A SIMULATION MODEL TO EVALUATE THE LAUNDRY ORDER SCHEDULING AND EFFECT OF DISRUPTIVE EVENTS IN INDUSTRIAL LAUNDRIES

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ABSTRACT

Flexibility with respect to response to the customer requests as well as an optimized resource consumption and associated cost savings hold a potential to increase the competitiveness of laundries. Consequently, it is essential for them to operate quick, reliable and cost effective. Simulation analyses are a suitable method to illustrate laundries processes, to evaluate different laundry order scheduling strategies, to identify the effects of errors in the operations and to improve the sequences within commercial industrial laundries. In this paper we describe two developed discrete-event simulation models for characterizing logistical processes in laundries. The results showed an increased lead time by using a random arrangement of the laundry order. The FCFS (First Come First Serve) as well as the EDD rule (Earliest Due Date) are qualified to schedule and optimize the order. Furthermore, a simulation study has shown that urgent jobs have a most influence on the lead time of the textiles.

Keywords: laundry, microscopic simulation model, laundry order scheduling, disruptive events

1. INTRODUCTION AND MOTIVATION

Industrial laundries are production systems in which manual and automatic processes are combined. Due to an increasing competition and a strong customer orientation, the requirements for laundries have increased in recent years. Achieving these requirements, like low prices, fulfilment of individual customer wishes or the customer satisfaction by quick, flexible and on time cleaning as well as delivering, is essential to ensure an economic success. In contrast to manufacturing companies, laundry product are not produced by existing resources but pass through a wash cycle within an industrial laundry. Based on the increased variety in customer and product structures, the laundries are confronted with complex and stochastic processes and handled with a varied number of articles. In order to fulfill the customer orders on time, the sequence order has to be carefully planned. Thus, information about the type and number of articles in the incoming goods are of major relevance. However, there is a limited predictability and transparency of orders and processes in the laundry logistics.

Due to this lack of information regarding the composition and amount of orders, the scheduling of the laundry order is based on uncertain data and is determined by the use of personnel's empirical knowledge.

Scheduling of jobs in industrial applications has been extensively researched and thereby a variety of schedule concepts are described in previous works (Vinod and Sridharan 2010, Ramasesh 1990, Blackstone et al. 1982, Maccarthy and Liu 1993, Graham et al. 1979). However, these solutions mainly target applications in general manufacturing sectors or for example the automotive industry and therefore, are not aligned with the predominant targets and restrictions in industrial laundries. Cheng et al. (2015) described an algorithm of laundry lining procedure scheduling based on RFID.

Despite the automation of processes in washing, drying, mangling, folding and stacking, the interfaces between the processes are still little automated and are usually carried out manually. These interfaces between the automated processes can cause highly variable handling times. Even short disruptions or a complete failure of machines often occur due to overloading, unpredictable defects or mishandling. Since the laundry is a service provider, there are often additional special orders of customers, which are then introduced as express orders in the processes. These urgent orders cause delays and are difficult to predict. On the current status, a suitable and extensive maintenance as well as a fault management is still missing. Consequently, there is an absence of consideration of random errors and their effects on the processes in the work of laundries. However, the mathematical optimization of scheduling does not represent this dynamic and stochastic behavior with the effects of disruptive events. Therefore, the previously determined optimum wash sequence must be tested and assessed by a material flow simulation on robustness against disorders.

In order to evaluate the scheduling of laundry sequences and the influence of stochastically occurring errors, simulation analyses need to be determined. The implementation of such simulation studies were shown to be a suitable method to characterize conventional production systems (Kuhn 1998, Dangelmaier et al. 2013, Verein Deutscher Ingenieure 2000). However, the applications for the industrial sector of laundries are currently insufficient described.

2. CONCEPT OF THE MODELS

A commercial industrial laundry facility consists of several regions and laundry circulation flows. The customer provides the input for the laundry in form of dirty items. Within the laundry, the items are sorted and the order of handling steps in a particular sequence is defined. Fig. 1 shows an exemplary overview of the process structure and possible process routes the item pass through in an industrial laundry. Each step in the process contains numerous case processing or machining steps. For instance the drying area consists of different drying machines, shafts or transport/unloading elevators. A detailed structure and values of processing times of each operation step have been adopted from a reference laundry.
The order and selection of the processing steps and their individual processing time varies for each article, taking into consideration the type of laundry, textile type (e.g. mangling or terry cloth), the consumer (hotel or hospital), type of economy (own or leasing textiles) and type of customer (normal or urgent customer) (Brandau et al. 2015).

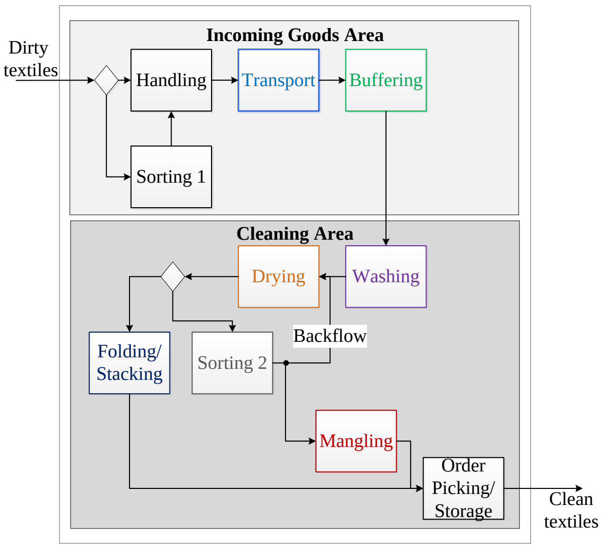

Figure 1: Scheme of the Process Steps and Material Flow in Laundries

By using the RFID technology as well as an automatic reading/identification system in the incoming goods department, the necessary transparency is given. This offers the possibility of optimal planning, management and monitoring of processes and the entire system. Moreover, the RFID technology offers the ability to respond to potential process errors and the maintaining of competitiveness.

2.1. Wash Sequence Scheduling

Currently, the schedule is prescribed due to the route plan and customer order. The washing orders are assigned in the ratio of terry to mangling cloth of 1:3. By providing detailed information about the incoming goods, further sequencing strategies can be implemented.
The scheduling is based using input data as a delivery list given with customer orders. Contrary to the real system, the detailed structure of all delivered orders is known at the beginning of the planning period. The determination of the order strategies was carried out in two steps (see Tab. 1). In the first one, the customer orders are sorted in accordance with predetermined practical priority rules (RND: randomly distributed, FCFS: First Come First Serve and EDD: Earliest Delivery Date). The sorting is carried out separately in each tour due to the different delivery times of the goods.

Table 1: Strategies of Scheduling the Laundry Order

<table>
<tr><td colspan="8">Step 1</td></tr>
<tr><td colspan="3">RND</td><td colspan="2">FCFS</td><td colspan="3">EDD</td></tr>
<tr><td colspan="8">Step 2</td></tr>
<tr><td rowspan="2">RND</td><td rowspan="2">T</td><td rowspan="2">C</td><td rowspan="2">T</td><td rowspan="2">C</td><td rowspan="2">T</td><td colspan="2">C</td></tr>
<tr><td>1:3</td><td>2:4</td></tr>
</table>

The second phase involves sorting the washing jobs within the customer orders. The subjective experience and knowledge of the laundry employees cannot be displayed. Therefore, the arrangement of orders is selected using fixed predetermined priority rules, which are inspired by the behavior of the staff:

- The washing jobs are randomly arranged (RND),
- The arrangement is time-oriented in order of decreasing processing time (T),
- The arrangement based on the change of the washing jobs with the different textile type (with a ratio 1:1 of mangling and terry cloth) (C).

The strategy of changing washing jobs in step 2 (with EDD rule in step 1) was extended with different ratios to characterize the model under more realistic conditions. The conditions 1:3 and 2:4 describe the ratio of mangling to terry cloth. The priority rules are based on the assumption that customer orders are processed successively according to the sequence of the first step.

2.2. Effect of Disruptive Events

The categorization and analysis of disruptive events are based on the model structure of an industrial laundry (see Fig. 1). To determine the effect of disruptive events, all possible occurring errors in industrial laundries were recorded for each handling process within each area (sorting area, transport area, buffer area, washing area, drying area, folding/stacking and storage area) in the model structure under the following aspects: element, reason, effect, duration and frequency.
The failure element is defined as the laundry item. The reasons, effects as well as the duration and frequency of various errors like stopping, falling or snagging of articles or quality defects through cleaning/handling processes were categorized. Reasons could be

sensor/technical defects, capacitive problems, foreign objects in the system, insufficient filling or the input of unplanned jobs. The effect of a disruptive events are demonstrated by the damage of laundry items, repeated process runs, short blockages, long standstills of processes up to direct sequence influences. Errors resulted in an increased lead time and quality defects.
The selection and illustration were implemented by an adapted Failure Mode and Effects Analysis (FMEA) method and clustering with a bubble chart. The rating with the FMEA method is based on a multiplicative calculating of a Risk Priority Number (RPZ) (Illés et al. 2007). The classification was performed with the parameters effect, duration and frequency. Thus, the degree of severity of a disruptive event can be classified. It could be observed that disturbances, which occur during the automated applications or flow production, are very serious.
Equally critical is the input of urgent orders. The error evaluation based on the three rated parameters is shown in Fig. 2. The duration is illustrated in the x-axis and the frequency in the y-axis. The diameter of the bubble demonstrates the failure effect. The figure shows that the majority of errors can be classified in the Quadrant III. They are highly frequented and of limited duration. In particular, disturbances of the areas transport, buffer, mangling and the folding/stacking region fall into this quadrant.
The disrupted events were included in the model as integrated distributions and scenarios. They were applied based on the categorization and their influence on the laundry order:

- quadrant 1:
  - high effect: scenario
  - medial effect: no consideration
  - less effect: no consideration
- quadrant 2:
  - high effect: scenario (errors of the washing machine)
  - medial effect: scenario/ individual
  - less effect: individual
- quadrant 3:
  - high effect: distribution/scenario (errors of folding/stacking region)
  - medial effect: distribution
  - less effect: distribution
- quadrant 4:
  - high effect: scenario (loss of laundry items)
  - medial effect: distribution
  - less effect: individual

Consequently, most of the failures of the areas transport, buffering, mangling and folding/stacking were applied using distributions, whereas scenarios serve to apply errors in the washing and drying area.

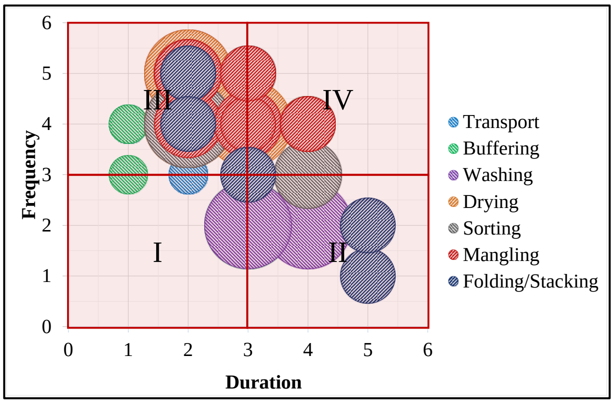

Figure 2: Degree of Severity of Disruptive Events

3. SIMULATION MODELS

To evaluate the selected strategies for planning the washing sequence and determine the effect of errors, the production process of a laundry was replicated with two simulation models. Therefore, the flow of material or laundry item is considered from arrival to the delivery.
During the simulation, individual laundry items are temporarily batched for washing and subsequently unbatched. Process times of manual as well as automatic handling steps are modelled as stochastic distributions. The random numbers limits were selected based on expert interviews.
The simulation model is thus intended to reproduce the stream of individual items of laundry. In this paper, the discrete-event simulation approach with a high level of detail was chosen to implement the simulation studies of logistics processes in industrial laundries (Schenk et al. 2006). The washing job, including a various amount, composition and type of articles as well as delivery date, serve as an input parameter for the simulation models (see Fig. 3). Values of a reference laundry served as input data. Therefore, an exemplary tour list was adopted with customer orders as input data. This list is based on the delivery in real systems, represents a partial section of the daily incoming amount of laundry and contains twelve sales orders, which are delivered at four points in time.

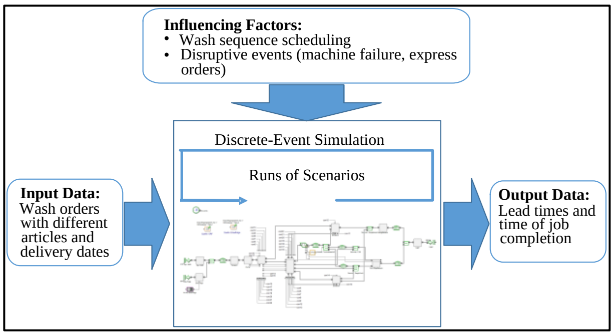

Figure 3: Input and Output Data as well as Influencing Factors of the Simulation Models (Brandau et al. 2015).

However, in order to represent the customer structure in the containers as well as the content of the containers, the filling of the container was determined by additional

programming. For this purpose, a random filling with a wide products range on the basis of the type of economy and textile type was selected. Through the knowledge of the weights of individual items and the permissible load of 100 kg per container, the number of products per container is randomly set between 1 and 100. By using an algorithm with a random number and the resulting weight of the articles, the container is loaded up to a cumulative value of 100 kg.
The output of the simulation include the lead time and time of job completion, which is an indicator for the delivery reliability. The fundamental factors to influence the simulation model are the laundry order scheduling and disruptive events like machine failure or urgent orders (see Fig. 3).

3.1. Wash Sequence Scheduling

The following Fig. 4 shows the implemented simulation model using the software *Tecnomatix PlantSimulation* (Siemens). The verification was carried out by observing and controlling the several processing steps of laundry handling out in the simulation model (trace file analysis). Previous rough calculations supported additionally the model verification. Because of an insufficient data basis from the real laundry, the partial results of the simulation were validated by expert discussions. These were conducted by inspection and recording of process times and sequence descriptions in direct cooperation with the laundries.

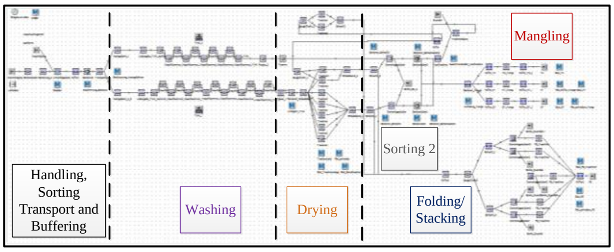

Figure 4: Simulation Model for Evaluation of the Wash Sequence Scheduling

To evaluate the washing order sequence, a base scenario, which includes a list of supply of articles, customers and delivery dates, were generated. This scenario does not contain any disruptive events. The selected strategies of scheduling were implemented and evaluated taking regard of the objectives of a short lead time and a high delivery reliability (Schuh 2006). Ten runs per strategy (step 1 and 2) were chosen for implementation. In total, 80 runs with 24 hours have been carried out.

3.2. Effect of Disruptive Events

The discrete-event simulation model was implemented using *ExtendSim* (Imagine That Inc.) (see Fig. 5). Optimized wash sequences with short lead times using suitable schedule rules, which are the result of the first model, was used as input values for simulation. The validation and verification were performed, similar to the simulation model of the wash sequence scheduling, by using a trace file analysis and expert controls.

In addition to the failure-free base scenario, the errors were included in the simulation with distribution functions or scenarios as described in section 2.
A disruptive event was realized using a shutdown of the activity. If a shutdown occurs, the actual process or activity stays down, the items were kept and the process will be resumed after the failure time.

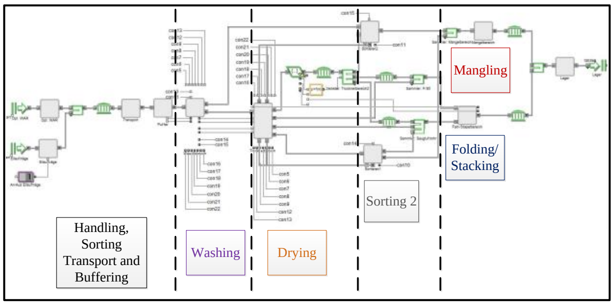

Figure 5: Simulation Model for Calculation of the Effect of Disruptive Events

A disruptive scenario includes the distributed errors as well as some selected failures. The implementation was realized through the following dramaturgy steps:

1. Base scenario (failure-free)
2. Interference scenario 1 (distributed errors)
3. Interference scenario 2 (distributed errors and urgent orders)
4. Interference scenario 3 (distributed errors, urgent orders and failures of the main process route)
5. Interference scenario 4 (distributed errors, urgent orders and failures of the side process route)
6. Interference scenario 5 or worst case scenario (all errors and urgent orders)

The simulation model was tested using ten simulation runs per scenario and evaluated in terms of the effect of the disruptive events on the lead time and delivery performance.

4. RESULTS AND DISCUSSION

4.1. Wash Sequence Scheduling

Nine scheduling strategies were tested and evaluated in the simulation. Tab. 2 shows the list of calculated values using various strategies, sorted according to their rating. The total process time is defined as the working time all twelve sales orders need from the initial time of the first article to the completion time of the last. The lead time of a customer order is determined by the entry of the first textile and the exit of the last out of the system. Here, the average value of the lead times of all orders and the corresponding standard deviation were calculated. Moreover, the amounts (AMT) of the delayed orders as well as the amounts of the delayed washing processes were listed.

Table 2: Lead Times and Delivery Performance in Dependency of the Scheduling Strategies

Strategy		Total Process of all Orders [h]	Mean Lead Time [h]	AMT of delayed Custo-mer Orders	AMT of delayed washing Pro-cesses
Step 1	Step 2				
EDD	C (1:3)	10.67	2.94 ±1.2	0	0
EDD	C (2:4)	10.7	2.97 ±1.2	0	0
EDD	C	10.65	2.92 ±1.2	0	0
FCFS	C	10.65	2.94 ±1.2	0	0
EDD	T	10.78	3.03 ±1.2	0	0
FCFS	T	10.8	3.04 ±1.2	0	0
RND	C	10.65	3.00 ±1.2	1	2
RND	RND	10.65	3.14 ±1.2	1	3
RND	T	11.17	3.28 ±1.3	1	6

These results show that the strategy of the random arrangement of customer orders leads to delayed finished washing jobs and is therefore unsuitable.
The constant standard deviation of 1.2 hours of the lead time can be explained with the distributed values of the various process times, the difference between the average lead time in dependence of the several textiles, e.g. mangling or terry cloth, and the type of consumer. By using the FCFS as well as the EDD strategy delays were avoided.
Moreover, the arrangement of the washing jobs by the largest processing time resulted in a higher lead time. Due to a changing arrangement of washing jobs with different textile type, the total lead time can be reduced. Both strategies are applicable for achieving the objectives.
Despite minimal longer total processing times compared to the strategies of an changing arrangement, the best results can be obtained from the strategies EDD/C (ratio 2:4) and EDD/C (ratio 1:3). By applying these strategies, delays can be avoided and maximum delivery reliability can be achieved due to an optimal machine capacity utilization of the dryer system reduced waiting periods. The minimal longer processing as well as lead time may be due to the consideration of a partial detail of a daily delivery list. The washing jobs cannot be continuously included in the system with an optimum relation. Waiting times due to exhausted resources of the dryer system are not completely avoidable. The EDD/C (1:3) strategy provides the best results in the considered example by using the simulation experiments.
The results of the simulation runs indicate that the scheduling strategies EDD/C (ratio 1:3), EDD/C (ratio 2:4), EDD/C and FCFS/C are suitable to plan the wash sequence. These were used in the study of the effect of disruptive events.

By consideration of the process times of each machine, the mangle of the small textiles was identified as a bottleneck with an occupancy rate of approximately 93%, based on the total simulation time. The high occupancy occurs due to long waiting times and blockage effects. This extension of lead times does not result in a delayed job completion in the considered order and duration of simulation. Nevertheless, these results illustrate the need of further research.

4.2. Effect of Disruptive Events

Fig. 6 shows the results of the simulation runs. As expected, the worst case scenario (scenario 6) shows the highest lead time. Moreover, the occurrence of urgent orders (scenario 3) has the most effect of the lead time and result in an increase of this value. The high standard deviation can be observed due to the reasons explained in section 4.1 and additional by using distributions to implement the Time Between Failure (TBF) and Time To Repair (TTR). Here, the triangular and exponential distributions were used, respectively. Interestingly, the strategies EDD/C and FCFS/C show a higher lead time compared to the other strategies for all scenarios. Failures of the main (scenario 4) as well as the side process route (scenario 5) generate a similar effect and lead time. In general, an increase of the lead time can be observed with an increased scenario.

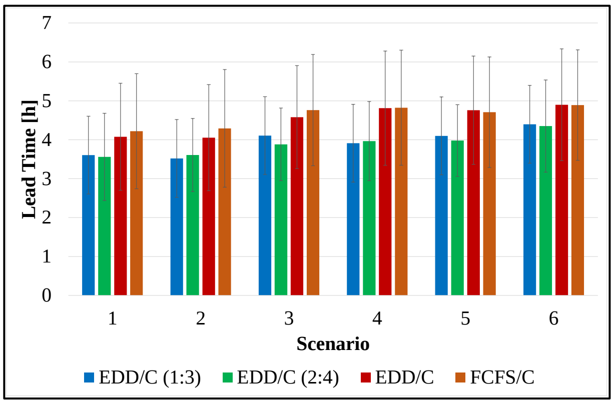

Figure 6: Lead Times in Dependency of the Occurrence of Disruptive Events and Scheduling Strategies

Tab. 3 illustrates the related total process times and the amount of the delayed customer orders. It is shown that scenario 1 as well as scenario 2 causes no delayed customer orders by using the four scheduling strategies. Furthermore, the total process time increases rapidly in scenario 3 and the occurrence of urgent orders. This confirms the trend from Fig. 6. One delayed order occurs by using scenario 3 and 5, respectively. However, no trend or relation can be observed. As expected, the worst case scenario generates the longest total process time and, in addition, two orders cannot be finished at the given time. These results show that the suggested scheduling strategies are suitable to plan the wash sequence and only in the case of errors in each area, which is an unlikely event, not all due dates can be fulfilled.

Table 3: Delivery Performance in Dependency of Disruptive Events and Scheduling Strategies

Scenario	Strategy		Total Process of all Orders [h]	AMT of delayed Customer Orders
	Step 1	Step 2		
1	EDD	C (1:3)	10.55	0
	EDD	C (2:4)	10.5	0
	EDD	C	10.61	0
	FCFS	C	10.64	0
2	EDD	C (1:3)	10.54	0
	EDD	C (2:4)	10.54	0
	EDD	C	10.65	0
	FCFS	C	10.65	0
3	EDD	C (1:3)	10.6	1
	EDD	C (2:4)	10.59	0
	EDD	C	10.69	0
	FCFS	C	10.78	0
4	EDD	C (1:3)	10.59	0
	EDD	C (2:4)	10.7	1
	EDD	C	10.72	0
	FCFS	C	10.82	0
5	EDD	C (1:3)	10.62	0
	EDD	C (2:4)	10.6	0
	EDD	C	10.7	0
	FCFS	C	10.75	0
6	EDD	C (1:3)	10.67	1
	EDD	C (2:4)	10.65	0
	EDD	C	10.73	0
	FCFS	C	10.74	1

In further project work, an evaluation system for the laundry order scheduling in terms of robustness will be developed. Therefore, a suitable weighting of the model parameters (scenario, factors) must be defined and tested. Due to this evaluation system it will be possible to judge the quality and robustness of wash sequences against failures or errors.

5. CONCLUSION

In summary, the suitability of discrete-event simulation model to characterize the processes in industrial laundries was presented. The simulation depending on the laundry order scheduling strategies show an increased lead time by using a random arrangement of the laundry order. The FCFS (First Come First Serve) as well as the rule of EDD (Earliest Delivery Date) are qualified to schedule the order. The simulation study with consideration of disruptive events show a significant effect of urgent jobs on the lead time.

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Susann Arndt (Dipl.-Ing.) finished her studies of Biosystems Engineering at the Otto-von-Guericke-University Magdeburg in 2010. From November 2010 to January 2012, she worked as a member of the research training group 'Nano- and Biotechnologies for Packaging of Electronic Systems', investigating the inkjet printing of functional materials for sensor devices. From February 2012 until March 2015 she became a research assistant at the Otto-von-Guericke-University Magdeburg, Clinic for General, Visceral and Vascular Surgery. Her tasks had been the mechanical analysis and characterization of abdominal organs. Following, Susann Arndt got a position as research assistant at the Institute of Logistics and Material Handling Systems at the Otto-von-Guericke-University Magdeburg in cooperation with the Fraunhofer IFF and companies especially industrial laundries. The tasks are the modelling and simulation of intralogistics systems and the statistical evaluation of experimental setups. Her research topics are interdisciplinary methodologies for mechanical and process analysis.

Meik Hüppler (M.Sc.) was a Master student at the Institute for Logistics and Material Handling Systems (ILM) at Otto-von-Guericke University Magdeburg (OvGU). He developed the concept for the strategies of scheduling the laundry order.

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Since eight years Annegret Brandau has been working as project manager and researcher at the Otto von Guericke University Magdeburg in the Institute of Logistics and Material Handling Systems. During this time she managed different projects with companies especially industrial laundries to improve their logistics and manufacturing processes. In April 2015 she finished her PhD with distinction. Her topic was to develop an integrated concept to model and analyze state data of logistical objects. In addition she is a teacher for the university courses Information Logistics and Planning Logistics Systems. Previously Annegret Brandau studied mathematics as major subject and physics as minor subject at the University of Konstanz.