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A new Simulation Approach for Scheduling Consolidation Activities in Intralogistics - Optimising Material Flow Processes in Industrial Practice

Entwicklung einer Simulationsstruktur für die Planung von Konsolidierungsaktivitäten in der Intralogistik - Ein Optimierungsansatz für den Materialfluss in der industriellen Praxis

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Abstract: This study assesses the impact of different strategies for scheduling stock-release timings within a consolidation framework with two different sources in a schematic warehouse, which is investigated in cooperation with “Continental Geschäftsbereich für Antriebskomponenten”. The strategies are simulated in line with parameter inputs from the industry partner and compared in terms of average consolidation times per order and consolidation space requirements. Subsequently, a simulated annealing approach is deployed in order to identify optimised release timings for the given strategies. The results of this study show that employing these timings in combination with a “combined scheduling strategy” may result in a 20.4 % decrease of consolidation times as well as a 25 % decrease in space requirements.

1 Introduction and Problem Statement

A dynamic environment requires permanent adaptation of intralogistics processes in order to sustain the performance and competitiveness of a business. In many cases, distribution centres are equipped with automatic storage solutions and conveyer systems to ensure unobstructed processing of customer orders (Forstner et al. 2017). However, manufacturing companies with manifold production lines still struggle to efficiently coordinate their internal scheduling processes (Kallrath 2002). A large product assortment in terms of quantity and variety requires bundling of customer orders, which in turn necessitates elaborate picking and consolidation activities (Florian et al. 2011). Due to flexible and fast-paced customer requirements as well as a large product variety in the automotive industry, major suppliers of spare parts have to group and merge products, hereinafter called items, for individual customer orders to be able to cope with the given demand (Coronado Mondragon et al. 2006).

In the case of this simulation study, which is investigated in cooperation with "Continental Geschäftsbereich für Antriebskomponenten" (ContiTech), a schematic warehouse is given. The scheme represents a typical layout in industrial practice and features four depot parts: one depot for full pallets, two depots for half pallets and one fully automated depot for small items - automatic small part storage (ASP). Except for processes in the automatic storage area, warehouse operations are executed manually, with each storage depot featuring different picking, deployment and transit times. As in most manual warehouses, transportation activities within intra-processes are realized by employing forklift trucks. Required items are provided from a buffer in front of the respective storage depot, where they subsequently are collected and transferred to the consolidation area via a milk run circulation system.

For the transition from picking buffers to consolidation zones, autonomous guided vehicles (AGVs) are used. Correspondingly, the respective items are transferred by the AGVs to the consolidation buffers, which serve as limited entry areas for consolidation processes (hereinafter called consolidation zones). Pallets from the full pallet depot (FPD) as well as mix-full pallets with more than 350 handling units from the respective half pallet depot (MPD) are directly transferred to the shipping area and not processed in the consolidation zones. In contrast, low volume pallets from the second half pallet depot (HPD) carrying less than 350 handling units as well as small load carriers from the ASP are lead over to the consolidation zones and combined according to customer orders. The consolidation zones are homogenous in terms of orders, meaning that items for exactly one particular order are collected and provided in each zone. Consequently, stock-release timings for individual items from the respective storage locations have to be controlled in order to match arrival times of corresponding order items at the consolidation zone. When arriving at the consolidation area, the AGVs automatically unload corresponding items and assign them to a consolidation zone. As soon as an order has been processed, the zone becomes available for the next order, whereby all consolidation jobs are processed with a given processing time per employee and job. Items that cannot be assigned to a zone due to high occupancy have to be inter-stored to be consolidated at a later stage. Finally, the consolidated orders are transferred to the packaging line and consecutive outbound processes. An exemplary layout and a schematic overview of the relationships between items, staff and AGVs as well as the storage conditions is given in Figure 1.

Accordingly, in consideration of limited available spaces, inter-storage of items due to full zone occupancy has to be avoided to guarantee an efficient workflow. Moreover, it needs to be ensured that the idling and processing times within the zones are minimized in order to optimally utilize the given resources. In general, a goal correlation between consolidation times, stock-release timings (SRTs) and full time equivalents (FTEs) is given, whereas the releasing activities act as influencing factor in order to avoid idling times of FTEs in the consolidation area. While the area itself is constant and not subject to be changed, mainly the scheduled release times from the ASP and the HPD can be variably adapted in order to identify a set-up where the above mentioned objectives are met.

With this simulation study, we aim to develop a simulation model for analysing processes for a prospective consolidation area of our industry partner and consequently improving the organization's scheduling activities concerning SRTs.

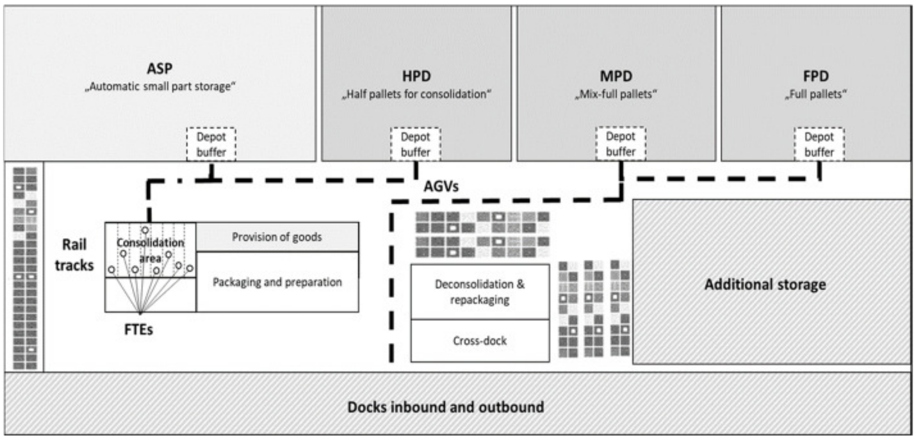

Figure 1: *Exemplary warehouse layout*

In the first step of the research, generic strategies for scheduling the mentioned parameters within the scope of an industrial production approach are outlined. Subsequently, a simulation model representing the use case system is developed and executed with parameter set-ups according to the identified strategies. Finally, simulation results are analysed and evaluated in order to provide recommendations on optimising consolidation-scheduling activities in terms of low volume stock-release timings. An overview about the research approach is shown in Figure 2.

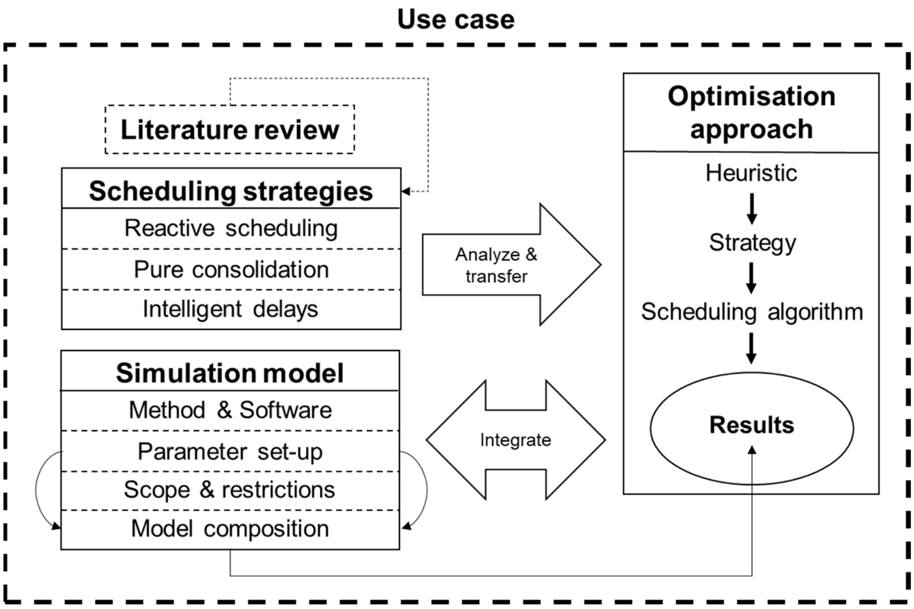

Figure 2: *Research approach*

2 Related Work

In line with various simulation modelling methodologies, process-oriented intralogistics and material flow simulation for scheduling consolidation activities can be classified in two categories: discrete-event and agent-based simulation.

Discrete-event simulation deploys micro-processes as basic modelling unit and therefore often is used for process applications (Long, 2016). With first approaches of this technique already evident in the early 1950s, to date, manifold studies have examined its scope of application in logistics processes and in a supply chain context (Tako and Robinson 2012; Mourtzis et al. 2014; Seebacher et al. 2015).

In contrast, agent-based simulation uses agents as basic entity within a simulation model, representing physical as well as non-physical and fictional objects within the material flow network. This modelling approach aims at both, decision-making support on a microscopic as well as macroscopic level and works by simulating agent-behaviours, interactions in multi-dimensional flows and interdependencies within agent-networks. Relevant studies on agent-based simulation models and techniques for supply chain applications and intralogistics have been conducted by Roidl and Follert (2007), Güller et al. (2013) and Hübl and Strasser (2015).

In general, scheduling approaches can be classified in network-based and batch-based approaches, whereby the former is used to address problems in complex networks with batch mixing, splitting and recycle streams, whereas the latter is used for discrete, single-stage, multi-stage and multi-purpose processes where batches are processed sequentially, as in the case of consolidation activities (Maravelias and Sung 2009). Generally, generic scheduling problems in production contexts are defined by the flow shop pattern, namely job shop, flow shop, open shop, single machine shop and permutation open shop. While these have extensively been reviewed since the 1950s in less (e.g. Bowman 1956; Rodammer and White 1988) as well as more recent literature (e.g. Lu et al. 2016; Patisson et al. 2017), research in the field of scheduling SRTs for different sources is rather limited.

Huercio et al. (1995) propose a reactive scheduling algorithm, where a supervisory system is used to flexibly adapt current schedules to real time disturbances. Within this strategy, changes concerning starting times of tasks are considered in a decision tree level based on heuristic rules. Another popular scheduling strategy in production environments was developed by Abdelwahab and Sargious (1990), who suggest a "pure consolidation policy", where relevant items for a customer order are dispatched from the respective warehouse location as soon as they are available. Finally, based on research on the impact of delays between tasks on consolidation patterns from Dewan et al. (1997), we introduce an "intelligent" approach, where items from different sources belonging to the same order are delayed dynamically based on the release duration of individual order items, allowing to match the arrival time of corresponding order items at the consolidation zone.

While several simulation approaches and best practice papers for intralogistics are available, very limited simulation studies for the given use case, namely scheduling SRTs for consolidation sources are present yet (McWilliams et al. 2008; Elbert et al. 2015). In contrast to the given studies, we use a multi-method modelling approach in order to reflect material flow network realities and provide an effective, collaborative simulation model. Moreover, multi-dimensional flows, acting as major influencing factors in an intralogistics network operation, are included in the simulation methodologies. Thus, to fill the research gap, this paper addresses the research on solving scheduling problems related to consolidation activities within the scope of a typical material flow network system and establishes a multi-methodological collaborative simulation model to support decision-making and improve consolidation processes in terms of SRTs from several depots.

3 Preparation of the Simulation Study

The simulation model for the given case is developed with the java-based multi-purpose tool AnyLogic 8, featuring multi-method modelling, including discrete-event, agent-based and system dynamics simulation. In order to reflect the autonomous behaviour and interactions of certain agents (e.g. reactive control of storage depots by a supervisory system) within the process-centric consolidation model, a combined simulation approach featuring discrete-event as well as agent-based simulation techniques has been chosen. The overall scheduling problem as given for the consolidation activities in the use case can be described as follows:

According to the given customer orders, x consolidation jobs $\{J_1, J_2 \dots J_x\}$ have to be processed, with eight available consolidation zones $\{Z_1, Z_2 \dots Z_8\}$. The flow pattern of zones for any job is flexible, but homogenous in terms of orders. The processing of job J_i in zone Z_i is called an operation, denoted by O_{ij}. Depending on the order list, each zone receives at least two consolidation jobs and operations before a shipment $\{S_1, S_2 \dots S_n)$ is released. For each operation O_{ij}, an associated processing time t_{ij} is given, after which the operation is completed and released from the respective zone in the consolidation area. A schedule in this context describes the SRTs of the ASP $\{ta_1, ta_2 \dots ta_n\}$ and the HPD $\{th_1, th_2 \dots th_n\}$ for controlling the chronological assignment of jobs to consolidation zones. To measure items that have to be inter-stored due to zone occupancy, a virtual buffer is implemented, counting the amount of inter-stored items on a working day. To increase the practical relevance of the study, an exemplary, historical order list from the industry partner is used for compiling customer orders and generate consolidation jobs.

The simulation model has been developed in line with the characteristics and processes of the use case described in the introduction. It is utilised to investigate ideal stock-release schedules as well as strategies concerning the given target variables and includes all internal operations affecting the performance of consolidation activities within the system, such as sequencing, processing and transporting. In accordance with frequent scheduling theory literature (e.g. Maccarthy and Liu 1993; Sawik 2016), it is assumed that each consolidation zone can process an unlimited amount of consolidation jobs in total. Required processing capacities in the consolidation area, namely FTEs, are always available and no pre-emption is allowed. HPD and ASP are simulated as black boxes with unlimited capacities. Access times in the warehouse depots are determined in line with the mean values of real data from our industry partner. In order to avoid poor results due to deterministic access times and reflect real research scenarios, access times are stochastically varied by means of a normal distribution. Hence, the only control variable for the depots are stock-release timings, whereas human resources, picking times, picking strategies, depot layout and other performance indicators for storage areas are not considered. Figure 3 supplies a synopsis on relevant input parameters and scheduling conditions included in the simulation model.

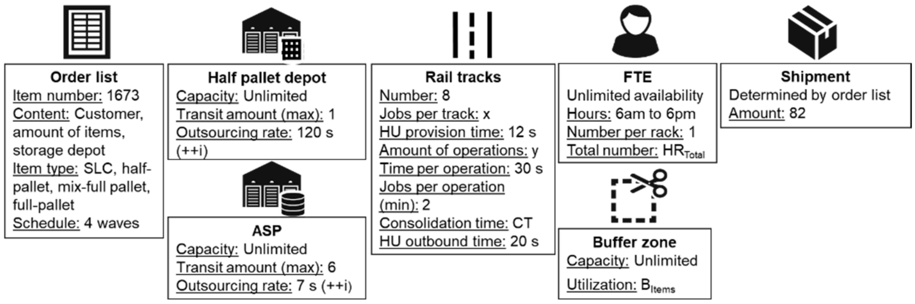

Figure 3: *Parameter overview for the given use case*

4 Optimisation Approach

Within the context of this study, we compare three different scheduling approaches for the given consolidation problem. While “pure consolidation” is a static concept, proposing set rules for timing release activities of the storage depots, “reactive scheduling” requires flexible adaptation of timings depending on the given process flow. Accordingly, the virtual buffer measuring the amount of items that need to be inter-stored acts as influencing factor. As soon as the zone utilisation increases to a specified threshold value, the simulation model dynamically adjusts the release timings of the storage depots in an iterative process to avoid buffer utilisation. Consequently, SRTs for ASP and HPD are delayed based on the following rules, whereby the ideal value of the multiplier has been priory computed by means of a parameter variation simulation experiment:

1. Zone occupation <= 4: SRT
2. Zone occupation = 5 – 6: SRT raised by 10% (ASP) and 4% (HPD)
3. Zone occupation = 7 – 8: SRT raised by 20% (ASP) and 8% (HPD)
4. Buffer utilisation (Z > 8): SRT raised by 40% (ASP) and 16% (HPD)

For the „intelligent delay“ strategy, each order is separated into a different queue, representing orders from the ASP as well as the HPD. Afterwards, an algorithm complements the shorter release time by the difference of the longer and the shorter release time in order to match arrival timings at the consolidation zone.

Subsequently, simulated annealing is used in order to find and compare optimised SRTs for ASP and HPD within the use case scenarios. In the context of the simulated annealing approach, a meta-strategy local search heuristic starts by generating an initially random solution s, which is inter-stored as current solution C(s). Afterwards, using a move strategy at each iteration, the heuristic generates a new solution s’ and subsequently compares the quality of both solutions in terms of avoiding buffer utilisation (B_{Items}) and minimising the amount of utilised consolidation zones (Z_{Total}) as well as consolidation times of all orders (CT_O with O = {1 … n}) in a specific zone (Z). If the quality is ranked higher, the heuristic replaces the current solution, otherwise the new solution is discarded. In order to avoid a poor local optimum, the algorithm follows a random acceptance strategy, where the process of replacing a current solution is distributed randomly, with a given probability of

$$P = \exp\left(\frac{\Delta Css'}{T_k}\right) \quad (1)$$

with $\Delta C_{ss'} = C(s') - C(s)$ and T_k being a control parameter called "temperature", which is updated in accordance with a deterministic "cooling" schedule (Metropolis et al. 1953). For initialising the cooling schedule parameters, a search test cycle covering all initial solutions s is performed, without exchanging values in order to obtain the largest and smallest change (Δ_{max}, Δ_{min}) as well as an estimate of the total number of feasible changes N_{feas}. Results of the test cycle are set as follows:

$T_s = \Delta_{max}$, $T_f = \Delta_{min}$, $T_r = T_s$, $\alpha = n \times N_{feas}$, $\gamma = n$, and $k = 1$.

Temperatures are updated by a normal decrement rule:

$$T_{k+1} = \frac{T_k}{(1+\beta_k T_k)} \text{ with } \beta_k = \frac{T_s - T_f}{(\alpha + \gamma\sqrt{k})T_s T_f} \quad (2)$$

The stopping value is set by limiting the maximum value for k. As move strategy within the simulated annealing algorithm, the random move strategy is applied, where a universal set of all solutions obtainable is created by generating a new random permutation. For evaluating the quality of each new solution, a scoring algorithm maps each permutation against three decision variables. The primary scoring condition is to minimise the average consolidation time of all orders (ACT_o), while secondary the amount of utilised consolidation zones (Z_{Total}) is minimal and the buffer storage will not be employed ($B_{Items} = 0$), with ACT_o equalling

$$\sum_{O=1}^{n} \frac{CT_O}{n} \quad (3)$$

5 Results

By means of multiple simulation runs, a total of 205,205 solutions have been created. In the first step, "pure consolidation", "reactive scheduling", "intelligent delay" as well as a combined strategy deploying both "reactive scheduling" and "intelligent delay" have been individually assessed concerning the prior defined target variables. For comparison purposes, we additionally simulated a base case, where all order are released in an unstructured and unsorted manner (FiFo-Principle). For all scenarios, SRTs have been set in accordance with data from our industry partner **(ASP = 8 s, HPD = 310 s)**. In order to identify ideal release times for ASP and HPD, a simulated annealing approach with a random acceptance strategy has been used, indicating specific timings capable of reducing the average consolidation times for all orders. In line with information from the industry partner, ASP release times cannot fall below 7 s, while the fastest release time from the HPD equals 185 s per item. Because one zone always contains one FTE, Z_{Total} simultaneously indicates the total amount of required human resources for consolidation activities.

Figure 4 shows the results for each strategy in terms of average consolidation times per order, including the amount of consolidation zones required. In the first case, if parameters are not optimised, ACT_o is minimal for the "combined strategy", with a difference of 18 % compared to the "FiFo" case and 3.5 % compared to "pure consolidation". However, even though "reactive scheduling" requires more time (2.1 % compared to "combined"), this approach allows for a decreased zone utilisation (Z_{Total}) of seven zones, potentially resulting in reduced operational costs. In contrast “pure consolidation” and “intelligent delay” do neither result in decreased consolidation times, nor in less consolidation zones required.

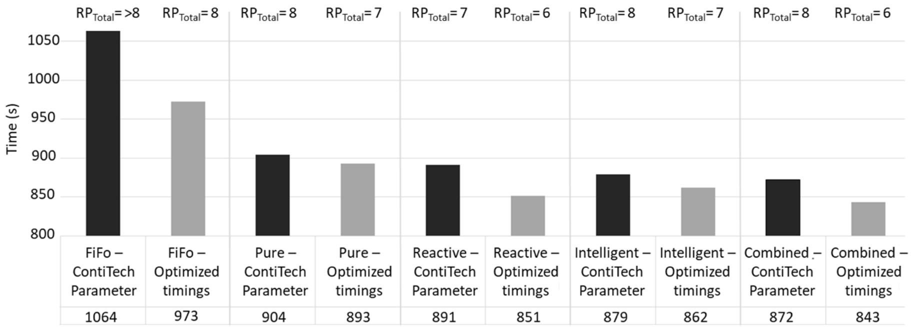

Figure 4: *Consolidation time per order and utilised zone based on chosen strategy*

If optimised stock-release timings are applied, namely **190 seconds for the HPD and 14 seconds for the ASP**, ACT_0 as well as Z_{Total} are also minimal for the “combined strategy“, with “reactive scheduling” being less effective by 1 % in terms of ACT_0 and both scenarios requiring six consolidation zones. On average, when optimised parameters are deployed, consolidation times for the “combined strategy“ are 13.4 % shorter compared to the ”FiFo” set-up and 20.7 % shorter, when compared to the worst performing strategy within the initial framework. This leads to an overall improvement of the average consolidation time of 221 seconds per order. In the course of our analysis, a strong correlation between HPD, SRTs and ACT_0 as well as Z_{Total} has been observed, as an increasing release time results in lower spreads between the “combined strategy” and “reactive scheduling”.

6 Conclusion

We have provided an approach for assessing and optimising release timings in the context of consolidating customer orders from different storage depots. Several timing strategies have been exploited and analysed in order to identify a suitable approach to decrease consolidation times and consolidation zone utilisation, potentially resulting in decreased operational costs as process flows can run more efficiently and the number of FTEs for consolidation activities can be decreased. The “combined” and the “reactive scheduling” approach have proven to be very effective strategies in terms of reducing average consolidation times as well as zone utilisation, both for initial and optimised SRTs from the different sources, whereby the “combined strategy” slightly outperformed “reactive scheduling”. On the contrary, “pure consolidation” and “intelligent delay” strategies always are less favourable in comparison to the other strategies. A “combined” approach is also useful, if an organisation has reasonably high SRTs for a given source (here HPD). In general, the results of our research provide an indication about suitable scheduling strategies when it comes to consolidation activities in an intralogistics setting. Moreover, the simulation and optimisation approach serves as valuable foundation for assessing and improving consolidation procedures, especially as multi-method modelling approaches for industrial intralogistic problems are yet very limited. Nevertheless, the specific results presented in this paper depend on manifold individual factors like the order list, the production setting and the warehouse layout, for which reason the generalisability is limited.

While current results already aid in improving operational performance of production organisations engaging in consolidation, future research needs to address different target variables like operational costs depending on fixed and variable factors. Moreover, it can be beneficial to evaluate the impact of the amount of FTEs per zone and to develop an additional approach for optimising the order sequence.

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