COMPARISON OF A MICROSCOPIC DISCRETE-EVENT AND A MESOSCOPIC DISCRETE-RATE SIMULATION MODEL FOR PLANNING A PRODUCTION LINE

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ABSTRACT
This paper compares a microscopic discrete-event simulation model and a mesoscopic discrete-rate simulation model to support the planning of a production line in the automotive industry in terms of simulation results and modeling and simulation effort. Mesoscopic discrete-rate models represent logistics flow processes on an aggregated level through piecewise constant flow rates instead of modeling individual flow objects like in microscopic discrete-event models. This leads to a fast model creation and computation.

Keywords: Mesoscopic simulation models, discrete-rate simulation, discrete-event simulation, production line planning

1. INTRODUCTION
Practitioners often prefer to use microscopic discrete-event simulation models because most production and logistics processes are of discrete nature (Scholz-Reiter et al. 2007) and because discrete-event models allow for a very high level of detail. Discrete-event models are state of the art in production planning and logistics planning in the automotive industry (Huber and Wenzel 2011). The term discrete-event modeling stands “for the modeling approach based on the concept of entities, resources and block charts describing entity flow and resource sharing” (Borshchev and Filippov 2004). Since discrete-event models are able to represent workstations, technical resources, carriers and units of goods as individual objects, they can depict production and logistics systems with a high level of detail and are also referred to as microscopic models (Borshchev and Filippov 2004, Pierreval et al. 2007). Models in this class can be very complicated and slow and their creation and implementation can be time and labor consuming (Pierreval et al. 2007; Law and Kelton 2007; Kosturiak and Gregor 1995; Huber and Dangelmaier 2009; Scholz-Reiter et al. 2008).
Mesoscopic simulation models based on the discrete-rate simulation approach have the potential for reducing modeling and computation efforts and allow for sufficient accuracy for many problems in production and logistics planning.
In cooperation with the MAN Truck & Bus AG at the Salzgitter plant, a microscopic discrete-event simulation model with Tecnomatix Plant Simulation was developed to compare different planning variants for the production line of truck parts. A mesoscopic simulation model with ExtendSim based on the discrete-rate simulation paradigm was implemented for the comparison.

2. MESOSCOPIC SIMULATION MODELS
The mesoscopic simulation approach proposed by the authors of this paper is situated between continuous and discrete-event approaches in terms of level of modeling detail and required modeling and simulation effort (Reggelin 2011, Reggelin and Tolujew 2011). It supports quick and effective execution of analysis and planning tasks related to manufacturing and logistics networks. The principles of mesoscopic simulation models to describe processes in logistics and production networks have been derived from and have been applied to the actual development of several mesoscopic models (Henning et al. 2016, Hennies et al. 2014; Hennies et al. 2012; Tolujew et al. 2010; Schenk et al. 2009; Savrasov and Tolujew 2008; Tolujew and Alcala 2004).
Mesoscopic models represent flow processes in production and logistics systems through piecewise constant flow rates. This assumption is valid since logistics flows do not change continuously over time. The control of resources is not carried out continuously but only at certain points of time like changes of shifts, falling below or exceeding inventory thresholds. The resulting linearity of the cumulative flows facilitates event scheduling and the use of mathematical formulas for recalculating the system‘s state variables at every simulation time step.
The simulation time step is variable and the step size depends on the occurrence of scheduled events. This leads to a high computational performance. The principles of event-based computation of linear continuous processes are employed in the discrete-rate simulation paradigm implemented in the simulation software ExtendSim (Krahl 2009, Damiron and Nastasi 2008) and the hybrid simulation approach described by Kouikoglou and Phillis (2001).

3. PRODUCTION LINE

The preferred planning variant of the production line is shown in figure 1. The key figures for evaluating the planning variant are:

- Throughput per hour [p/h]
- Cycle time [s]
- Workload [%]
- Technical degree of utilization N_T [%]

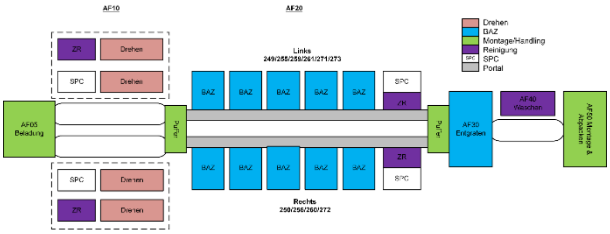

Figure 1: Preferred Planning Variant of the Production Line

The production process consists of the following six work sequences (WS):

- WS 05 Loading blank workpiece
- WS 10 Turning + cleaning
- WS 20 Milling + cleaning
- WS 30 Deburring
- WS 40 Washing
- WS 50 Assembly & discard

The production line consists of two strings (see figure 1), which produce different variants and alignments of a steering knuckle. These strings are brought together by one work sequence and are linked by fully automated facilities. Buffers are arranged between every work sequence. The production line operates in three shifts (22.5 hours per day).

4. MICROSCOPIC SIMULATION MODEL

The microscopic simulation model (see figure 2) was created with Tecnomatix Plant Simulation (V12.4) in conjunction with the VDA building blocks (V12.0-06.030). It depicts the process steps for the production of steering knuckles for commercial vehicles. It represents the flow of forged near net shape blank work pieces in the system until the discarding of finished parts.
The material flow is directed by the work plan feature of the VDA objects. The model offers the opportunity to manage different sets of settings like lot size, number of work piece carriers, processing times, breakdowns, tool change times and set up times.

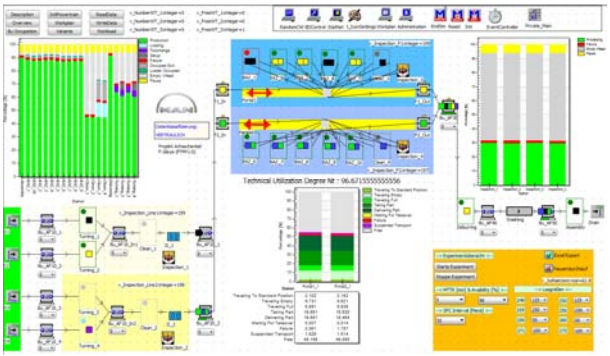

Figure 2: Microscopic Simulation Model in Plant Simulation

5. MESOSCOPIC SIMULATION MODEL

The mesoscopic model (see figure 3) is derived from the microscopic simulation model. For the implementation ExtendSim (V9.1) was used. The model uses objects from the rate (blue), item (green) and value (yellow) library. The item and value objects are only used to control the flow through the rate objects which represent the material flow. The value blocks are also needed for the evaluation of the simulation results.
The mesoscopic model consists of two strings of material flow which get reunited at one work sequence through a merge block. The model uses aggregated times for the different variants and not a work plan.
A discrete-rate model uses flow rates. The unit can be set freely in the model. One result is the throughput per hour. It is advisable to specify the flow unit in parts per hour (p/h). In this way, a target number can be determined directly. The concept of the discrete-rate model is conceivable in various levels of detail (Schenk, et al., 2008).

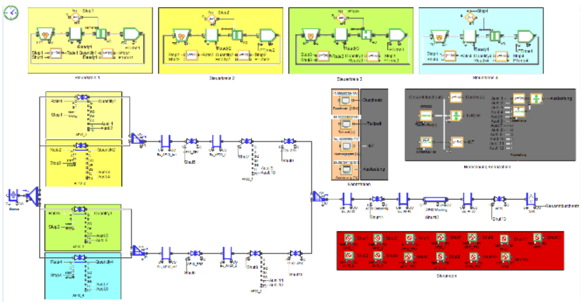

Figure 1: Mesoscopic Simulation Model in ExtendSim

In the model, the flow from the source to the sink is calculated by a linear program (LP) at each event (Krahl, 2009). The source (WS 05) can be represented as a tank. In the mesoscopic view, individual machines can be represented by a valve. A valve has a maximum and an effective rate. The effective rate is calculated from the inflow and outflow of a valve. The tool change, set-up procedures and breakdowns reduce the effective productive time of the individual stations. The results of the simulation correlate with the existence of these influences in the model. Work piece carriers as well as measuring stations are not considered in the mesoscopic simulation. The assumption is made that sufficient work piece carriers are available in this configuration. The measuring stations can be neglected. They merely increase the mean throughput time because the process takes place only every fifty work pieces. The influence on the results is classified as low and is neglected.

Each machine is shown as a valve. The maximum rate of the valves corresponds to the average machining time from the work plan in the unit p/h for the respective lot size. The WS 20 is aggregated as a valve. The rate is calculated from the average machining time. The remaining work sequences are implemented as valves. Between the stations are buffers with the capacities from 5 to 10 pieces (like provided in the base model). A control circle of item elements is designed to model the tool changes and setup operations. Item elements are discrete-event blocks from the item library of ExtendSim, which can be used to control the flow in the mesoscopic model (figure 4). The control algorithm composes the delay time (PTime) from the manufactured quantity of the valve (Quantity). In a second control, the rate of the valve is controlled as a function of breakdowns (Shut_n), set-up and tool changing processes.

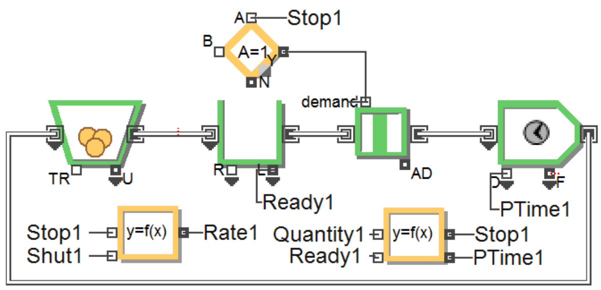

Figure 4: Control Circle

Distribution parameters of the Erlang distribution (MTTR) and the exponential distribution (MTBF) are prepared for the breakdowns. These distributions correspond to the selected distributions in the microscopic discrete-event model.

The breakdowns can be calculated in a shutdown block. The signals required to determine the key figures are processed from the information flow. The sink provides the current rate as well as the total throughput. Equities and Math blocks can be used to compile the key figures. The implementation of the conception requires a tank as a source. The source (WS 05) is initialized with infinite initial content. The flow from the source is divided into four individual flows with a diverge block using the diverge mode "neutral" and fed into the valves which represent WS 10. The initial rate is set to the calculated rate in p/h. Between the work sequences, buffers are represented by a tank. The flows from the WS 10 are directed into a flow through the merge block. The flow runs in two strands into the valve for WS 20. The flows from the valves (WS 20) are merged into one flow through a merge block. The flow is routed through the remaining work sequences (WS 30 to WS 40) and destroyed in the sink (WS 50).

For the breakdowns, the output signals of the shutdown blocks are connected to the "maximum rate" connector of the valves. The key figures cycle time, throughput per hour and the technical degree of utilization are calculated from the total throughput, the time per run and the goal cycle time. The rate can be distinguished between = 0, > 0, limited or not limited. Overlapping, the value-adding time is assumed to be the time in which the rate is above 0. The signals from the "time-limiting" and "not time-limiting" connectors are processed through the equation block.

6. RESULTS

Due to the stochastic proportions, more than one replication is required. Using the confidence interval method, at least two replications are necessary to maintain a statistical confidence of at least 95 %. The average value with two replications does not differ greatly in comparison to three or more replications. If we perform more than two replications we only attain more effort. The simulation has a running time of 450 hours (20 days with 22.5 hours each day) like the microscopic model. Table 1 shows the full experiment set-up. The set-up is equivalent to the microscopic model.

Table 1: Experiment Set-up

Start time [h]	0
End time [h]	450
Run Time [h]	450
Replications	2

Table 2 and table 3 compare the results of both models.

Table 2: Simulation Results

	Discrete-event		Discrete-rate	
	Average	Standard deviation	Average	Standard deviation
Through-put [P/h]	42,53	0,14	41,10	0,13
Cycle time [s]	84,65	0,28	87,59	0,29
N_T [%]	97,81	0,32	94,64	0,31
Work-load [%]	76,39	0,27	85,52	0,28

Table 3: Deviation

	Through-put [p/h]	Cycle time [s]	Technical degree of utilization N_T [%]	Work-load [%]
Deviation	-1,43	+2,94	-3,17	+9,13
Deviation [%]	-3,35	+3,47	-3,24	+ 11,95

A survey of Schauf (2016) asked the production planners which margin of error they are willing to accept, see figure 5. The willingness to accept errors decreases with an increasing duration of a simulation project. Production planners are ready to accept errors of 5 % for simulation project which take less than a week. In simulation projects with a duration of more than six months they are willing to accept an error of about 1.5 %.

These results could mean that production planners would accept to work with models which have not such a high level of detail but are capable of providing simulation results faster.

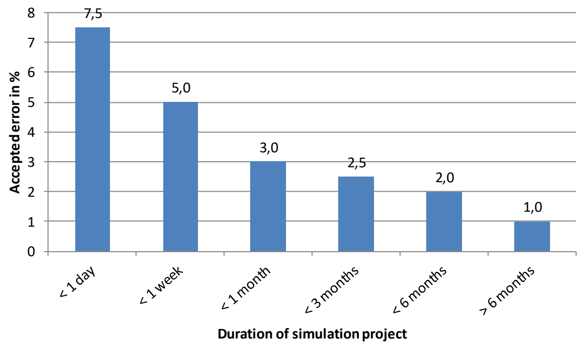

Figure 5: Accepted Errors by Production Planners in a Simulation Project (Schauf 2016)

There are different aspects to compare. A general statement regarding the total expenditure does not allow any statement about individual aspects. The following aspects were identified regarding modeling effort:

- Conception
- Data collection and processing
- Implementation
- Experiments

From the user's point of view, the assessment of the effort is subjective. Depending on the aspect, a rough classification of the effort can be made. Table 4 shows the assessment of the aspects for the DRS approach. This rating is in comparison to the DES approach.

Table 4: Effort for the DRS Approach

Phase	DRS
Conception	+
Data collection and processing	+
Implementation	+
Experiments	++

Scale: ++ very beneficial; + advantageous; 0 neutral; - disadvantageous; -- very disadvantageous

In the design phase the effort is reduced. Components of the system can be idealized, as well as times and events over the runtime can be considered as mean values. This has an impact on the data collection effort. Due to less required data and a mean of influencing data, advantages can be achieved at this point. In the implementation, the mesoscopic model has fewer required blocks, but the function and interaction of the blocks are limited. The experiments can be performed with less effort due to the greatly shortened run time of a replication (1 min runtime of the discrete rate model and 5 min runtime of the discrete-event model).

After the effort for the simulation approaches, the accuracy of the results must be assessed. Table 3 shows the deviations of the models. An average deviation of 5.5 % occurred across all results. With acceptance of a safety of 95 %, the suitability of the mesoscopic approach can be confirmed for the throughput, the cycle time and the technical degree of utilization. The deviation of the workload is clearly above the acceptance threshold with 11.95 %.

7. CONCLUSION

The results of the simulation experiments show that mesoscopic simulation models based on the discrete-rate simulation paradigm are capable to support planning tasks in production and logistics systems. For several key figures, their results differ only slightly from the results of a discrete-event simulation model. The results deviation stays within a margin that is accepted by production planners.

Mesoscopic simulation models can save enormous amounts of modeling and computational time compared to discrete-event models and thus comply with the requirements of production planners to receive simulation results within a short period of time.

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