3rd International Industrial simulation Conference ISC'2005 June 9-11 Berlin Germany
Eurosis-ETI. ISBN 90-77381-18-X

A SIMULATION APPLICATION FRAMEWORK FOR PRODUCTION PLANNING AND SCHEDULING

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KEYWORDS

Model design, Discrete simulation, Decision support, Production control

ABSTRACT

This paper presents a general framework for the application of simulation during the different phases of decision making in production control. Each phase of decision-making requires a different simulation model with different goals and characteristics. The modeler should be aware of these characteristics in order to take full advantage of the use of simulation. The paper shows the decision-making structure and explains the way how simulation could support and improve this. Finally a general framework results with different interacting models, reflecting the decision-making structure of a company.

INTRODUCTION

Currently, simulation is commonly being used for decision support in the design of transport, production and service systems. Models for this type of use were disposable until the last decade. Nowadays, the use of simulation for operational decision support in project planning, production planning and scheduling is growing, although it is not common yet. The general trend is to directly use control algorithms, developed during design, for the real operations (e.g. [ConCannon et al, 2003]). Also some isolated models exist for project planning and production planning /scheduling (e.g. [Chong et al., 2003]), which cover a part of operational decision making. In both cases the major difference with the traditional use of simulation modelling is that the model software is not meant to be disposable, but should operate frequently, user-friendly and integrated in the operational decision making structure.

In this paper a framework is presented for the integrated use of simulation in production design and control. The framework is restricted to customer order controlled production environments.

First a conceptual view of decision-making in production environments will be defined. It will be shown that there are three different levels, each with its own goals, but all are connected in a hierarchical way. In this three level concept, five model types can be distinguished. The relation between these model types will be explained in terms of interface data. The functionality of these models, required to support (and improve) production planning and scheduling will be discussed. Based on this concept, a structured framework for simulation modelling will be derived. The resulting framework is now being used as the basis for further research into simulation integrated production planning and scheduling.

PRODUCTION CONTROL

Decision-making (human or automated) is an essential part of production control. The requirements, possibilities and restrictions of operational production control are defined during the (re)design of a production system.

According the Delft Systems Approach [in 't Veld, 2002], effective production control can only be achieved if and only if all of the next conditions are met:

1. *there is a clear goal*. For a production process the general goal is to deliver the right products at the right time and location in the best economical way.
2. *The goal is feasible.* If a goal is unfeasible then there is no sense in pursuing it.
3. *There are possibilities to intervene*. If one can't intervene then there are no possibilities to react to disturbances.
4. *There is a perception of the consequences of interventions.* Without perception of the consequences, interventions may easily move the production farther away from the goal; in the best case one simply doesn't know what will happen.

The second condition states that a goal has to be feasible. From the viewpoint of the simulation domain, only quantitative feasibility is considered, for example production rates, lead times and stock volumes. During design, a system structure and capacities have to be derived that are capable of achieving the goal in general. The conditions are defined under which the system should operate and the structure and capacity of the system are established to suit these circumstances. The structure is expressed in terms of operational "functions" to be fulfilled and they are combined into a production "organisation". If the original conditions change structurally (when the system has become operational), the system may have to be redesigned. This process will be called 'function design' from now on.

Operational decisions should guarantee the goal's feasibility for specific situations. For example, during operation the order stock is known (real or by forecast) and the state of capacities is known. Feasibility means in this case that a match can be made between orders, capacities and materials. In other words: will the system function (fulfil its requirements) under these circumstances and how can this be achieved? This is "function control", which delivers a prescription or "standard" for the near future.

The third condition refers to the fact that interventions are required if disturbances cannot be excluded. This is the case in every customer order controlled environment. Function control cannot take specific disturbances into account by definition; it can only provide the capability to deal with future disturbances (e.g. by providing "slack"). In order to deal with it, the standards from function control are used to define the correct intervention. Concrete disturbances in the process, input or output should be solved. This is called "process control".

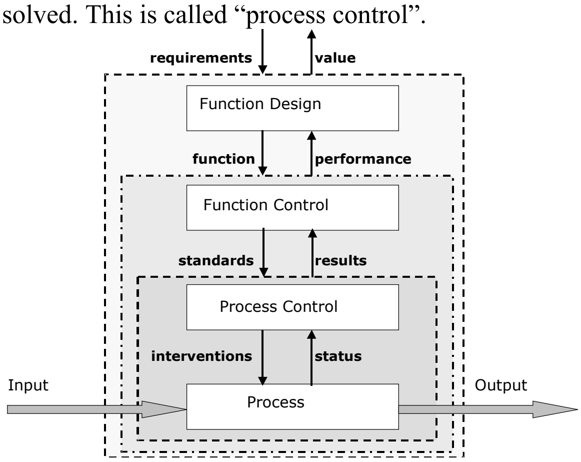

Figure 1. A functional view of production control

The fourth condition, perception of consequences of interventions, is usually based on experience of the decision maker, but it will be later explained that simulation is extremely useful for this purpose, specifically for production planning and scheduling.

The requirements entering the system on top in figure 1 are the result of policy making. Fulfilling these requirements should result in the required company- and/or customer-value, leaving the system at the top. Function design has a lot of possibilities to fulfil them, but the selected function should guarantee feasibility at least. Function design decides on the functions to be fulfilled and resources to be used. The result of the developed system is called the "performance". Function control includes specific circumstances into the general function structure and formulates standards for the coming operation period. These standards are used to prescribe the expected progress of the processes and to decide on interventions if necessary. The results of repetitive executions of the process are being reported to function control, which (re)defines new standards for the near future. Finally, the whole system of function control, process control and the process itself determines the performance of the production system. This conceptual view will now be used to define the position of production planning and scheduling.

PRODUCTION PLANNING AND SCHEDULING

The function of production planning is defined as:

"to provide the best economical way to produce the right products at the right time at the right location <u>for an expected situation</u>".

Production planning usually fulfils its function by determining the orders to be executed and by determining the required capacities and materials for these orders in quantity and time.
The function of production scheduling on the other hand is:

"to provide the release and execution of orders according the conditions of production planning <u>in a certain situation</u>".

For this function, materials and work instructions are collected and the execution sequence is determined. The phrases "for an expected situation" and "in a certain situation" in the definition of planning and scheduling respectively, are essential. The production planning function always uses an idealized image (a model) of the future, where production scheduling has to deal with real (often disturbed) situations. From this it becomes clear that production planning belongs to function control while production scheduling is a function within process control.

Function control monitors the results of execution and checks their accordance to the requirements; it derives standards (makes a production plan) for the process itself that will hold for a certain period of time (the planning horizon). Process control continuously monitors the real state of the process (progress according the production plan, errors, flow rates etc.) and eventually intervenes to keep the process within the defined production plan.

Zooming further into 'Function Control', makes it clear that the production plan is the final result of echelons of similar planning functions with ever increasing levels of detail. These echelons can be found in the usual structure of MRP-II systems (see figure 2).
In this structure the master planning is the leading plan for the material requirements planning and the capacity requirements planning. It shows however the (intermediate) results of the functions, but in no way the processes to achieve them. Above that, there is no connection with the results of function design, which reflect the feasible requirements of the production facility. For planning purposes the basic element is taken to be an indivisible work unit: "a task". Standards for tasks are required in order to deliver a production plan. These task standards express processing time, setup time, lead-time, required capacity etc. Combinations of tasks represent complete orders.

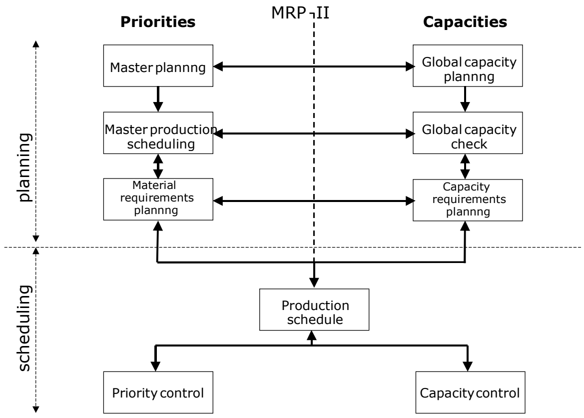

Figure 2. MRP-II planning structure

Orders can be very complex and may require a standard for sequencing, capacity assignment and material use. These complex orders are considered "projects" and all usual methods like CPM, Pert etc.[Wild,1999], may be applied. Therefore the standardization of projects (complex task structures) is considered a separate function, the results of which are used during the formulation of the total production plan. Figure 3 shows the general functions required to make a production plan.
Function design defines both initial data and technological / organizational changes. The results are data included in the "function" description.
Finally it is noted that the interaction between function control and process control should be balanced very carefully. Too much detail in the production plan may result in an ineffective scheduling function, because there is no room left for interventions.

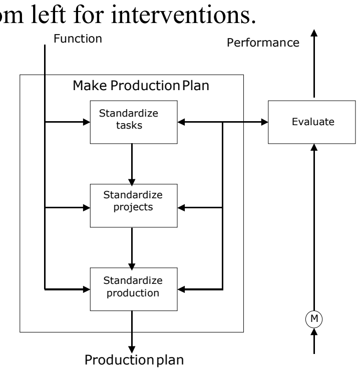

Figure 3. Production planning functions

The result is that the production plan has to be recreated with every disturbance adopting the role of production schedule. On the other hand, production scheduling should not be used to adopt the role of production planning. In this case the principles of modelled future and hard reality are mixed up and the relation with the original goals of the system are lost. A modelled future usually uses averages and expectations; the hard reality fully consists of individual (i.e. non-statistical) data. The hierarchical functional approach as presented here is a precondition for the preservation of a correct view for effective control.

MODELLING AND SIMULATION IN PRODUCTION PLANNING AND SCHEDULING

The previous paragraph explained the functions of plans and schedules to be used for production control. When simulation is being used, these functions also determine the goals of the simulation models.
As explained, there are three function levels where decision-making for production processes takes place:

1. function design
2. function control (planning)
3. process control (scheduling)

At the function design level, simulation is applied in the traditional way. This means that simulation is used to construct a model for a new or improved situation and to investigate the results to be expected. Simulation models at this level are primarily used once only, but a tendency is becoming evident to use the same control software in a real-time environment that has originally been developed for the simulation model. The models at this level will be called "system models" from now on and mostly they are concerned with the layout, organization and productive use of resources assuming order arrival patterns and order compositions. The primary goal is the correct functioning of the system. The results of these models are structures, behaviour descriptions, capacity definitions, stocking requirements and –last but not least- control concepts and algorithms (such as a planning principle), all in order to realize the required performance (see figure 4).

In function control i.e. planning, simulation should be used as an operational tool. The goal of planning (and thus of the models used) is to provide conditions in which the required performance can be reached with a given order stock and/or with forecasted orders. Restrictions that conform to priorities, availability and technical feasibility, are in fact added here to the system definition of function design. A simulation model here represents the real system and focuses on required due dates and minimum costs. Results are (required) available capacity, order and task release dates and material requirements. They all should be checked for feasibility at least. This is the primary goal of simulation models at this level. They are called "planning models" from now on. It is already shown [Veeke,2003] that simulation is able to deal with combinatorial problems that cannot be solved (in time) with analytical approaches. Orders are task structures. When orders are very complex or when they become repetitive or when they have very strict due date requirements, they can be considered "projects". For these projects the usual project planning methods are applied in order to define optimal sequencing, capacity assignment and lead times. This type of projects is also often encountered in maintenance environments. As shown in figure 3, these project plans precede the production planning. Actually, a project plan is a standard to be used in the production planning. It has already been shown that project planning with simulation leads to new interpretations of a traditional project characteristic like the critical path [Ottjes, 2000]. Above that, the interaction between project models and production models may lead to new ways of using priorities, capacities and materials. The interaction fits perfectly to the matrix organization principle, and supports decision-making between project managers and department managers. Although there are many multi-project planning models already, they don't distinguish project and production planning goals.

At the scheduling level (process control), the use of simulation is also widespread. It is especially at this level that simulation models try to find optimum solutions for detailed scheduling problems. Nevertheless it is generally acknowledged that "production scheduling in industrial practice is still primarily a manual task, despite the immense research efforts and the fact that manual scheduling is a very complex task" [Wiers et al, 1996]. Therefore the main goal of these "scheduling models" should not be to present optimal solutions from a complex algorithm, but rather solutions that would be found by the human decision maker. The model should primarily represent the behaviour of the decision-maker and show the consequences of the decisions. Here the use of simulation offers the added value of giving perception and understanding of consequences, the fourth condition for effective production control. It is also not useful to implement algorithms that use data that are not available in reality. For example, a rather simple scheduling algorithm like "minimum slack" is based on the slack of tasks at the moment of decision making; It assumes almost automatically that the slack is continuously known. However, most small to medium sized companies register progress once a week and therefore the decision-maker does not have this attribute and will not use it. This example makes it also clear that simulation can be used to show the consequences of better decision-making when new technologies like barcodes and RFID (Radio Frequency Identification) enable the continuous registration of progress.
Figure 4 shows the resulting structure of models and relations, derived from the decision-making structure of figure 1. At the bottom the term "process model" is used for simulation models that describe the real processing.

THE USE OF THE FRAMEWORK

The framework represents the 5 different types of simulation models and their relations that can be used during design and operation of a production system.
The contents of each of these model types will be discussed shortly.
The *System models* should offer the facilities to support the definition of production systems according the production requirements and an expected or known disturbance behaviour. For this purpose they should be able to calculate the occupation of a system stochastically, where a workload is assumed. Production patterns, a maintenance program and the disturbance behaviour of the equipment usually specify this workload. Above that they should be able to determine stock levels and tool demands, in order to perform the production process.

A *project model* is part of function control. It is capable to define repetitive complex orders. It takes available capacity into account, materials, tools, job sequences and processing times.
In general these project models offer the following facilities:

- Stochastic calculation of a project structure, with pessimistic, average and optimistic task times
- Determination of a realistic lead-time with finite and infinite capacity
- Determination of critical activities with different acceptable project lead times.
- Determination of project costs
- Determination of the tools and materials requirements.

Project models are also very useful in maintenance environments for the determination of a preventive maintenance program.

Planning models should offer the same facilities as project models, but for non-related orders and projects in restricted capacity environments.
Scheduling models show the consequences of different scheduling rules based on the behaviour of the decision-maker(s). Such a model is able to:

- Deal with capacity calendars and all kinds of shift schedules
- Deal with capacity restrictions for each task
- Deal with job structures and sequencing for projects and activities
- Establish orders and projects in predefined periods and to show the consequences of deviations therein
- Fix tasks in predefined periods (both automatic and manual) in the planning schedule
- Add capacity automatically under predefined conditions
- Take material and tool requirements into account.

Process models can be made as detailed and specific as required. The models can be logistic oriented, and in that case model the operational specifics very globally, because the main interest lies in the sequence of operations. There are also numerous technological models that describe a process in detail for example by means of differential equations.
Figure 4 finally shows the most important interface data between the models that can be used.

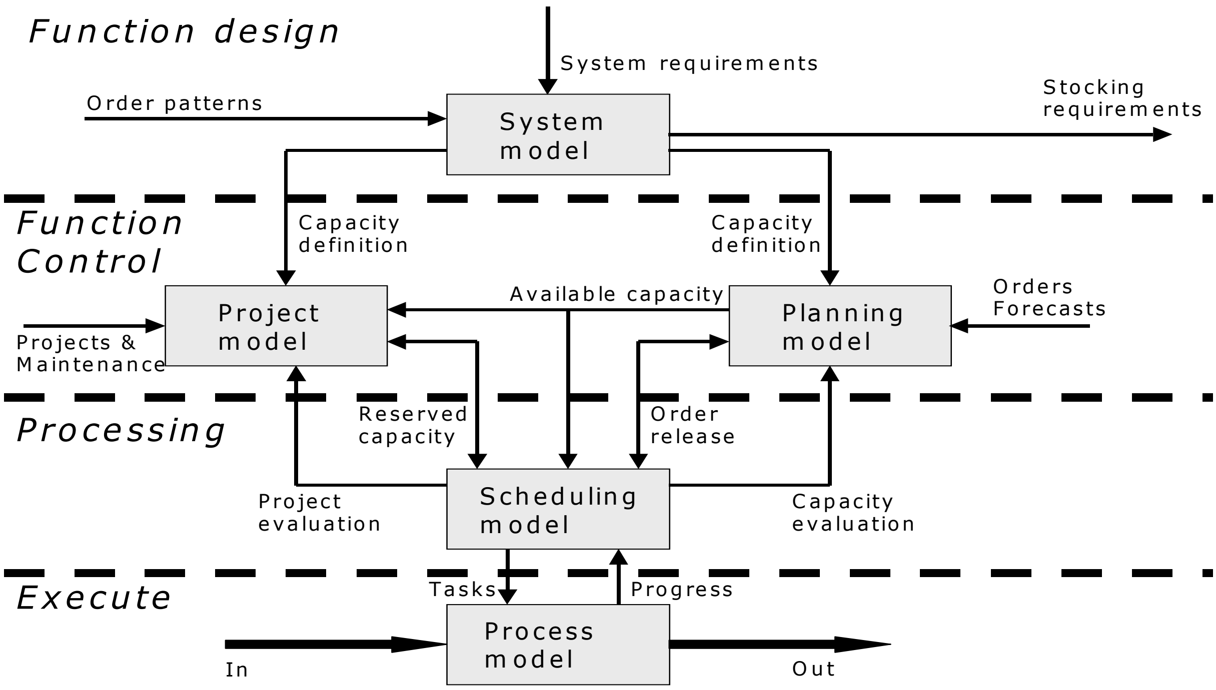

Figure 4. The simulation application framework

CONCLUSIONS

The framework shows that :

- the goals of the model types differ, each representing only a part of the functions that are required for production design and control.
- A model originally meant for one of these functions cannot be automatically extended to serve another one. Including a lower function level in an already developed model requires extra data and more detail; including a higher level would introduce more degrees of freedom.
- The models serve functions, which are part of a well-defined decision-making organizational structure. If the organization has separated these functions, one should be careful to combine them into one single model.

The model structure shows a number of interesting aspects for the application of simulation in production design and control.

- Each model can use a model of the lower level. A planning model may use a scheduling model in order to make a realistic planning; a system model may use a planning model to simulate control during layout and organization research etc. The structure represents the use of simulation within simulation.
- The information flows between the models are guidelines for a distributed simulation network, which conforms to the decision-making structure within the company. For example a project model can be connected to a planning model in order to interactively harmonize decision-making within a single project and a multiple project environment. They influence each other with respect to capacity reservation and availability.
- The structure enables the correct positioning and thus the correct goal-definition of simulation models to be constructed. Although advanced algorithms can be defined within simulation models, if they don't fit the decision-making structure of the company then the algorithms are useless.
- The structure shows the relation between logistic research and technological research explicitly. The simulation world can be roughly divided into:
  - The technological world that models technological (and often continuous) processes in great detail
  - The logistic world that models operational decision making in great detail, thereby modelling technical processes just as time-consuming activities.

  In practice there is a tendency in both worlds to extend to the other world. It is however quite difficult to implement the achievements of each world completely. The structure expresses how to connect both simulation worlds and so how to take advantage of the achievements of both worlds.

The model structure is now being used to define several simulation research projects for the development of a virtual industrial environment. This environment will be used to investigate new operational and control structures in highly automated production systems. Above that, prototyping of new technology will be a major topic

which is supported by this structure (hardware-in-the-loop simulation).
The functional view as presented here ensures that a variety of industrial organizations can be modelled within the model structure. This is also the main requirement to investigate the use of simulation itself within production control.

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