FLEXIBLE PRODUCTION SIMULATION FOR APPLIED SCIENCES

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ABSTRACT

In this paper the structure of a flexible simulation model for production systems based on discrete event simulation is presented.

The basic idea of this flexible simulation model is to generate the shop floor structure of the studied production system based on work schedules and on the bill of materials. The production machines are not connected directly but the material flow is routed according to the information in the work schedule and the bill of material.

The model structure is based on different modules which use material flow entities and production order entities to communicate with each other and to simulate the production system.

As a result, the created simulation structure leads to a flexible simulation model generation which maintains a low effort for generating simulation models concerning different production system structures.

Keywords: Flexible Simulation, Production Simulation, Production Planning

1. INTRODUCTION

Manufacturing companies are often faced with challenging market situations concerning product complexity and changing demand. Their customers frequently focus on their logistic performance in additional to product quality. The logistical performance can, for example, be measured as the service level, delivery leadtime or average lateness. To influence this logistic performance, decisions have to be taken about capacity investment, production planning strategy and parameterization of the production planning method.

The influence of such decisions is discussed by analytical models in literature (e.g. Hopp/Spearman 1996 and Koh/Bulfin 2004). Since such models often lack the practical applicability, another method often applied in research papers as well as for applied research projects with companies is simulation. For example Jodlbauer/Huber (2008) compare different production planning strategies with simulation, Kutanoglu/Sabuncuoglu (1999) study different dispatching rules for production systems by applying simulation and Abdul-Kader/Gharbi (2002) provide a simulation model for capacity estimation of production systems. Furthermore, Huang et al. (1998) for example discuss different production planning strategies in an applied research project for a cold rolling plant by using a simulation model.

Based on these cited applications of simulation studies in the field of production research, it is clear that simulation can be used as a flexible tool to analyze production structures or production planning systems. Since such simulation studies are usually quite difficult to set up and are also quite specific concerning their application (see Thomson 1994), this paper presents a flexible production simulation approach which can be used both for industry and for research. This approach is based on the idea of object oriented simulation (OOS) which is argued to enable flexible discrete event simulation models by Joines/Roberts (1998), Borenstein (2000) and Anglani et al (2002).

2. LITERATURE REVIEW

Simulation is a widely used tool to model production systems as discussed in the *Introduction*. This short review of developments in simulation, especially in discrete event simulation, is focused on the process of generating a simulation model.

As discussed by Thomson (1994), creating a simulation model can be complex as well as resource and time intensive, but simulation models are often built for only one special case, the so-called throw away model. The need to analyze a new alternative requires again personnel and time resources. An alteration of the existing models is also usually very complicated and time intensive.

Simulation models have to become more flexible to reduce the development time. For this reason, Kronberger et al. (2008) developed a model generator that atomically generates a simulation model with data out of ERP (enterprise resource planning). They discuss several limitations of their automated model generator and their model depends on a certain data structure in the ERP system.

McNally/Heaevy (2004) successfully implemented simulation as a desktop resource in a medium sized facility as decision support for various manufacturing personnel. The simulation model is used both for strategic and short term planning and is linked to the company's information systems. They report their main difficulties in model maintenance and data collection.

Son et al. (2003) developed a model generator for a real time shop floor control system which is based on simulation. They developed an automated simulation model generator which creates a simulation model for discrete part manufacturing based on a database and a certain structural information source about the shop level execution model.

Gravel et al. (1994) used simulation for a decision support system for production planning to support the production manager to in choosing the main parameters of a production planning system. The simulation model is again linked to the information system of the manufacturing company.

In the paper of Irizarry et al. (2001), a flexible simulation tool to discuss different manufacturing cell design patterns is introduced. The model is used to discuss different design patterns of a printed circuit board assembly cell.

Other models like the ones of Jodlbauer/Huber (2008), Kutanoglu/Sabuncuoglu (1999), Abdul-Kader/Gharbi (2002) and Huang et al. (1998) are all directly linked to one application or one structure discussed. Such models are, as already discussed in Thomson (1994), throw away models which often cannot be used for further applications.

Joines/Roberts (1998) show how flexible simulation can be realized with object oriented simulation. Different simulation modeling packages can be reused easily. Borenstein (2000) criticizes that major changes in simulation models cannot be performed easily and mentioned object oriented simulation as a method to increase the modifiability of simulation models. An application of OOS is delivered by Anglani et al. (2002) where it is used for flexible manufacturing systems simulation.

This literature review shows that some implementations of differently flexible simulation models already exist, but that there is still a need for further research in this field, especially if one is not discussing the link between simulation and the information system of manufacturing companies.

For this reason, this article describes a simulation approach applying flexible simulation modules that support applied research for fast and flexible production simulation.

3. FLEXIBLE SIMULATION MODEL

The simulation model described in this paper still relates to work in progress. The following section describes the planned features of the developed model which to date, are only partially completed.

It is based on the idea of creating different modules which can be used in the simulation software. These different modules are then combined to create a discrete event simulation model of different production systems. The software used for this model is AnyLogic 6.4.

In the first subsection, the targeted application of this flexible simulation model is described. The second subsection shows which data structure is needed to create a model. In the third subsection an overview of the functionality of the simulation model is given. The fourth subsection encompasses the description of the single modules used in the simulation model.

3.1. Application of the flexible model

This flexible simulation model is designed to be used for two purposes.

The first purpose is to enable applied research on the hierarchical planning process as conducted in many manufacturing firms. The hierarchical structure of the production planning in the simulation model is orientated at the MRPII (manufacturing resource planning) concept. The influence of different methods for the long term planning, the medium term planning and the short term control are addressed with that model. The methods used for these three levels of planning should be compared for different production system structures such as job shop or flow shop. Furthermore the influence of lotsizing policies, recursive production structures, scrap rates and processing time variation are discussed with the flexible model.

The second purpose of the model is to enable applied research projects with manufacturing companies through the ability to simulate their manufacturing sites with a considerable low effort.

Based on these two purposes the following concept for a flexible simulation model has been developed.

3.2. Data structure needed

Contrary to some of the literature cited above concerning flexible simulation systems, this simulation model has no direct link to an ERP system which a manufacturing company might have. According to the purposes the model is built for, it was decided to base it on a predefined data structure similar to the one available in ERP systems. The structure needed for the simulation model contains the following matrices:

Bill of material: Any kind of bill of material can be used for the model as long as it is available in a matrix structure indication how many pieces of different components are needed to produce one piece of a higher level component.

Work schedule: The work schedule matrix has to give the information concerning which machine or machine group is needed to transform a certain component into another component. Furthermore the processing time for each production step as well as the setup time for this combination component to machine or machine group is included into the work schedule. Additionally, the transportation lotsize between the single machines has to be defined in that matrix.

Production planning parameters: Up to now two different production planning methods are included in the flexible model, which are MRP (material requirements planning) and CONWIP(constant work in process). The planning parameters used in MRP are the lotsizing policy fixed order quantity, planned leadtime between production steps and safety stock per product or component. For CONWIP the parameters are lotsizing policy, WIP-cap and work ahead window. Additionally some dispatching rules for production control are implemented.

Structural information: The structural information about the simulated production system is a matrix including the machine type, the number of machines per type and the machine availability (MTTR and MTBF).

Customer demand: To create the customer orders a matrix including the average order rate, the average customer order lotsize, the variance of customer order lotsize as well as the average customer required leadtime and the variance of customer required leadtime is needed for each finished good.

3.3. Simulation model generation and functionality

The model generation is based on a certain data structure discussed above. The model generation is, contrary to some of the cited literature above, not based on an automatic link between the simulation software and the ERP system which a manufacturing company might use.

To generate a model the single machines or machine groups have to be created in the AnyLogic 6.4 simulation software by using the module Machine. Furthermore, all the matrices from the data structure needed have to be filled with the corresponding data. To finish the model generation, the runtime of the model (and an appropriate warm up phase) and the experiments to be performed have to be defined.

For each simulation run a set of logistical performance indicators including service level, tardiness, production leadtime, overall utilization, WIP and FGI among others, are written to an MS Access database. So the result of each simulation experiment is a database file.

Figure 1 provides an overview of the simulation model functionality for a better understanding of the model.

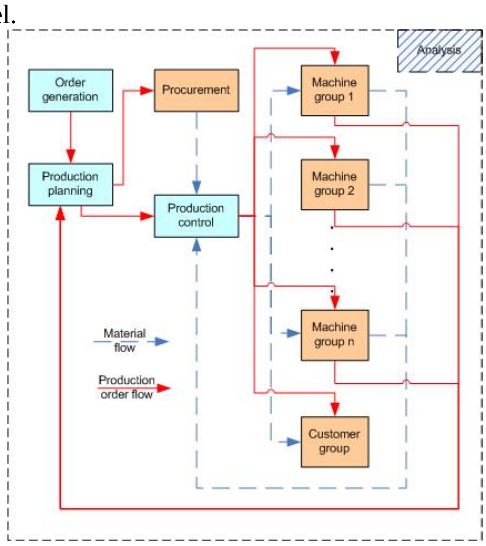

Figure 1: Functionality of the simulation model

As shown in Figure 1, the simulation model has two kinds of entity flows. The dashed line shows the material flow which is defined by the bill of material, the work schedule and the structural information. The bold line shows the production order flow which is defined by the bill of material, the work schedule and the production planning parameters.

The following steps are performed by a production order until the customer receives the products. The production order is generated via the parameters product type, amount and due date by the order generator and sent as an entity to the production planning module. Additionally, the production order is added to a list held in the analysis module. Based on the production planning strategy, production orders for the respective materials are created. These orders are sent to the production control module. The sorting of the production order according to the dispatching rule is performed in the machine group module. Based on the information in the production order, including the machine or machine group, the materials and the production order are routed to the corresponding machine or machine group. When a machine becomes idle, the next production order is produced. After the production order is finished, the materials and the production orders are routed to the production control module. In the production control module the availability of materials for the production orders is checked and the materials are sent to the corresponding machine group module whenever materials are available. All logistical figures needed are stored in the analysis module. Since no direct link between the single machines or machine groups is implemented in the model, but all flows are implemented with indirect links (AnyLogic implementation with Enter and Exit Blocks), the simulation model can quite easily be adapted to any production system structure.

3.4. Simulation modules

In this section the functionality of the seven modules as shown in Figure 1 is discussed in detail.

Order generation module: In this module the customer orders are generated with a quantity to deliver, the product type and the due date when to deliver.

Production planning module: The production planning module performs the complex task of creating and releasing production orders based on the customer orders. For the first setup of the model as discussed in this paper the two methods MRP and CONWIP are implemented in this module. For future research this module could be extended to other methods as Kanban, DBR (drum-buffer-rope) (see Schragenheim/Dettmer (2001)) or work load control (see Bechte (1998)).

Production control module: In this module the production orders and the materials are held and the material availability for the production order is checked. If the material needed for a production order is available, material and production order are released to the respective machine group. The module stores each of the finished goods, components and raw materials (one entity class called *material* in AnyLogic 6.4) used in the simulation model separately. Concerning the simulation model design, this storage is important for the flexibility of the production system structure which can be modeled. Since each product is stored before and after a certain production step, in this storage the flexible flow of entities in the simulation according to the work schedule is assured. For simplicity reasons no transportation times between machines and the storage have been modeled yet.

Procurement module: In this module the materials are delivered for the first time to the production structure. This means the material entities are created. For simplicity reasons the procurement process is only modeled with a certain distribution of the delta between planned arrival date to real arrival date. The procurement is triggered by the production planning module with production orders for raw materials.

Machine group module: The machine group module can simulate planned maintenance, unplanned machine breakdown, machine set up time, scrap rate and assembly of components. A transport lot size can also be created after production in this module. Furthermore, the orders are sorted according their priority applying dispatching rules.

Analysis module: This module records statistics such as the utilization of machines, lead time, inventory, delivery reliability and other logistic key figures. All the values stored are independent of the production system structure. The only adjustment needed when the structure of the production system to model changes, is the addition or deletion of machine group dependent statistics.

Customer Group module: This module simulates the customer demand at the due date. The last generated production order out of a customer order is the customer demand at the due date and the materials are sent from the production control module to the customer group module.

3.5. Flexibility of the model

Based on these seven modules and on the structure as shown in Figure 1, the flexible simulation model can be applied to various production system structures.

As discussed in section 3.2, for each product a working plan and a bill of material have to be created for the simulation model. The working plan and the bill of material contain all the necessary information about the component which is needed for the machine group module and also for the routing through the production. Since the information about the routing is stored in the working plan and separated from the structure of the model, there is no more a need to construct fixed paths for the material flow in the simulation model, which makes the model more flexible concerning production system structure. Additionally, the structure of the products produced (e.g. sequential, convergent, divergent bill of materials or different processing and setup times) can easily be changed in the simulation model since again only the work schedule and Bill of material need to be changed.

4. OVERVIEW OF ANYLOGIC MODEL

The flexible simulation model described in this paper is still work in progress. The following section describes some already available and some planned features of the developed model.

4.1. Model architecture

Figure 2 gives an overview about the architecture of the developed simulation model in AnyLogic 6.4.

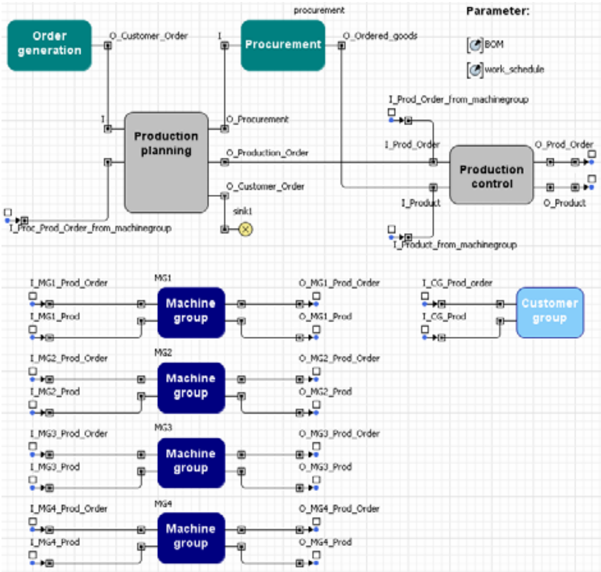

Figure 2: Simulation model in Anylogic 6.4

The Order generation module has for every good to finish a source which creates a customer order depending on a specific customer ordering rate as entity with the attributes due date, quantity to deliver and product type. All of the attributes have a specific variance depending on the predefined customer behavior. After creating the entity customer order the entity is sent to the production planning module.

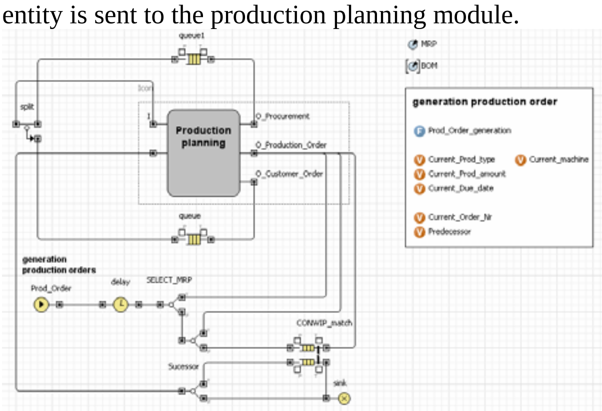

Figure 3: Production Planning module

In the Production planning module , as shown in Figure 3, the customer order is used for creating production orders. The function Prod_Order_generation controls the arriving entities customer order and checks the finished goods type. Each finished good has a parameter matrix working plan where the information about the routing of the components needed is also stored. The function gains the information about the routing for every finished goods type and creates a production order as an entity for every single machine group module. The entity production order contains the attributes of the machine group to be sent, according to the finished goods type and the production planning method.

In the “delay” Block (from Figure 3) every generated production order entity is kept until its release to the module Production Control, depending on the production planning method.

As explained above, the input for the Procurement module is the entity production order (for raw materials). In this module a Source Block creates the needed raw materials as an entity. When the production order arrives, a function checks the material type and product amount and creates the necessary raw materials. To simulate a stochastic procurement leadtime, a stochastic delay time can be integrated in the Procurement module.

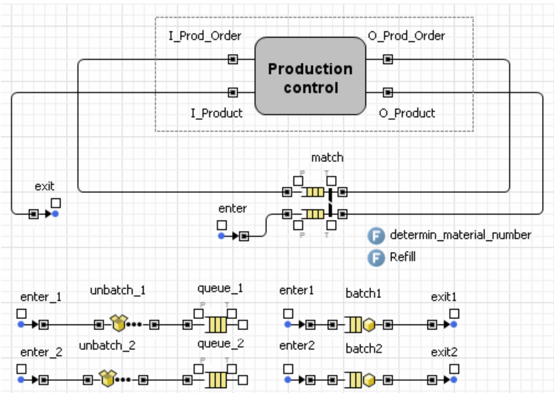

Figure 4: Production Control module

The Production Control module has two inputs: the production order entities for every single machine group from the Production Planning module and the material entities from the Procurement module or from the Machine Group modules. This module stores the material entities and checks the material availability for the released production order entities. The production order entities are stored in the upper queue of the “match” Block (see Figure 4) whereby the material availability check and the material release are triggered in the Function Block “Refill”. Each material entity has an own Queue Block within the Production Control module. Whenever a production order entity or a material entity arrives in this module, “Refill” checks the material availability. When material is available for a production order, the material entities get batched to the necessary production lot size and are sent to the second queue of “match”. In the “match” the materials and their respective production orders are released. After leaving the Production Control module, the material and production order entities are routed to the respective Machine Group module according to the work schedule.

In the Machine Group module the material entities (which are still batched to production lots) are sorted with a specific dispatching rule before they are released to the machines. Up to now, the EDD (earliest due date), FIFO (first in first out) and some other rules are implemented. Before the production of a lot starts, the batched material entity gets unbatched, then it is processed and after processing it is batched to the transportation lotsize again. Processing is interrupted by planned maintenance and unplanned machine failure. Scrap can also be simulated with a variable rate for each product. The material entities are sent back to the Production Control module immediately after a batching to transportation lots. The production order entities are sent to the Production Planning module after the last piece of a production lot is finished.

Additionally to the production orders for components, the Production Planning module creates one production order which triggers the release of the finished goods from the Production Control module to the Customer Group module.

The Analysis module consists of a set of variables and statistics which are continuously recorded.

4.2. Model application

The described simulation model can be applied to simulate a production with the production planning methods MRP and CONWIP. Since there are no necessary fixed routings between the machine groups, an easy and flexible application for different production structures is possible.

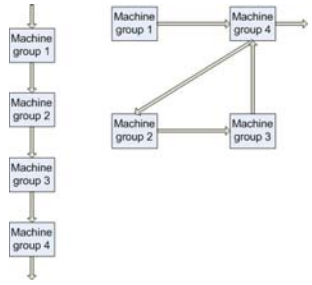

Figure 5: production structures

Both production structures shown in Figure 5 can be simulated without major changes in the model from Figure 2. Only the parameter matrix work schedule has to be adjusted.

5. LIMITATIONS OF THE MODEL

Based on the two proposed applications of the simulation model and on the implementation as described in sections 3 and 4, the following limitations occur.

The data included in the work schedule up to now does not include the variance of the processing time. The reason for this is, that the model is based on the assumption of exponential distributed processing times at this stage of development. In a further development, the model could be extended to other distributions.

No direct link between the simulation model and an ERP system of a manufacturing company is possible. Nevertheless, the work schedules and bill of material can be used in the model. Since no operational decision support is targeted with the model such a direct link is not necessary.

The simulation model is not generated automatically but there are still some manual tasks to perform to create a simulation model concerning a certain production system. However, the structure of the simulation model is programmed in such a flexible way that different production systems can be simulated with minor model development time.

6. CONCLUSION

This paper presents a flexible design of a simulation model for production system simulation. The model is based on discrete event simulation and different hierarchical levels of production planning and control can be tested. Parameter sets for the different production planning methods can be compared and optimized with the simulation model as well. The flexibility of the simulation model concerns mainly the structure of the simulated production system. For the production planning two different methods are currently available and dispatching rules can be applied for the production control.

The concept presented is based on the data usually available in ERP systems like work schedules and bills of material. The simulation model is not generated by applying fixed material flow paths, but any path described in the work schedule is possible.

Concerning the two kinds of application this model is developed for, the application in applied research on the behavior of different hierarchical production planning methods can be fulfilled. The flexible structure seems to enable the applicability of the model to applied research projects with manufacturing companies, but such projects have not yet been conducted.

This method of creating a flexible simulation model as presented in this paper could in further research be extended by additional modules and can for this reason be the basis for many different simulation studies concerning production logistics.

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