MESOSCOPIC SIMULATION MODELS FOR THE AUTOMOTIVE INDUSTRY

Andreas Hennig[(a)], Tobias Reggelin[(b)], Daniel Wolff[(c)]

[(a)] Otto von Guericke University Magdeburg
[(b)] Otto von Guericke University Magdeburg, Fraunhofer Institute for Factory Operation and Automation IFF Magdeburg
[(c)] INPRO Innovationsgesellschaft für fortgeschrittene Produktionssysteme in der Fahrzeugindustrie mbH Berlin

[(a)]andreas.hennig@st.ovgu.de, [(b)] Tobias.Reggelin@iff.fraunhofer.de , [(c)] daniel.wolff@inpro.de

ABSTRACT
Simulation models allow multiple options to analyse and improve production and logistic processes. The mesoscopic modelling approach is a relatively new concept which combines the advantages of the widespread continuous and discrete event simulation while minimizing the disadvantages. The paper verifies the feasibility of the mesoscopic concept in context of topics concerning the automotive industry. Therefore the approach is used to model a manufacturing process of components with the focus on resource efficiency. A discrete event model of the production line is used to validate and verify the mesoscopic model. Founded on a validated and verified mesoscopic model different scenarios are presented in order to optimize the aspect of resource efficiency. Based on the findings of the simulation study recommendations for action to improve the mesoscopic approach are provided. In addition, potential problems from the automotive sector are presented which can be examined in the future using the mesoscopic approach.

Keywords: mesoscopic simulation, resource efficiency, compressed air, production

1. INTRODUCTION

By using simulation models multiple tasks in production and logistics areas can be depicted and optimized. Due to an ongoing increase in the complexity of many production systems the relevance of simulation will most likely increase as well. There are two main modelling approaches to investigate these topics: System Dynamics (SD) and Discrete Event Simulation (DES). In most of the cases DES is used as modelling approach for production logistic aspects. But both mentioned approaches have some disadvantages which will be described in the following. To reduce these disadvantages the mesoscopic approach was developed.
So in this work, possibilities of the relatively new mesoscopic simulation approach for topics in the field of the automotive industry are presented and examined using a practical example concerning aspects of resource efficiency.

2. DESCRIPTION OF SIMULATION APPROACHES

2.1. System Dynamics

The System Dynamics approach was invented in the 1950s by Jay W. Forrester at the Massachusetts Institute of Technology (MIT) and is a continuous modelling approach (Borshchev and Filippov 2004). It is characterised by terms of stocks, flows between these stocks and information about the values of the flows. So Systems Dynamic models use an aggregated view and abstract from single events. This leads to the most significant downside of this approach: the results of the simulation cannot be very exact. But on the other hand it reduces the time for modelling and simulating. Some topical papers can be found which use System Dynamics in order to simulate production and logistic processes. (Herrera et al. 2014) use a System Dynamics model to describe the introduction of RFID technology and the associated impact on the supply chain processes of groceries. (Aschauer 2013) describes the application of a System Dynamics model for the development of a sustainable transport concept to reduce pollution.

2.2. Discrete Event Simulation

In contrast the widely spread Discrete Event Simulation approach is characterized by the concept of entities, resources and block charts which describe the entity flow and resource sharing (Borshchev and Filippov 2004). Every single unit of the system can be represented. These aspects enable the user to adjust the level of detail of the system at will. But especially for complex systems this results in high efforts for modelling the system and in long lasting simulation runs (Law and Kelton 2007). As stated above there are many examples of simulation studies using DES. For example (Witthaus et al. 2014) take a discrete event simulation as a planning assistance for a multiple stage distribution network. (Klaas and Klibi 2015) combine the discrete event simulation with mathematical optimization to strive for a holistic supply chain optimization.

2.3. Mesoscopic Simulation

The findings of this work are based on the mesoscopic approach which was developed for logistical purposes at the Otto-von-Guericke-University Magdeburg, Germany in cooperation with the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg, Germany and is based on the Discrete Rate Simulation approach which is described in (Krahl 2009).

As mentioned before one of the aims of the mesoscopic simulation approach is to reduce the disadvantages of the Systems Dynamics and the Discrete Event approaches. So the approach should provide more exact results than System Dynamics models and decrease the time for modelling and simulation in comparison to discrete event models at the same time.

In order to reach the aims the mesoscopic approach uses aspects of both aforementioned approaches. This is achieved by using a medium level of detail which is sufficient for most tasks. Unlike in discrete event models not every single unit is depicted. Instead the approach uses flow rates like Systems Dynamics models do. But here they are only piecewise constant. So a new calculation is only necessary when the rate changes, e.g. after reaching a predefined limit and can be predicted. This aspect leads to an immense decrease in calculations during a simulation run. In addition to this the mesoscopic approach offers the possibility to trigger impulses with includes the aspects of discrete event models (Reggelin 2011).

3. DESCRIPTION OF THE SIMULATION STUDY

3.1. Classification and Motivation

As mentioned in the introduction the mesoscopic approach was investigated with focus on topics in the automotive industry. Therefore at first a representation of typical planning, analysis and design tasks in the automotive field was given. Here a subdivision into the following four categories can be made:

- business simulation,
- supply simulation,
- supply chain simulation and
- traffic flow simulation.

For detailed information on these categories see (Müller-Sommer and Strassburger 2009).

To illustrate the practical relevance of the investigated topic in the simulation study the reasons for the simulative consideration of resource use strategies were worked out. Here, both economic and ecological aspects are taken into account. Due to a decreasing amount of natural raw materials companies are confronted with increasing purchase prices. In order to improve their balance sheets companies are willing to optimize their usage of raw materials. On the other hand the user awareness of ecological aspects grew dramatically over the last years so companies can get a unique selling proposition through an environmentally friendly production system.

Because the practical example specifically relates to the compressed air consumption of a component manufacturing area of an automobile manufacturer, various measures were introduced additionally which can be used to optimize a compressed air system. These measures can be divided into the following categories:

- generation,
- processing,
- allocation and
- application.

The most significant reductions can be achieved by adjusting the dimensioning of the installed generators in combination with a superordinate control (EnEffAH, 2012).

3.2. Initial Situation and Objective Target

The aim of the simulation study was to verify whether the mesoscopic approach is suitable to analyse and optimize the resource efficiency of a component production of an automobile manufacturer (see Figure 1). If the applicability of the mesoscopic approach can be confirmed the optimisation of the usage of compressed air was another goal. Usually all analyses in this branch are performed using discrete event simulation. Therefore the production was already modelled as a discrete event model in the simulation tool Plant Simulation. Due to the importance and the increasing awareness of aspects of resource efficiency it can be assumed that proof of use will lead to many further application possibilities in this area.

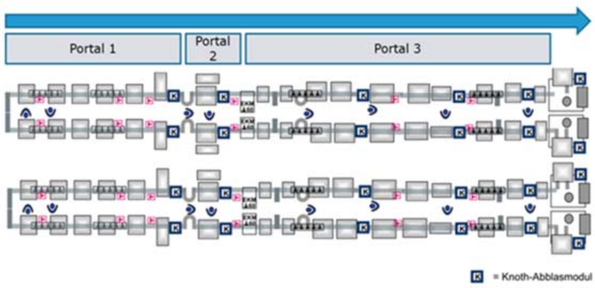

Figure 1: Schematic Overview of the Production

3.3. Procedure

To test the applicability of the mesoscopic simulation approach a simulation study on the basis of "VDI guideline 3633" in the simulation tool ExtendSim has been performed. So first of all the system was analysed and all relevant data for the mesoscopic approach from the DES model needed to be extracted and edited. The production process corresponds to a highly automated production line with 20 process steps. Six of these steps with so called dry cleaners are particularly significant since they use compressed air. Moreover they are only few variants produced which meets the requirements of the mesoscopic approach (Reggelin 2011).

As mentioned before the investigated system was already modelled in Plant Simulation. That is why the relevant data can be extracted from the existing model. Due the fact that the DES model is frequently used and under maintenance the timeliness of data is provided. Nevertheless the extracted data needed to be checked for plausibility to avoid transmission errors.
After collecting the data the actual systems needed to be transformed into a conceptual model. As shown in Figure 2 the original concept was to model the system in a low level of detail. The production line was divided into four black boxes which were defined by the used means of transportation. Based on this concept the system was modelled in ExtendSim (see Figure 3) and the first test runs were executed.

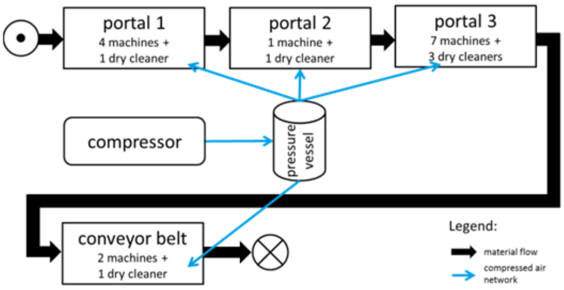

Figure 2: Abstract Conceptual Model

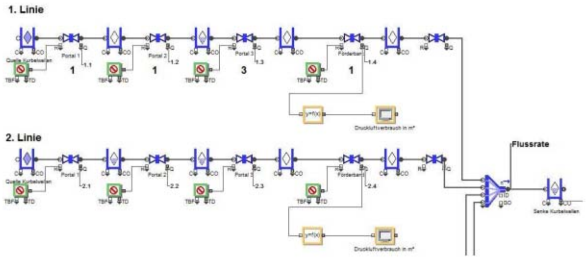

Figure 3: Detail of Abstract Modelling Approach

Within the test runs it became obvious that this approach would lead to a deviation in the throughput per production line of about 8.5 % compared to the DES model which was not satisfying. In order to reduce the deviation the level of detail of the mesoscopic model was increased (see Figure 4).

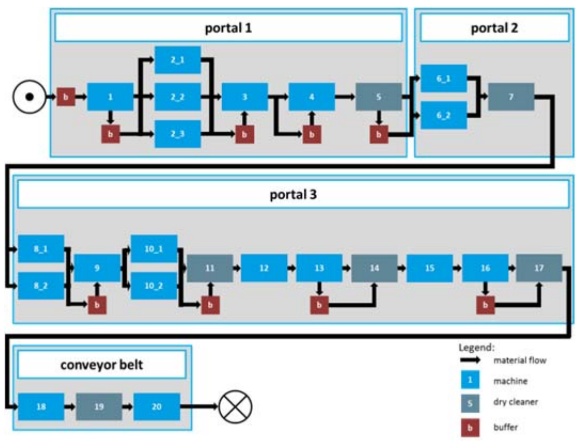

Figure 4: Detailed Conceptual Model

The most significant changes are that the black boxes were modelled in detail and buffers were implemented separately. The investigation showed that the implemented buffers led to an enormous decrease in the deviation.

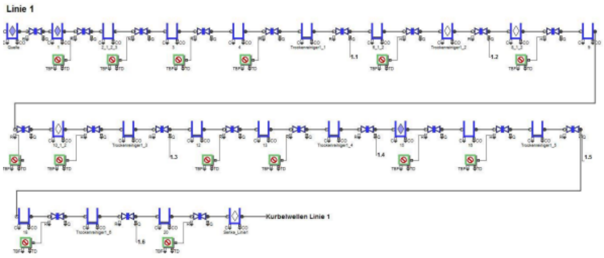

Figure 5: Detail of Final Model

The final concept (see Figure 5) of the mesoscopic model was validated and verified based on a discrete event model which illustrates the same production area. For this purpose, among others, the throughput per hour per production line, the overall compressed air and energy consumption as well as the operation of the compressor were compared (see Table 1). It can be seen that using the detailed mesoscopic approach led to almost the same results as in the DES model. So it can be stated that the detailed mesoscopic model was applicable for the investigated topic.

Table 1: Comparison of Verification and Validation Criteria

	DES Model (100 %)	Detailed Mesoscopic Model	Deviation [%]
Throughput per Line and Hour	42,3	42,0	-0,71
Compressed Air Consumption [m³]	50.813,26	50.370,20	-0,87
Energy Consumption [kWh]	1.785,37	1.774,98	-0,58
Duty Cycle [min]	30	29	-3,33
Interrupting time [min]	56	57	+1,79

After proofing the applicability of the mesoscopic approach the optimization of the energy demand caused by the compressed air generation and distribution was examined. In several scenarios variations of the performance specification of the compressor(s) used were studied, which should lead to a reduction of the required energy demand for the generation of compressed air. Figure 6 shows a detail of the pressure curve of a scenario in which a second compressor was installed. The red curve depicts the pressure curve in the initial situation whereas the blue curve represents the pressure curve in the scenario.

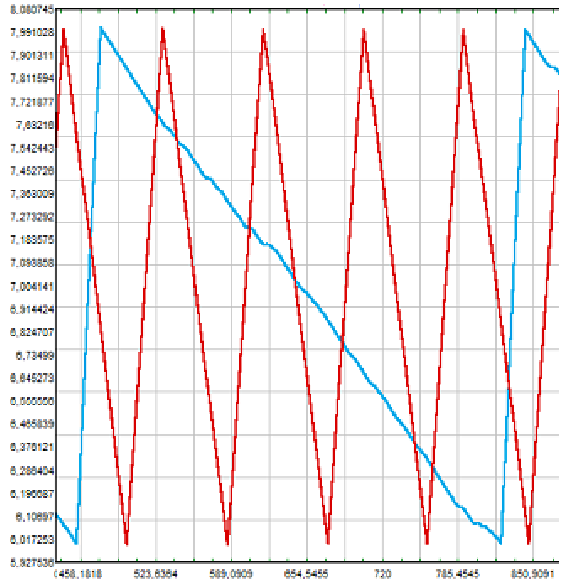

Figure 6: Detail Pressure Curve

Based on information obtained during the simulation study and by using expert knowledge of the modeller of the discrete event model, a comparison of the used simulation tools was performed. The aim of this comparison was the derivation of improvement measures for the further development of an independent mesoscopic simulator.

4. RESULTS

As a result of the work it can be stated that the mesoscopic approach is well suited for handling the analysed subject among the underlying constraints and assumptions. After initially deviations in the hourly throughput per production line of about 8.5 % were recorded, this deviation was reduced to about 0.7 % by adapting the way of modelling (see Table 2). The adapted model in this case has a significantly lowered level of abstraction compared to the originally pursued modelling approach. Based on the detailed modelling the described scenarios were investigated mesoscopicly. These differ in the number and the performance of the compressors used and will contribute to improve efficiency in the production of compressed air through an optimized dimensioning.

Table 2: Comparison of the Throughputs of different modelling approaches

	DES Model	Abstract Mesoscopic Model	Detailed Mesoscopic Model
Throughput per Line and Hour	42,3	38,7	42,0

The consideration of the scenarios leads to the realization that for the investigated manufacturing area a compressor with a significantly reduced performance should be used in comparison to the initial situation. Through the use of the compressor with the optimized performance, a saving of approximately 7.6% with respect to the compressed air related energy consumption compared to the initial situation could be realized (see Figure 7). Since the values obtained for the performance of the compressor are only slightly higher than the actual consumption of the production area, changes in the complete control logic of the pneumatic system could be considered. In the investigations of this work a discontinuous full load intermittent control of the compressor was implemented. On the basis of the results of the scenarios the control logic could be switched to a continuous, speed-controlled operation of the compressor. In order to change the control logic further investigations of the compressor and other components of the pneumatic system would be necessary.

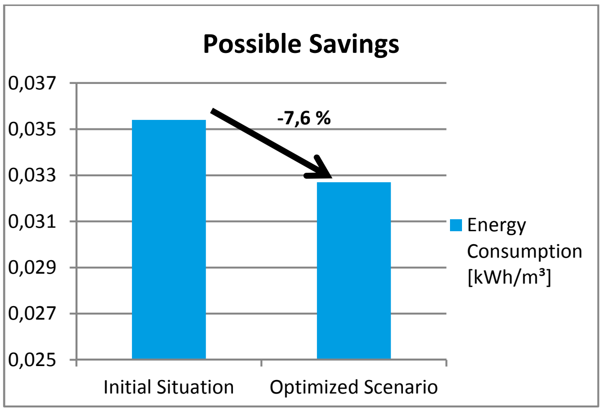

Figure 7: Possible Energy Consumption Savings

Furthermore a crucial requirement which was expressed in the development of mesoscopic simulation approach is confirmed. As required the mesoscopic approach leads to a significantly reduced simulation time for the examined subject compared to the discrete event approach. In actual applications, the mesoscopic model takes only a few seconds to perform a simulation run of the length of one day. For a run of the same observation period, the discrete event model takes about 12 minutes. With the expansion of the simulation period, the differences will be even much more pronounced in all probability. The mesoscopic approach demonstrates its better usability for very short-term, operational issues. To support this advantage even further a high user-friendliness should be ensured through appropriate input forms, in order to make quick and easy adjustments of model parameters.
In addition to applications in operations other potential application areas for the mesoscopic approach were identified in the field of automobile industry. To promote the development and dissemination of the approach, it is advisable to gain practice partners from this sector to model other automotive topics mesoscopicly.

Therefore implementing further mesoscopic models in the automotive industry with partners should be the next step. Particular emphasis may be placed on the consideration of supply chain networks. These networks correspond very well to the principle of the mesoscopic approach through their abstract nature, for example by using average rates for transport times or the use of handling time packages. Furthermore forwarders may also be interesting partners for such studies who want to deal with the optimization of their regional forwarding network. Another possible area directly from the automotive sector to support the development of the mesoscopic approach can be found in the simulative consideration of trades such as the press shop that are characterized by a lot size production or a small number of variants.
In the course of these investigations, the independent mesoscopic simulator should be further developed and adapted to the requirements of the customer. Another interesting aspect arises in the question whether already existing discrete event models can be converted automatically into mesoscopic models to achieve an even higher acceptance by the users. Since many production areas in the automotive industry are already present as discrete event models, another time advantage could be generated through this automated conversion of models, as an entirely new model could be omitted.

5. CONCLUSION

In summary it can be said that the mesoscopic simulation approach offers much potential for further investigation of practically relevant applications in the automotive sector but also for other industries. More interesting tasks and collaborations may arise that can proof the efficiency of the approach.

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AUTHORS BIOGRAPHY

Andreas Hennig, M.Sc. studied industrial engineering and management with the focus Supply Chain Management and Network and Sustainable Logistics at Otto von Guericke University Magdeburg, Germany. He received his master's degree in 2016.

Dr.-Ing. Tobias Reggelin is a member of the faculty of the Institute of Logistics and Material Handling Systems at Otto von Guericke University Magdeburg and a Research Manager at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg, Germany. Tobias Reggelin studied industrial engineering and management at Otto von Guericke University Magdeburg and Rose-Hulman Institute of Technology in the USA.

Dipl.-Ing. Daniel Wolff is the head of the division Production Systems and Information Processes at INPRO GmbH. He studied mechanical engineering with the focus factory planning and operation at TU Chemnitz, Germany.