and paper and other processing industries. The company's new positioner factory in Helsinki will strengthen its presence in digital control and automation solutions.

Throughout the world Kone is well known for its elevators, including the MonoSpace concept, in which the elevator does not require a dedicated machine room. Instead, an EcoDisc hoisting machine is installed on top of a standard elevator shaft.

6.4.2 Using The Tool

A simulation run in these pilot applications is a batch process (Figure 12). A simulation run is usually a few months of production time.

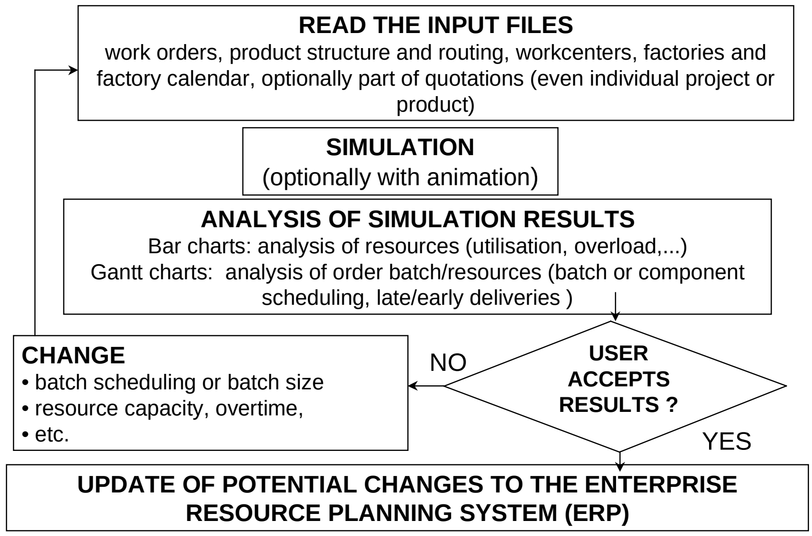

Figure 12. Simulation flow

Run-time 3D graphics is an option, which is not usually used because it slows the processing. If graphics is used, the user can, for example, see graphically the load queues in front of the resources and the simulation run can be halted and a study of the status of orders and resources in different times can be made. There are several types of run time output information available: utilization, work in progress (WIP), buffers, storage status, throughput time, queue and waiting time, etc.

6.4.3 Simulation Analysis

Simulation output analysis is done using the visual user interface:

- capacity loading with bar charts,
- order status with Gantt charts, project milestones can be shown also
- production resource status with bar chars (load) and Gantt charts showing the orders in production

- problem reports, late or early orders, exception found during the simulation run.

The system gives a proposal for re-scheduling of production orders by showing late or early orders and components. The user does re-scheduling with the visual interface and can do optional re-running of the simulation to check the results. Currently the user approves all the changes. Optionally all the simulation data is available: utilization, WIP, buffer, storage status, throughput times, queues and waiting times, etc.

6.4.4 Pilot of Neles Automation

The aim of the system is to compensate the missing features of the ERP. With this developed simulation tools the effects of quotations are shown. Secondly the capacity manager can do what-if analysis with simulation without disturbing the production. This can not be done with the ERP database, while a change in the database means that the user is changing scheduling of orders.

The system is installed on a workstation PC and there is one main user. The simulation analyses are show using standard office programs, like spreadsheet and project management. Main use of the system: Balancing the load, synchronizing the component production, improve delivery accuracy, creation of order book (scheduling of quotations).

6.4.5 Pilot of Kone

The aim of the use of the system is to increase the delivery punctuality of customer orders. The developed simulation tool and graphical user interface for order database replaces some older stand-alone software applications. The developed tool is an integrated solution. It gives the production planners graphical tools to visualize the order database and do re-scheduling.

System is real server/client application for many users, based on database. The user interface is programmed with visual programming language. The users have different rights, the planner can do re-scheduling and viewers see only the results. Main use of the system: Improve delivery accuracy, balancing the load, visualization of production and order status.

7 Case Conclusions

7.1 System Development

The design of semiautomatic assembly system is very complex. Simulation is indispensable here. Both the technical and economic properties of the conceptual system design can be analyzed by means of a discrete simulation model. The authors have justified the use of simulation techniques in the design of semiautomatic assembly system. The result shows that the use of the virtual system does speed up the design process and increases the quality of design. Use of simulation can speed up sales cycle of system vendor, while the engineers create better design faster and solutions tested. Secondly the simulation model is a document of the system, improving communication between end-users and development engineers. Thirdly simulation model can be used for training of personnel and operators.

`Don’t speculate - simulate before doing.`

7.2 System Management

The developed tool is useful in make-to-order manufacturing, it adds features for the capacity managers, that the standard tools do not provide. Both of the industrial partners, Kone and Noels Controls are currently using the system.

The created tool enables flexible model building. The end-user can modify the model by changing input files. There is some limitation in the size of the model still, but usually no programming or simulation specialist is needed. The developed solution is flexible and can adapted for many companies. The concept is also a cost-effective solution, it runs on a PC platform under a 32-bit operation system. The users need only a run-time version of the commercial simulation software. Standard office programs can be used as the user interface, spreadsheet and project management or custom made graphical user-interface. This developed tool can be implemented for other enterprises, but some modifications to the user interface and data interface are required.

Reference:

Banks, J., Carson J.S., and Nelson B.L., 1996. Discrete-Event System Simulation. 2nd ed. Prentice Hall. Upper Saddle River. N.J. 1996.

Banks J. (ed) 1998. Handbook of Simulation. Principles, Methodology, Advances, Applications, and Practice. John Wiley & Sons, Inc. 1998.

Harrell, C., and Tumay, K., 1995. Simulation Made Easy, A Manager’s Guide. Industrial Engineering and Management Press. 1995.

Heilala, J. and Voho, P. 1997. Human touch to efficient modular assembly system. Assembly Automation vol. 17(1997):4, pp. 298 - 302. SS: 0144-5154

Heilala, Juhani; Montonen, Jari. 1998. Simulation-based design of modular assembly system - use of simulation module library. Eurosim Congress 1998, 3rd International Congress of the Federation of EUROpean SIMulation Societes. Espoo, FI, 14 - 15 April 1998. VTT Automation 1998, 6 p.

Heilala J., Montonen J., Hentula M., Salonen T., Hemming B., Autio T., Alhainen J., Makkonen E. 1998. Capacity Management. Simulation and visualization tool for enterprise manufacturing operations planning. Poster. Winter Simulation Conference 98. Washington, USA, 13 - 16 December 1998.

Heilala, Juhani. 1999 Manufacturing operation simulation in make-to-order manufacturing. VTT Industrial Horizon, Espoo. 1999 January

Heilala, J., Montonen J., Salonen T., Sorvali E., and Suuronen J. 1999 Simulation Based Operations Planning In Make-To-Order Manufacturing. ICPR99 (International Conference on Production Research. 9-13 August. 1999. Ireland

Law, A.M., and Kelton W.D.,1991. Simulation Modeling and Analysis, 2nd ed. McGraw-Hill, New York.

Robinson, S., 1994. Successful Simulation. A Practical Approach to Simulation Projects. McGraw-Hill International..

Shannon, Robert E. Introduction To The Art And Science Of Simulation. Proceedings of the 1998 Winter Simulation Conference. D.J. Medeiros, E.F. Watson, J.S. Carson and M.S. Manivannan, eds.

Thompson, Michael B. 1993. The Marriage Between Simulation & Real-time Control. APICS, August 1993 pp. 43-46.