Simulation and Optimization of a Pull-Strategy in the Order-Picking Area of a Distribution Warehouse

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Abstract

In this paper, an approach using simulation and optimization to maximize the throughput of an order-picking area is presented. The retrieval of pallets from a high-bay warehouse to the picking stations is formulated as an assignment problem and solved. To consider the dynamic effects of the materials handling system (conflicts, blocking), the optimal static assignment is validated with simulation.

The obtained results are very promising. The throughput was significantly improved.

Introduction

Industrial material flow systems consist of several sources and destinations, connected by different kinds of materials handling systems such as conveyors, forklifts or automated guided vehicles (AGV). The demand of every station has to be satisfied (under the given capacity restrictions), work-in-process (WIP), sojourn-time have to be minimized and throughput respectively maximized.

To achieve this, typically non-mathematical approaches such as heuristics are implemented (Tompkins and White, 1984), (White and Pence, 1989), (Han et al., 1987). The problem of heuristics is, that the mathematical optimum is not necessarily obtained and an estimation is not given in regard to the quality of the solution in comparison to the optimum. The application of Operations Research methods is only found in a few papers (Askin and Standridge, 1993).

Distribution warehouse

In order to fulfil rising customer orders, an existing distribution warehouse was completly redesigned. Changes in the layout, the order-picking, packing and shipping areas were made and a new computer system for inventory control and order processing was installed.

To meet the customer-demand at minimal time of delivery, it is required that an order accepted around noon will be complete until 3 pm at the shipping docks, ready for delivery.

Each customer order contains any number of line items. The orders are collected into time-frames (batches) using the EDD-rule (earliest due date). Each batche has a fixed size of 2 hours.

The completion of orders is done in a two-stage strategy. In the first stage, each line item of the current batch is put into a different bin. In the second stage, the bins containing the line-items of one order are collected, packed, labeled and transported to the shipping docks. The advantage of this strategy is the implicit parallelism to the first stage. It is not necessary to retrieve a pallet only for one pick. All possible picks of the current batch are made in sequence. Moreover, the transport can be done

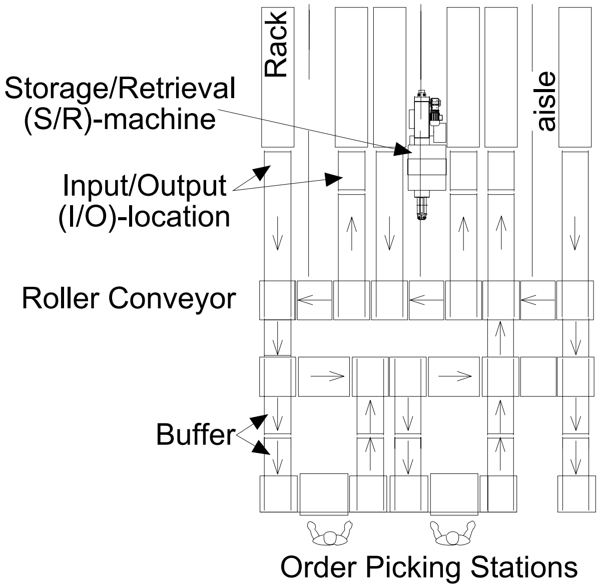

Figure 1: Partial layout of the distribution warehouse. Shown are 3 aisles with the rack, the Storage/Retrieval-machine (S/R), the Input/Output locations (I/O), roller conveyors and two picking stations.

automatically (figure 1) using roller conveyors.

A high-bay warehouse with an automatic storage and retrieval system is used to store the pallets and supply the order-picking area, partially shown in figure 1. Each pallet contains exactly one type of item.

The batch around noon (1pm-3pm) contains the most orders and is called a *peak*-batch. With the existing control strategy, it was not possible to fulfil all orders of the peak-batch until 3pm. That means, the shipping of some orders is delayed for one day.

In order to gain high utilization of the workers at picking stations, a *pull*-strategy is introduced. Each worker automatically triggers the retrieval of the next pallet when the current one is completed.

Maximizing the throughput in the static case

The problem of maximizing the throughput can be modeled as an assignment-problem of storage locations to picking stations under certain constraints. The result can be obtained by a standard LP-solver (Section *Optimization Model*). At bottlenecks (high utilization around 100 %, here the order-picking-area) stochastical influences and dynamic behaviour become more important. Therefore a simulation is necessary to validate the static optimal assignment (Section *Simulation*).

Optimization Model

The throughput of pallets can be maximized by minimizing the transportation-time. Every pallet should then be transported on the shortest path. In this application the length of the path is equal to the transportation time.

Let x_{ij} be the number of pallets transported from storage location i to picking station j, y_{ji} vice-versa, n the number of S/R-machines and m the number of picking stations. With the velocity of the conveyors the matrix of transportation-time t_{ij}, respectively u_{ji} can be computed.

With this, the objective function is:

$$\begin{aligned} MIN\ Z(x,y) &= g_1 \sum_i^n \sum_j^m x_{ij} t_{ij} \\ &\quad + \sum_j^m \sum_i^n y_{ji} u_{ji} \end{aligned} \tag{1}$$

with

$$\sum_j x_{ij} \leq \mu_i \quad \forall\, i \tag{2}$$

$$\sum_i x_{ij} = \gamma_j \quad \forall\, j \tag{3}$$

$$\sum_i \mu_i \geq \sum_j \gamma_j \tag{4}$$

$$t_{ij} \leq \frac{N_{p,j}}{\gamma_j} \quad \forall\, j \tag{5}$$

$$\epsilon \geq \left| \frac{\sum_i \sum_j x_{ij}}{n} \right| - \sum_j x_{ij} \quad \forall\, i \tag{6}$$

$$\epsilon \geq \left| \frac{\sum_i \sum_j y_{ji}}{n} \right| - \sum_j y_{ji} \quad \forall\, i \tag{7}$$

$$\sum_i x_{ij} = e \sum_i y_{ji} \quad \forall\, j \tag{8}$$

The objective is to minimize the total transportation-time. Any unnecessary delay in supplying the picking-area should be avoided. A delay leads to loss of utilization at the picking stations and the successive processing steps. Therefore, a weighting-factor g_1 is introduced to force the transportation *to* the picking area rather than *back*.

The maximal retrieval and picking rates are μ_i, respectively γ_j. Constraints (2) and (3) ensure that the capacity-restriction of the retrieval/picking rates are not violated and the demand of the picking stations is met.

When applying order-operating with a pull-strategy one has to ensure that the transportation system isn't the bottleneck. This can be obtained by the installation of local buffers.

Constraint (4) ensures that the sum of the retrieval rate of the S/R-machines is higher than the demand rate of the picking stations (which are the bottlenecks in our case).

With the number of pallets $N_{p,j}$ in the buffer of picking station j, the higher bound of the transportation-time of a pulled pallet is $\frac{N_{p,j}}{\gamma_j}$, stated in constraint (5).

If the picking rate is much lower than the retrieval rate (which can happen during the afternoon hours or seasonly dependent), some S/R-machines would be idle. To avoid this, constraint (6) ensures that the number of retrieved pallets of every S/R-machine is beyond a certain ϵ-bound. Constraint (7) ensures this for the restoring of the pallets after picking. This constraints lead to an equal utilization of the S/R-machines.

Constraint (8) is the flow conservation for every picking station. The factor e is introduced to capture the number of pallets, which became empty during the picking and are not transported back.

Simulation

The object-orientated simulation-tool *SiMPLE++* was used to model the order-picking area. A library of classes like picking stations, S/R-machines, I/O-locations and the different conveyor elements was implemented to allow easy adaption for other applications.

The arrival rate at the receiving docks, the representative storage/retrieval rates of every S/R-machine, the velocity of the conveyor, the time needed for switching at the divert elements, the picking rate and buffer-size of every picking station were stored and implemented as a global input. The picking rate was assumed to be normal distributed.

S/R i	x_{i2}	$\frac{x_{i2}}{\gamma_2}$	e_{i2}	r_{i2}	d_{i2}	prio
4	15	0.3	48	47	-1	2
2	25	0.5	80	83	3	3
3	10	0.2	32	30	-2	1
sum	50 (γ_2)	1	160	160	0	

Table 1: The dynamic priority table to control the pull-strategy for picking station 2 after updating, before sorting.

With this, the optimization model was automatically generated and solved.

For each picking station the resulting assignment of the LP-Model was stored in a table. Let's state r_{ij} as the *real* number of pallets already been transported from the S/R-machine i to picking-station j. Than the *expected* number e_{ij} can be computed by

$$e_{ij} = \frac{x_{ij}}{\gamma_j} \sum_{i=1}^{n} r_{ij} \tag{9}$$

After every completion of a pallet, r_{ij} is updated and the new differences $d_{ij} = r_{ij} - e_{ij}$ are computed (see table 1). To get the new sequence in which the aisles have to be checked for pallets, the table is sorted by d_{ij}.

If the S/R-machine with the highest difference between real and expected number of retrievals is busy and the buffer of the I/O-location is empty, the S/R-machine with the next lower difference is checked.

If a retrieval is not possible (back-order-demand), the demanding picking station is put into a queue. When a new pallet is retrieved by any S/R-machine, the back-order-demands are satisfied first.

For unused or disturbed picking stations respectively S/R-machines the retrieval/picking rate is set to zero. Therefore the user can perform a *what-if-analysis* to check how much workers for every batch, or the whole day are needed.

Experimental design

The main goal of the project was to maximize the throughput of the picking area. Four parameters can be modified, the lower value is calculated by the planners of the distribution warehouse:

- Buffersize of each picking station, N_p: Due to layout constraints the number is the same for every station. Increasing the number would be a big effort, but under certain circumstances it could be necessary to take it under consideration.

- Picking rate μ_p: The picking rates are assumed to be the same for each picking-station. If the batches are larger, the worker has to pick more line-items per pallet. With this, the handling-time in the station is reduced. Therefore the picking rate is increased.

- Retrieval rate of the S/R-machines μ_r: The retrieval rates are assumed to be the same for each S/R-machine. Strategies like zoning (Goetschalckx and Ratliff, 1990), (Guenov and Raeside, 1992), where pallets with the highest exchange-rate are stored next to the I/O-Location, can increase the retrieval rate without changes in the hardware. The strategies are (relatively) easy to implement.

- Usage of the assignment as calculated by the linear optimization or the practical (rule of thumb) one.

These four parameters are analysed using a 2^k factorial design, giving 16 design points (for description of experimental design, see (Law and Kelton, 1992), (Box et al., 1978)). The coding chart is shown in table 2.

Factor j	Parameter	-	+
1	N_p	2	4
2	μ_p	45	55
3	μ_r	35	45
4	assignment	thumb	LP

Table 2: Coding chart

For each design point, 5 replications are made, the results are shown in figure 2. A steady state is reached after a simulation run time of 2h, every replication is run 48h. In real-time this takes around 65 min on a Pentium Pro Workstation.

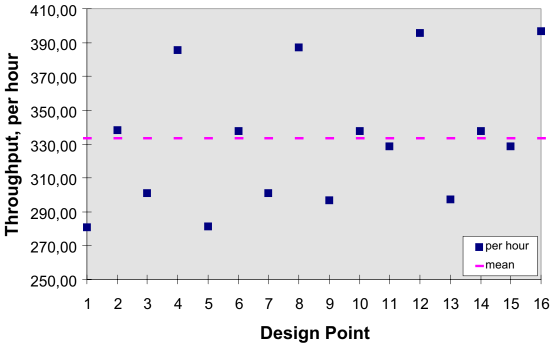

Figure 2: Output-Analysis: Throughput per hour

Figure 3 shows the 95% confidence intervals in percent of the corresponding mean for each design point.

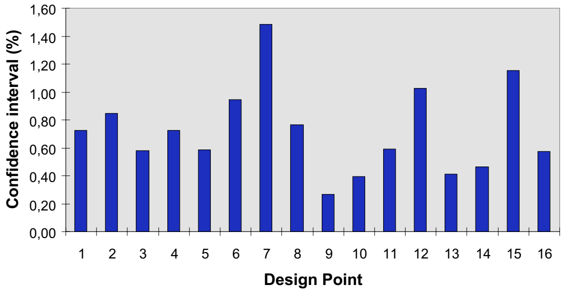

Figure 3: Output-Analysis: Confidence interval, in percent of corresponding mean

Interpretation of Results

The main, two-, three-, and four-factor effects are shown in figure 4, given in percentage of the *overall mean.*

The main effect is caused by *factor 1*, the buffersize. The zone was planned using only the static transportation time, but the simulation shows that the dynamics of the system can not be neglected when creating the system. Even if the number is doubled, the utilization of the workers at the picking station does not

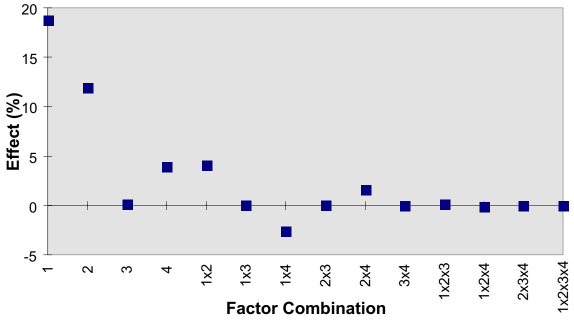

Figure 4: Effects of factors j

exceed 0.94, as shown in figure 5. This results shows, that enough buffer-capacity must be provided if a pull-strategy is operated.

Increasing *Factor 2*, the picking rate, causes an increase in throughput, because ordering of a new pallet can be done faster. At the same time, this leads to a higher system load and due to dynamic effects, an increased transportation time.

The effect of *factor 3* is negligable, the retrieval rate of the S/R-machines does not influence the pull-strategy and the total throughput.

Factor 4 shows, that using an optimized assignment causes an increase of 4% in throughput, dependent on factor 1 and 2. The transportation time, and therefore the system load is reduced, the utilization of the worker is increased. If we analyse the real scenario, where factors 1, 2 and 3 are at their low level, and only factor 4 is varied, the increase in throughput is 5.3%. This result is remarkable, because it would be easy to implement it in the inventory control and order processing system and no changes in the hardware are necessary.

The two-factor effects (figure 4) show that factor combination 1x2, 1x4, and 2x4 are dependent.

Practical Application

The distiribution warehouse was planned for the static case. The simulation showed that the influence of dynamics on the system can not be neglected. The *rule of thumb*-assignment was replaced with the optimal one.

Increasing the batch size impacted the entire system, therefore further analysis is necessary. The installation of more buffers led to higher costs and should be financially evaluated.

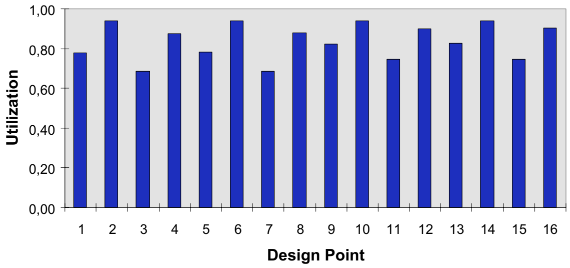

Figure 5: Utilization of picking-stations (mean)

Summary and Outlook

In the reengineering of a distribution warehouse a strategy to maximize the throughput in the order-picking area had to be developed. The system was modeled using SiMPLE++ and an optimization model for the assignment S/R-machines to picking-stations was formulated and solved.

The simulation showed, that the planned buffer size is to small to work well with the used pull-strategy. The usage of the optimized assignment gained 5.3% in throughput.

Further research will focus on the analysis of the pull-strategy and non-linear dynamic effects of the system caused by conflicts, deadlocks when the system load is closed to the maximal capacity.

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