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SIMULATION-BASED PLANNING AND DIMENSIONING OF AN AUTOMATIC LAUNDRY STORAGE AND RETRIEVAL UNIT WITH DYNAMIC STORAGE LOCATION SIZES

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ABSTRACT

Industrial laundries in Germany face a high pressure to increase their efficiency due to an ongoing market concentration. While many processes in an industrial laundry are already highly automated and optimized, order picking is still done manually. As RFID proliferates in industrial laundries, goods become traceable and identifiable. This enables the effective use of automated picking systems. Automation systems in the laundry industry face the challenge of pliable (form unstable) goods. This paper shows how the planning and dimensioning of an automated Laundry Order Consolidation System (LOCSys) can be supported by simulation modelling, already beginning in the early conception stage of the system.

1 INTRODUCTION

The laundry industry in Germany reports constantly growing sales. According to the trade association "WIRTEX", the total sales of the textile services industry in Germany increased from 3.155 billion euros in 2013 to 3.388 billion euros in 2016 (WIRTEX 2018). The annual growth rates in these years have been in the range of 1.9 to 2.7 percent. The cost structure is characterized by a high proportion of labor costs, which have increased sharply due to frequent wage increases in recent years. Textile service companies specialized in flat linen can have a share of labor costs up to 50 percent of their total costs (WIRTEX 2018), which increases the need for more automated processes in this field of the laundry industry. Table 1 shows the consequence of this economic development: The number of laundries decreases and a market concentration occurs (Destatis 2018).

Table 1: Laundries in Germany and their deliveries and services sales in the years from 2012 to 2016. Only laundries with more than € 17,500 in taxable annual sales were recorded.

year	2012	2013	2014	2015	2016
number of laundries	5722	5524	5316	5166	5052
sales in deliveries and services in bn €	2.847	2.931	3.050	3.188	3.172

Innovative automation systems are a possible solution for industrial laundries to counter the increasing competitive pressure. Prerequisite for automated systems is the use of RFID in the laundry cycle. With RFID, the goods can be tracked and identified. Laundry items circulate in a closed-loop supply chain (Figure 1).

It is useful for the laundry industry to attach the RFID transponders directly to the product and not to a pallet or the packaging, because of the loop structure of the system and changing loading equipment. In addition to the usually highly automated and optimized washing process, there are still areas of industrial laundries that are characterized by labor-intensive and less-mechanized solutions. The picking area in industrial laundries is a typical example for manual and labor-intensive work.

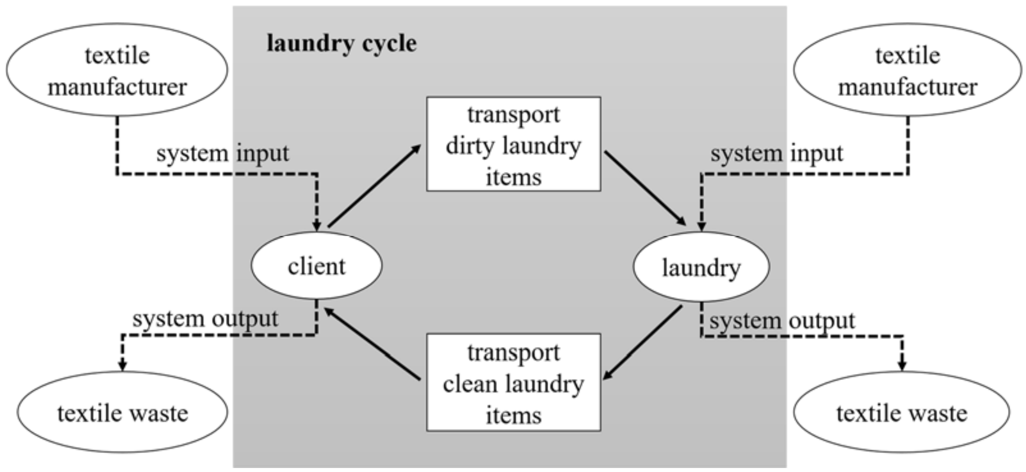

Figure 1: The overall system laundry cycle is not completely closed. The input and output flow increases or decreases the number of laundry items in the system.

The project "Laundry Order Consolidation System (LOCSys)" aims to improve the picking & storing processes in the clean area of an industrial laundry through automation. Figure 2 shows an overview of the typical processes of an industrial laundry with the picking & storing processes right before the shipping of the cleaned laundry.

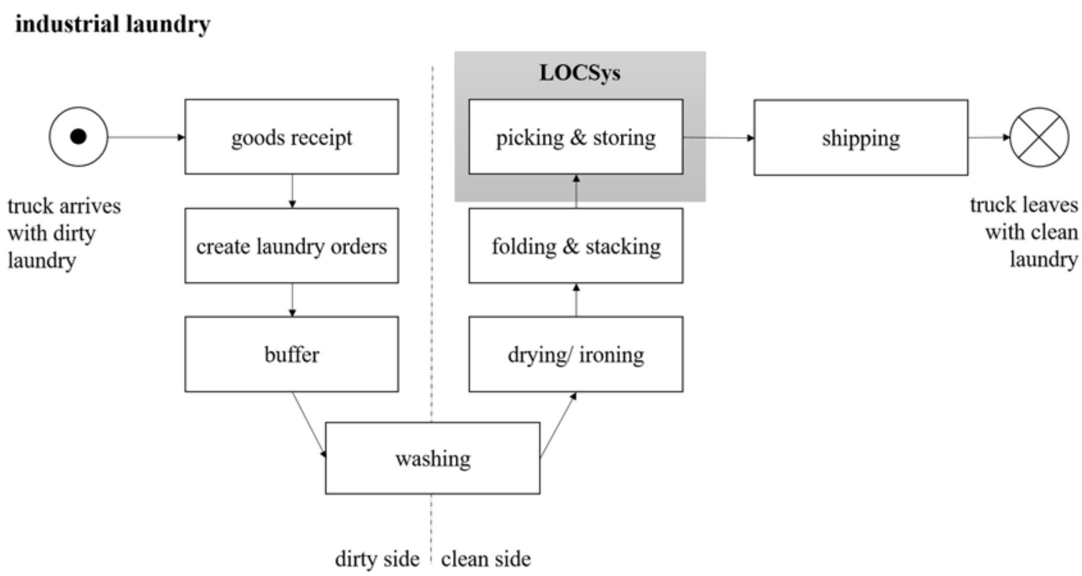

Figure 2: Processes in an industrial laundry with the suggested picking & storing system "LOCSys".

Typical sorter and batcher systems do not work for laundry items because the items are pliable (form unstable) and additional outer packaging is usually not allowed for. The approach of LOCSys is, therefore, a new picking system with a storage and retrieval unit (SRU), which reliably handles laundry items with a special gripping mechanism. Figure 3 shows an early sketch of LOCSys. The intended warehouse system with dynamic storage allocation and dynamic storage dimensions will address the issue of low available space in industrial laundries. The stacking-order problem of laundry items is similar to the mathematical puzzle “Tower of Hanoi” and will be addressed with an algorithm that is similar to the ones that solve the Tower of Hanoi problem (Hinz et al. 2013).

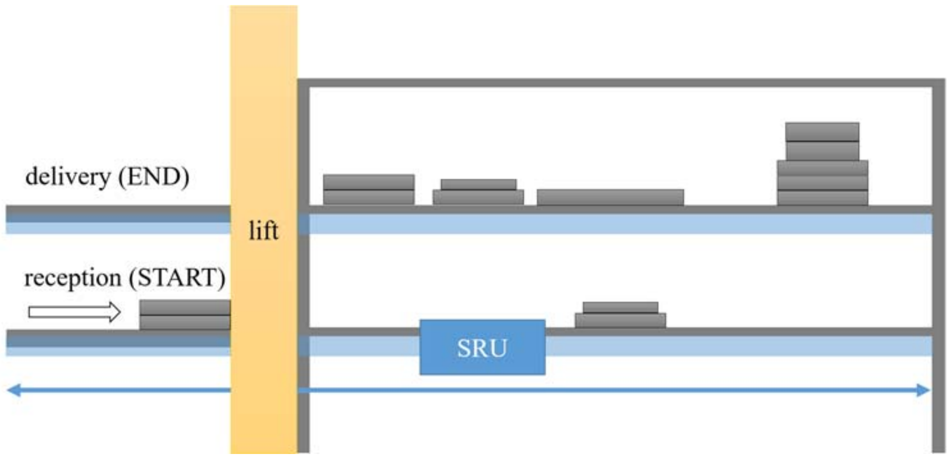

Figure 3: In an early sketch of LOCSys, the system consists of a shuttle with a gripper and a lift to change the height of the storage and retrieval unit.

The simulation study has to fulfill different tasks within the project. The first task is the simulation of the planned picking system and algorithm before its implementation to find early errors and optimization potentials. Secondly, the simulation model will be used as an operational model to make forecasts based on real-time data. The third task of the simulation model is to use the model for virtual commissioning of the picking system and to create a digital twin of the real system. It is obvious that different variations of the simulation model have to be created during the project.

The first results and findings of the first task will be presented in this paper. In the next sections, we first look at the structure of the system and describe the different problems. We refer to similar problems in the literature, which appear individually, but not exactly in this combination. Then, we give an overview of our conceptual model and present the first results in terms of robustness and sensitivity of the model.

2 LAUNDRY LOGISTICS

2.1 Circular Economy, Closed-loop Supply Chain, and Material Cycles

There are numerous terms to describe cycles in business and logistics, including “circular economy”, “closed-loop supply chain”, or “material cycle”, which are strongly influenced by a concept of sustainability and less by the business idea or properties of the flow object itself. According to Murray et al. (2015), circular economy “represents the most recent attempt to conceptualize the integration of economic activity and environmental wellbeing in a sustainable way”. Korhonen et al. (2017) state that circular economy “[…] have almost exclusively been developed and led by practitioners, i.e., policy-makers, businesses, business consultants, […]” and not by scientists. In the context of supply chain management, there is another term: closed-loop supply chain. It is sometimes, but not always, mentioned in the context of sustainability. Yildiz (2016) defines the closed-loop supply chain as “integrated model of forward and reverse chains”. Shaharudinand und Zailani (2012) define it also “as the integration of forward and reverse logistics whereby the returned products are recovered and reinserted back into the traditional forward flow”, but connect it with an aim in the context of Green Supply Chain Management: “economic, environmental, and social accomplishments”. The term “material cycle” is often considered together with recycling, sometimes also with remanufacturing.

The structure of the laundry cycle is very similar to the mentioned concepts, but it is not congruent with remanufacturing, recycling, or repairing processes, because the laundry item is fundamentally still in its original condition and can in principle (though not recommended) continue to be used. Therefore, the laundry item is neither waste nor broken but must undermine a state change. This state change consists of processes like "cleaning" or "decontamination" as well as getting in shape despite the form instability. The laundry cycle is not infinite, because the material wears out after a certain time and, thus, assigns the laundry item a determined lifetime depending of the material. In some concepts or models, this input and output is also considered. However, the primary objective of the laundry cycle is not sustainability or the protection of the environment. It is the business idea to fulfill the demand of cleaning textiles, which determines a circular material flow. Usually, people tend to use clothes again instead of throwing them away and, therefore, the client already forces a sustainable approach. In our opinion, the best way to describe the structure of a laundry system is to use the approach of the supply chain perspective and consider the laundry cycle as a nearly closed-loop supply system.

2.2 Handling and Storing of Laundry Items

Laundry items are difficult to handle, especially in a clean and folded state. They are pliable parts and, therefore, form-unstable. In most cases, repackaging or additional loading equipment is inadmissible, as the customer does not allow for using it or it is excluded by general hygienic requirements, like for hospital laundry. This leads to the situation that classical automated warehouse systems, which are defined to "perform high-speed picking of small- or medium-sized non-fragile items of uniform size and shape" (Zijm and van den Berg 1999), are not used in industrial laundries.

Laundry items often arrive in the order picking process as an unmixed stack. This stack is usually not finished yet for a client order. Therefore, the stacks must be sorted, which is a typical optimization problem in logistics. There are numerous approaches to solve sorting problems and to handle their different restrictions.

Rei et al. (2008) describe a simulation-based approach to solve a steel stacking problem with the three different strategies "minimize conflicts", "delay conflicts", and "flexibility optimization" to minimize the number of movements. Their simulation model is used to provide results in different situations and in their case the strategy "flexibility optimization" has the best performance. Kofler (2014) shows in different case studies in her dissertation various aspects of storage location assignment and gives a wide overview about stacking problems. The stacking problem is often associated with yard storage while warehouse racks (which we want to use) are usually just considered with the route optimization of storage and retrieval units. Another aspect is the physical nature of the goods, which affects the stacking order. Bódis et al. (2017) consider more the geometry properties of the goods than other references, which also applies to our problem.

The automation of picking in industrial laundries is basically the combination of the three mentioned approaches. We need to solve the routing of the storage and retrieval unit and the optimization of the stacking order, while considering the special physical nature of the laundry items. Not only that there is no automation in the picking area. Most industrial laundries do not even have classic shelf warehouses. Instead, mobile roll containers are used, which occupy a lot of space, but do not really use the height. Storage shelves for halls with the appropriate height would have great potential to increase the amount of storage space.

3 LAUNDRY ORDER CONSOLIDATION SYSTEM - LOCSYS

3.1 Dynamic Storage Location Dimensions and Allocation

Since the industrial laundries suffer from considerable lack of space, our solution approach should have a particularly high degree of space efficiency in the warehouse. This can be achieved by a dynamic storage allocation. The dynamic allocation is often called "chaotic warehousing" which would mean a random allocation. One part of our approach consists of the development of an algorithm which will be optimized with a simulation model. Over an application programming interface, the algorithm will give orders to the storage and retrieval unit of the warehouse in the simulation model. The results of the simulation model will then lead to a new variation of the algorithm in the planning process. The exact rules and strategies where and when to store the laundry items are not yet clear and part of our project. The algorithm might use random elements, but it will not be completely random. Therefore, the term "dynamic storage allocation" is more appropriate than "chaotic warehousing". But, not only the allocation of the laundry items is dynamic. As shown in Figure 4, the fixed storage locations are dissolved and are now determined by the width of the goods. The distance between the laundry stacks Δx is determined by the precision of the storage and retrieval unit and irregularities in a stack itself. Figure 4 shows also the obvious space savings of this method.

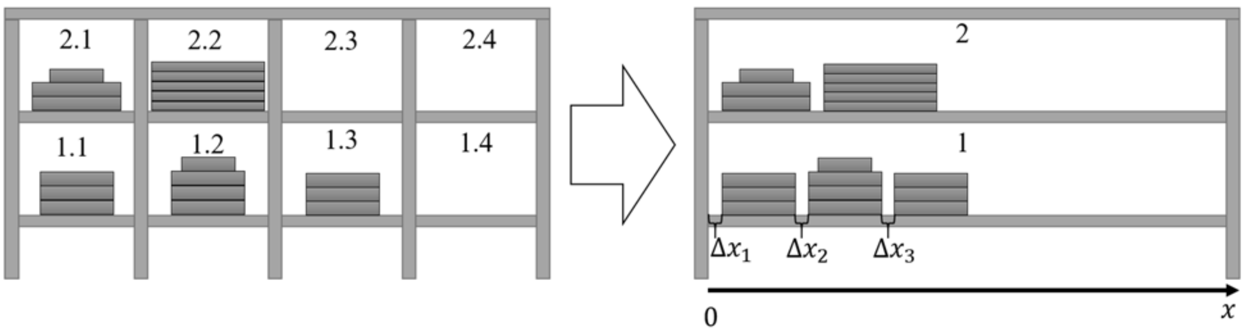

Figure 4: The left side shows classic shelf levels with determined storage locations. Our approach on the right side identifies the ID of the shelf level and uses the x coordinate to allocate the laundry item.

The storage space allocation is, therefore, no longer assigned by a unique ID of the storage space, but a booking point based of the x-coordinate of the respective shelf level. This leads to the circumstance that not only the width of the laundry item is important, as it was already before to check if the dimensions of the storage space were big enough. But, also the position of the two ends of the laundry items is important, because it can no longer be checked via a simple number whether a storage space is occupied or not.

For our approach we create for every shelf level a corresponding coordinate system with only one relevant x-axis. The origin of the coordinate system is the left end (assuming a front view) of the shelf level. We name the left end (with a lower value of x) of a laundry item in a shelf x_{left}. The right end is called x_{right} and its x-value is consequently higher. We define also a booking point $x_{booking}$ as the center of the laundry item and assume a symmetry of the laundry stacks. This leads to the following simple relationship:

$$x_{booking}=x_{right} - \frac{width\ of\ the\ laundry\ item}{2}$$

When storing laundry items, two conditions are checked to allow the storage of the goods: If the booking position of a laundry item x_3 that has to be stored is smaller than the booking position of the next laundry item x_1, then the right end position of laundry item x_3 has to be smaller than the left end position of laundry item x_1. However, if the booking position of the laundry item x_3 is bigger than the booking position of the laundry item x_1, then the left end position of x_3 has to be bigger than the right end position of laundry item x_1. Figure 5 visualizes the problem and shows the consequences of laundry stacks in shelves.

The geometry of the laundry items already has an influence on the stacking order. Laundry items with a big width cannot be placed on top of a laundry item with a smaller width. Therefore, the relevant stern and bow positions, which have to be compared, are determined by the laundry item with the biggest width in the stack.

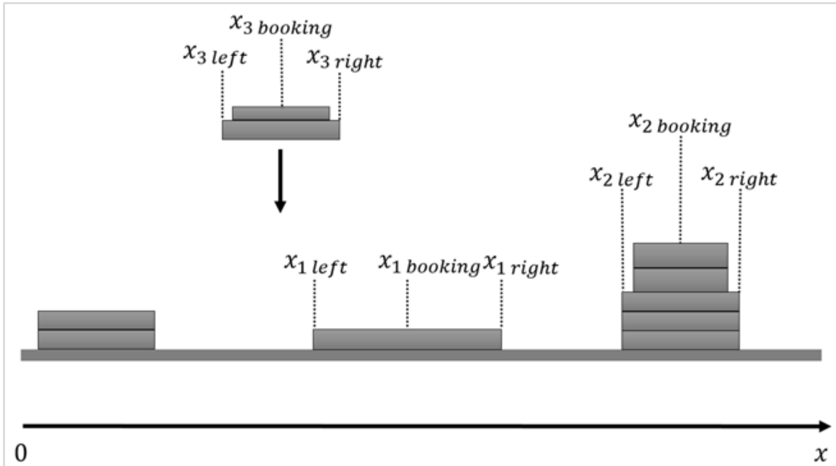

Figure 5: This example shows how laundry items are getting stored. In this case, laundry item three would not fit because its right end would overlap with the left end of laundry item one. The booking position would have to be changed (e.g. lowering the value a bit in this case).

3.2 Discrete Event Simulation

The planning of the automated picking system is supported by a simulation model that uses a microscopic approach. While other simulation models already have shown that mesoscopic models are also applicable for the simulation of industrial laundries (Müller 2014; Brandau et al. 2015), our approach with the consideration of the specific stacking orders requires a microscopic one. The task of the simulation model is to test different layout variations, basic controls, and detailed operating strategies, which are provided by a special picking algorithm and technical parameters of the picking system. A variation of the model is used operational and process-accompanying to give short-term forecasts and to emulate the control logic.

Figure 6 shows the current state the model, which is divided into three sections: the adjustment parameters, the manually created model and the automatic created shelves. The adjustment parameters will be replaced in the future by a more appealing user interface. The manually created model elements represent the supply of the laundry items and include the identification point. The source of the model is supported by a method to create the laundry items and group them according to their type of laundry to stacks. As in reality, some laundry stacks are identified as defective. Another conveyor belt redirects them to a re-stacking process and then the new stacks are re-supplied to the original conveyor belt to identify them again. The automatically created rack row depends highly on the adjustment parameters. The length, width, height, and number of shelves are customizable. The vertical lift rail and its connections to the horizontal rails are then also generated automatically.

The already mentioned particularities of the laundry logistics also create challenges in the development of the simulation model. For example, the technical implementation of dynamic storage location dimensions needed a workaround in the chosen simulation software, because the software does not allow for working with geometry inside one storage location. This is not a software-specific problem. Storage blocks in simulation software usually assume fixed storage space dimensions. For our workaround, we used the conveyor elements of the program which use a measure of length. Thus, we could use them with some changes as the layer for the shelves. But, then there was another problem: it was not allowed for stacking entities on a conveyor like in a storage object. We had to create invisible load equipment for the laundry items to represent the laundry stacks. The loading equipment allowed us completely visualizing the shelves with laundry stacks, without the observer noticing that the laundry has loading equipment and the shelves are actually conveyor belts, as Figure 7 demonstrates.

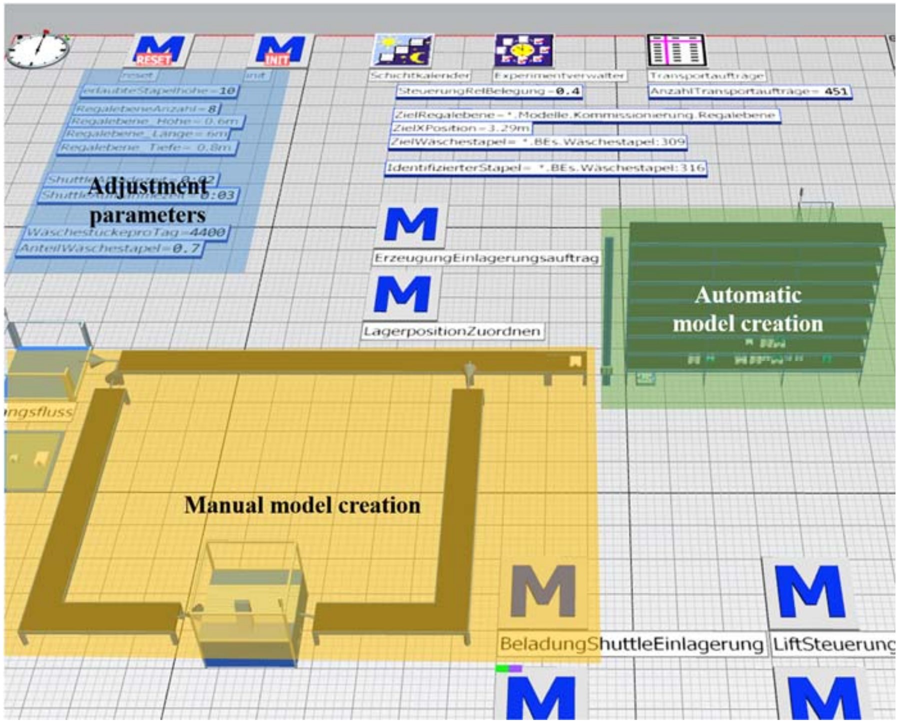

Figure 6: Current state of the simulation model, which is used for adjusting the planned parameters and testing the picking algorithm. The INIT-method creates the elements (without the laundry) in the green area during the initialization of the model.

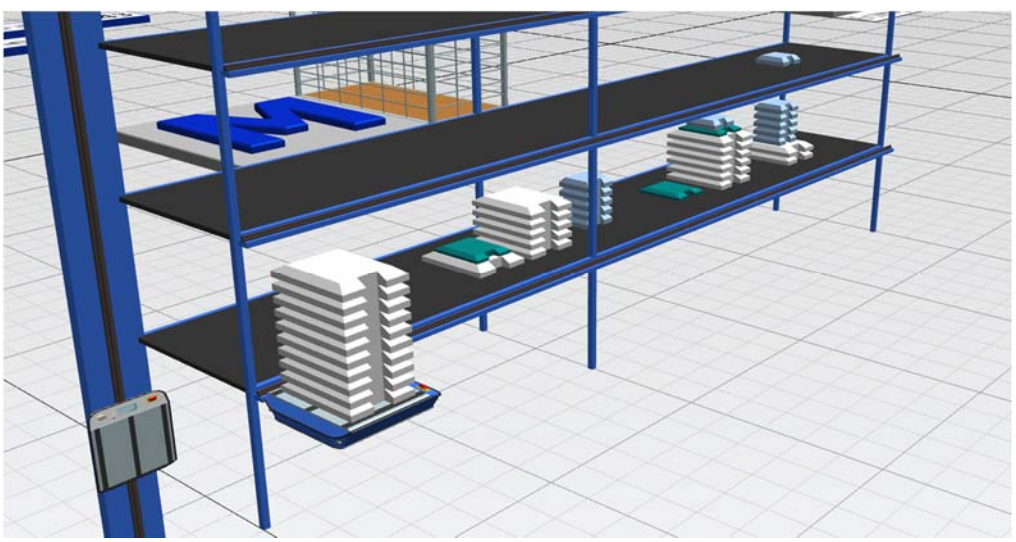

Figure 7: The 3d model allows an easy way for verifying the functionality of forming laundry stacks. In this case, there is a random distribution of the laundry stacks (three different laundry types) on the shelf. The distance Δx between the stacks is, therefore, variable but has a minimum value determined by the precision of the planned gripper system. The storage and retrieval unit is picking a full stack of white laundry items.

The simulation model currently uses some basic methods to allocate the laundry stacks. Firstly, it considers the lowest shelf level if there is any matching laundry stack or enough empty space. If this is not the case or the relative occupancy of the shelf level is higher than the adjustment parameter, the method searches the next higher shelf level. This basic controls will be replaced by an external picking algorithm in the future. The interface with the picking algorithm is planned with an intermediary database (e.g., SQLite) to swap relevant data records.

3.3 Robustness of the Model and Results

Based on our assumptions and planned construction parameters, the input material flow of laundry items is firstly limited by the characteristics of the supplying conveyor belt. This in turn depends on the width of the incoming laundry items and, therefore, also on the composition of the different laundry types. The average width of laundry items depending on our current composition is $\bar{x}_{laundry}=0.246\ m$. The minimum distance is set to $\Delta x=0.5\ m$ and the conveyor belt speed is $v=0.3\ m/s$. The throughput Q is calculated as followed:

$$Q = \bar{x}_{laundry} * \frac{v}{\bar{x}_{laundry} + \Delta x}$$

$$Q = 0.246\ m * \frac{0.3\ m/s}{0.246\ m + 0.5\ m}$$

$$Q = 0.0989\ m/s$$

We also assume that our picking system can only operate during the two-shift system for the workers with 8 hours for each shift, which means that $t = 16\ h$. The amount M is then calculated as followed:

$$M = Q * t$$

$$M = 0.0989\ m/s * 57{,}600\ s$$

$$M = 5{,}698.23\ m$$

The approximated possible number n of laundry items transported by the conveyor belt is therefore:

$$n = \frac{M}{\bar{x}_{laundry}}$$

$$n = \frac{5{,}698.23\ m}{0.246\ m}$$

$$n = 23{,}164$$

This does not yet take into account that the laundry items can be stacked. If about half of them come in piles of 5 or 10, this leads easily to a throughput of ca. 40,000 laundry items. The target of our current picking solution is to be able to handle about 4,000 – 5,000 laundry items per day but, as the calculation shows, we could greatly increase the input flow. Depending on the adjustment parameters, the throughput of the automated picking system varies a lot. In the first experiment, we assume 5,000 laundry items per day and change the probability of incoming laundry stacks from 0 (Experiment 0) to 100 percent (Experiment 11) in steps of 10 percent. Figure 8 and 9 show the results for the system limits. The number of entities decreases continuously in Figure 8 because there are more laundry stacks that can contain laundry items. Figure 9 shows that the number of completed laundry stacks increases in the first experiments, but when the stacking probability reaches 60 percent, the numbers stagnate. The conclusion is that the picking system cannot handle the material flow when there are less stacks and more individual items. At the rate of 60 percent of laundry stacks, the picking system is able to consolidate every picking order for an amount of 5,000 laundry items. The performance limit of our picking system is, therefore, about 5,000 laundry items, which are stacked at a rate of 60 percent.

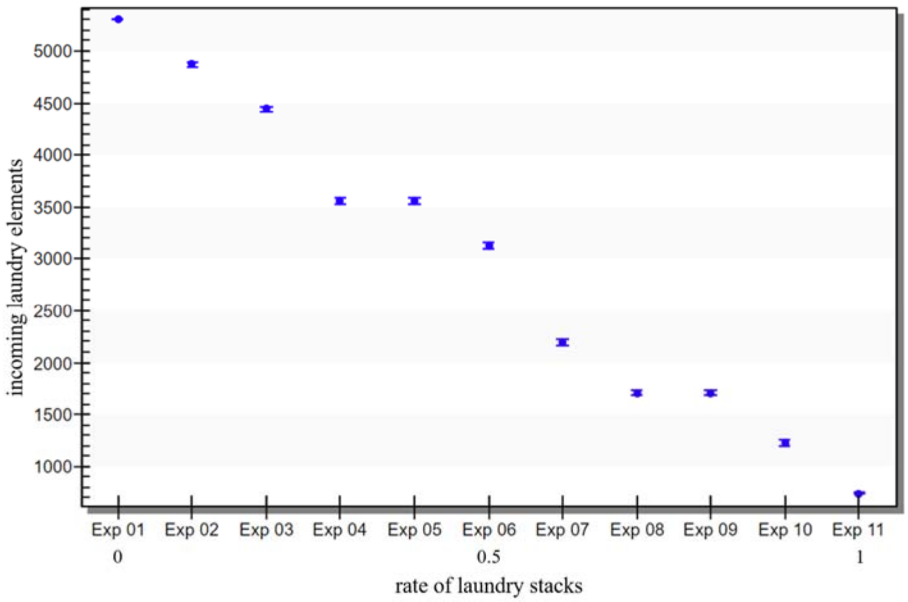

Figure 8: Confidence interval and average number of incoming elements in dependence of the rate of incoming laundry stacks.

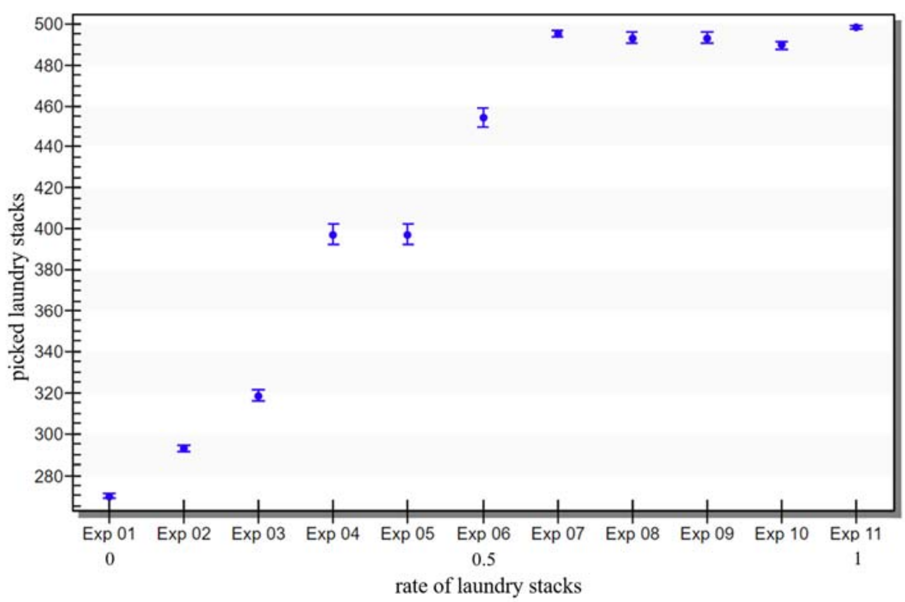

Figure 9: Confidence interval and average number of picked laundry stacks leaving the sink in dependence of the rate of incoming laundry stacks.

Another aspect is the dimensioning of the rack row. Initial experiments show whether long or high shelves are more effective and when it is useful to place a laundry item the next higher shelf level. For this experiment, we set the laundry stack rate to 50 percent to see different throughput at the sink, because the picking system cannot handle every picking order. The changing adjustment parameters were the length of the shelves from 5 – 10 meters, the number of shelf levels from 3 – 8 and the target relative occupancy of the shelf levels from 40 to 80 percent. Even with big increments, the different combinations resulted in 180 experiments and in consequence of 10 observations per experiment in 1,800 simulation runs. Figure 10 shows the average results of the experiments and their confidence interval. Six larger cluster are recognizable which are the result of the changing length of the rack row.

The first cluster (experiment 1 – 30) represents the results with a shelf length of 5 meters and the last cluster (experiment 151 – 180) consists the results of a shelf length of 10 meters. The cluster with the best performance has a shelf length of 7 meters (experiment 61 – 90). There are also some outlier values (experiment 1, 6, 11, 16, 21, …), especially in the first clusters. They have in common a targeted relative occupancy of 40 percent. Our conclusion from this is that, especially with shorter shelves, a high relative occupancy of the shelf levels should be sought. For longer shelf levels, the negative deviations are smaller and could also be considered as a strategy. The number of shelf levels currently does not seem to have a significant impact on the throughput. We suspect that this is due to our assumed incoming material flow, which does not yet require large quantities to be stored for a longer period and, therefore, also does not need to utilize the higher shelf levels.

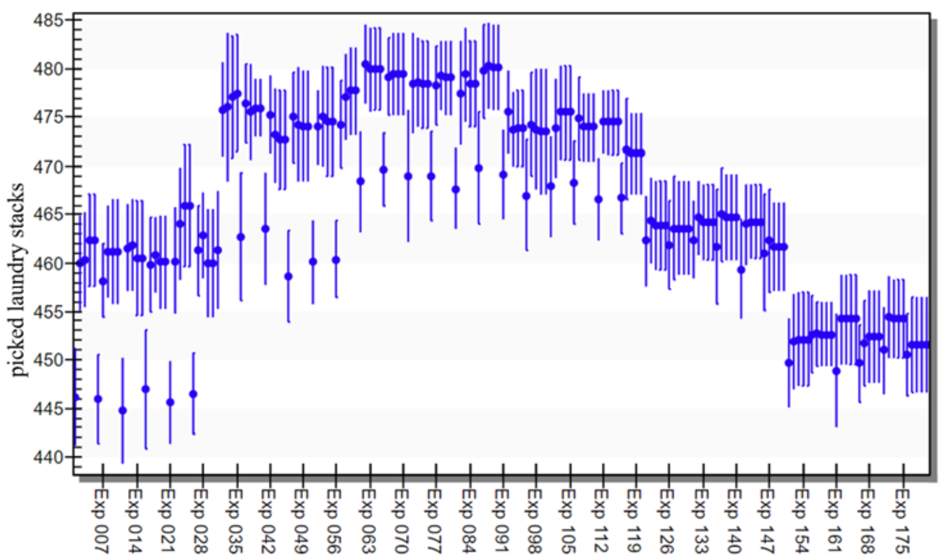

Figure 10: Confidence interval and average numbers of picked laundry stacks leaving the sink in dependence of length of shelves, number of shelves, and target relative occupancy of the shelf levels.

4 CONCLUSION AND OUTLOOK

In this paper, we have shown, how simulation models can help in early stages of planning processes of automated picking systems. The microscopic approach allows us with a 3d model for visualizing and testing special situations to early detect possible problems in the future. It is possible to model and simulate flexible storage allocation and sizes together with stacking objects.

Our initial calculations have already shown that it is a difficult field to develop cost-saving picking solutions due to the peculiarities of laundry logistics. The cost pressure does not allow for a high amount of storage and retrieval units and in consequence the throughput of the system is restricted. The right balance of the target figures is a task for the coming year.

The results of the first experiments show that different parameters have a different impact on the throughput. It also turns out that when parameters take specific values, the target figures can have outliers. This was the case for the target relative occupancy of shelf levels. Another aspect is the composition of the incoming material flow. The rate of laundry stacks and the type of laundry (because of the dimensions) are decisive for the actual load of the system.

In the further course of the project "LOCSys", the interface between the picking algorithm and the simulation model will be realized. Next year, the connection will be made to the PLC to generate forecasts using real-time data and to issue intelligent commands to the picking system. We are excited for the final results of our project and we will share any further progress and findings in the future.

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