APPLICATION CASE STUDY OF A QUEUEING NETWORK SIMULATION TOOL FOR ANALYZING AND OPTIMIZING A MANUFACTURING SYSTEM

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Abstract

A case study, demonstrating the use of a simulation and optimization tool to model and improve overall performance of a manufacturing system, is presented.

A simulation tool had to be found to model the job-shop of a gear-wheel production and to support an engineering group optimizing this production system. The tool is embedded in an automized data-retrieving system. An additional optimizer helps finding optimal lotsizes. Both, simulation and optimization, are based on queueing network approaches.

1 Introduction

In order to improve overall performance of a complex production system a cooperation between a group of researchers at the University of Karlsruhe and engineers at the Merceds-Benz AG was established.

The task of the reseachers was to find an appropiate set of software-tools to support the day-to-day planning and optimization of logistic processes done by the engineering group.

2 System elements

First an appropiate simulation tool had to be selected, based on two criteria: data interfacing and simulation speed.

To conduct interviews with workers is an appropiate method to retrieve input data for the creation of models with low or medium complexity. In this case however this method is too much time consuming to be used repeatedly [3]. It therefore was required, that the simulation tool must provide a possibility to create an interface to the existing databases in the enterprise. The input data was then retrieved and automatically converted into simulation models.

The purpose of the simulation study was to create reports about the overall performance of the real system. The model is then used as a starting point for further optimizations, which are done manually or with the help of a software tool (see section 4).

The subsequently described manufacturing system is large and complex. Furthermore long term impacts of decisions based on the simulation have to be revealed. Thus a simulation tool had to be found, whose simulation speed is sufficient to generate long term measures for huge simulatioon models.

2.1 The production system

The complexity of the system is best described by the following list, containing the most important features of the manufacturing system:

products A total of 152 products is produced in the cost-centers of the job-shop. Each product has up to 10 production steps. The average number of steps to complete a product is

4.8. 35% of the products visit only a single production facility which usually is a highly specialized tool.

machines 66 individual machines are representing the production capacity of the job-shop. They can be divided into 6 major groups depending on their functionality:

1. lathing (20 machines)
2. drilling (2 machines)
3. milling (32 machines)
4. gear slotting (6 machines)
5. washing (1 machine)
6. others (5 machines)

Most of those are individual machines but some are grouped together. Within a machine group the machines process almost the same products. Machine groups can be divided into two types:

1. All machines of the group start processing the same lot.
2. Each lot is assigned to exactly one machine at the arrival of the first part of a lot.

release policy Due to the fact that the sojourn time does not allow just-in-time production, releases of lots are based on demand forecasts. The lotsize was calculated with the well-known lotsize formula of Andler (also known as Wilson/Harris formula).

queuing disciplines The scheduling is done by human operators. As a guideline, their decisions could be described in the following manner: Lots which need only a few steps to completion are using the closest-to-completion rule for scheduling.

Parts that have been started recently are scheduled by FIFO. Additionally some jobs are processed with higher priorities, due to finished goods shortages which are caused by unpredicted events, e.g. scrap or quality problems in later processing stages.

setup Setup times and costs are not negligible. At some machine groups products can be processed using identical tools. These products form a so called product family. Within a product family there is almost no additional setup time, however when there is a switch from one product family to another the setup time can even exceed the processing time of a single lot.

overlapping manufacturing To increase the utilization of the production facilities while having a short sojourn time for the first parts of a lot, the lots are produced in an overlapping manner, resulting in some parts still being processed in one step, while others are already processed on the subsequently used machine. This and the beforementioned item gives an additional emphasis on the importance of an adequate queueing discipline for the machine group. The queueing disciplines and the setup-times are the reason for splitting and rejoining of lots.

2.2 Selection of the Simulation Tool

Recently designed tools like the object-oriented simulator *simple++* have graphical interfaces helping modelers to create models rapidly. These simulators also have a large set of different modules for various simulation tasks. Nevertheless there are some problems in using these tools for cases like the one described here.

- The models usually are created manually which is good for small systems but not for large ones.
- Graphical interfaces and time consuming animation are important to sell a tool (and sometimes the model to management), but the modeler never watches an animation longer than 10 or 15 minutes. In our case we have stochastically distributed variables inducing simulation runs with more than 20 years of simulation time, in order to get confidential intervals of appropiate sizes!
- Usually these simulators are general purpose simulators. The software design of the mod-

ules is not as efficient as the design of modules of a specialized simulator.

- Report generation functions on an aggregated level are not integrated in most of the general purpose simulators. In order to create them the modeler himself has to fulfill this task.

Finally we decided to take the simulation tool *delphi* [1] which is a simulator specialized for manufacturing processes. It was developed to modell the manufacturing of integrated circuits on an aggregated level. The idea is to model the production system as a kind of queueing network [2]. The reasons why we have choosen this tool for modelling a manufacturing system different from the one it had been created for are:

- The description of the model is completly text based (ASCII) and readable by users
- The vocabulary for describing the model follows technical terms used in manufacturing environments
- The level of abstraction is adequate to simulate any job-based manufaturing
- Multi-product-types, priorities, scrap and rework can be modelled easily
- Routing information for each product-type is of arbitrary length (and complexity)
- Interruptions of machines and machine groups can be triggered by different types of events
- All parameters except for a few can be modelled as stochastic variables
- The output report includes test statistics and confidential intervalls for all products and machines together or for individual production steps
- The tool can simulate very complex manufacturing systems in reasonable time

Because of its close relationship to manufacturing processes it is not very hard to transform already existing data for manufacturing into input data of the simulation tool *delphi*.

2.3 Modelling techniques

To ensure good results of long and medium term decisions, some influences have to be regarded that are of stochastic origin or should be modelled as stochastic variables. For two reasons long term simulation should always take stochastical elements into account. If schedules are close to optimal, stochastic effects become more apparent. To ensure a robust behavior, the system parameters should be modelled as stochastic variables to cover a greater range of values than observed in the past.

In this case the major stochastic inputs are machine breakdowns and varying demand patterns.

Most of the characteristics of the production system were easy to model. Nevertheless two items were difficult to implement with sufficient precission.

Although the queueing disciplines could be modelled correctly in general, the workers sometimes operate regardless of general rules. This usually is a hint that some hidden variables are important for scheduling. These variables are often called soft-variables and it is extremely difficult to model them and, equally important, to get input data describing them. We could not solve this problem in general. The interpreter of the results of a simulation run has to take into account some fuzziness of the output reports. The input parameter "Queueing discipline" can be changed easily and that is the reason why this data is maintained manually.

Many simulation tools are able to use setup matrices to simulate setup times. In reality we only could find data about setups in the past which is only a subset of all possible setup combinations. We have modeled setups as random variables with known average time and its variance.

For some machines and machine groups the difference between performance measures of the real world and the output of the simulator were unacceptable. These differences could be reduced drastically by grouping products into product families. Finally the forecast problem for the setup time of unknown setup combinations had to be solved. By adding some files for the definition of product families maintained by simulation experts we were able to achieve acceptable results.

2.4 Data Retrieval

Because of the control mechanism of the real world job-shop production, there is only little knowledge about long or medium term impacts of decissions on the production system. The workers have a lot of information on an operational level, but there is only little knowledge about long-term performance measures like the variance or bandwidth of the sojourn time for individual products. This gap of information had to be be filled with a simulation study.

For some items the access to relevant data was a problem. The reason for this was not a restricted access to required data but their absence. On the operational level there is a different need for information compared to the requirements of a simulation study. Most of the opertional data is relevant only for a few days or hours (e.g. breakdown events and the time to repair them), and is therefore not always tracked and archived. Data quality is another problem for any automatic retrieving system. We tackled this problem with the help of the industry partner (see section Validation).

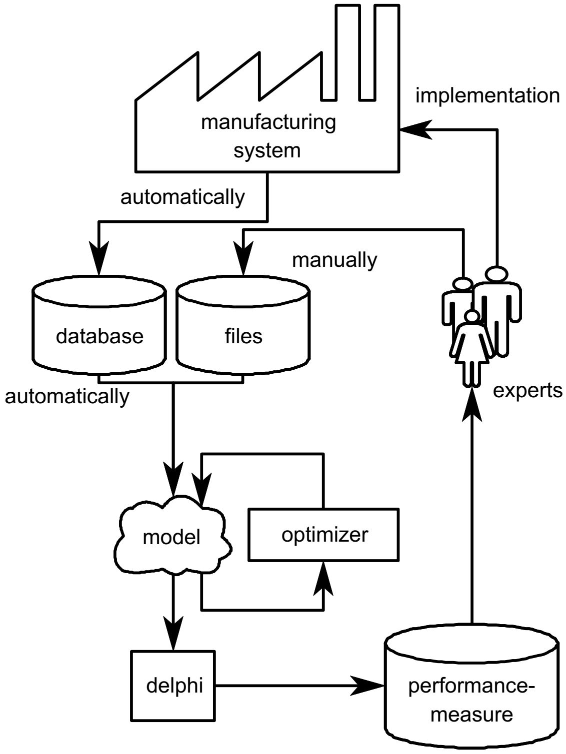
One goal of the system design was the integration of the simulation tool into the database environment of the enterprise. The automatical retrieval of 90% or 95% of the data from a host system could be acomplished while maintaining an acceptable level of complexity for the interface.

The existing data sources drive the modelling the system. In combination with the openess of the simulation tool for integration, this is a very important aspect to establish the continous use of the simulation tool as a day-to-day support for the planning group [3].

Here is the list of the input files that was used. This list is devided into a section of files including automatically retrieved data and files having entries the planer can add, delete or modify:

1. automatically retrieved:
   - Products
   - Routings
   - Setup information for each step of the routings
   - Up time of machines based on shifts
   - Breakdowns
2. manually maintained:
   - Queuing disciplines
   - Product families

The following graphic shows the flow of data and the complete environment of the simulation tool.



3 Validation

The pilot installation of the simulation model and the simulation tool was validated by a team of workers, planners, engineers and managers of the factory. The first attempt failed because problem of ensuring sufficient data quality was underestimated. After including an experienced engineer with knowledge about data quality of production data in the team, a second attempt passed the interrogation and validation step successfully.

In both cases overall measurements like average sojourn time of all products and total-setup time was examined. A few products were selected randomly and examined in detail.

4 Optimization

The analysis of the simulation result showed, that the sojourn time of the products coverd a wide range between one or two days and several weeks. As a reason for long sojourn times very heterogenous service times at the machines could be identified. They did result from the application of the lot-sizing formula of Andler, which only minimizes setup and stock-holding cost but does not take into account the work-in-process (WIP) inventory. Due to the complex manufacturing system, the WIP surpasses the finished-good inventory approximately by a factor of three.

In an effort to reduce sojourn times and work-in-process inventory, alternative methods to determine lot-sizes have been evaluated. A backdraw of Andler's formula is, that its application results in large coefficients of variation, which in turn lead to longer waiting times at the toolmachines. To effectively reduce the coefficients of variation, a queuing network model was used for estimating the total WIP. As shown by Suri[4] even with simple formulas good approximations for measures like total WIP could be computed.

This approach was used to develop an optimization model with the objective to reduce the total cost afflicted by lot-sizing decisions. These are setup costs, finished inventory related costs and WIP related costs. Setup costs and finished good related costs are approximated the same way it is done in the well known Andler formula, additionally the WIP was approximated by using an queuing network, consisting of $M|G|1$- and $M|G|s$-queuing systems.

Now with a steepest decent heuristic, the lot-sizes of the products were varyied in order to reduce the total cost. For the 152 products involved this task requires the repeated computation of the WIP which is only feasible with a simple queuing network model.

Due to the fact, that the queuing network was a very much simplified model of the real system, the newly computed lot-sizes are fed back to the simulation-model in order to verify the results, i.e. to assure that an improvement of the total cost was achieved. In this special case, cost reductions amounted to about 15% with average sojourn times reduced by approximately 20%. These results are of course not optimal in the mathematical sense, but helped to improve performance with simple means.

This approach is distinct from LP-based optimizations, because not actual schedules are computed, but instead a set of lot-sizing parameters are generated, that could be used to harmonize lot-size in manufacturing and at the same time being applied in the purchase process. The results of the optimization process are not very sensible to changing parameters, as for instance growing demand for a specific product, but with repeated application (i.e. monthly) directs the manufacturing process to a appropriate level of operation without inducing additional nervousness [1].

References

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