Performance of Storage Strategies in a Highbay Warehouse

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***Abstract*— Storage and retrieval times of goods in inventory processes determine the efficiency of highbay warehouses in companies. These times are highly dependent on the performance of rack feeders. Storage strategies have the greatest influence on this performance. This paper shows the impact of an efficient control of rack feeders through storage strategies. Storage strategies which are typically used in industrial inventory processes are analysed. For the analysis, a simulation system is implemented, so that the real process times are similar to the simulated ones. This results in recommendations for the use of storage strategies in companies.**

Keywords-Inventory processes, simulation of storages and retrievals of goods, storage strategies, highbay warehouse.

I. INTRODUCTION

In industrial production, huge warehouses, mostly in the form of a highbay warehouse, are used for the coordination of procurement processes, production processes and distribution processes within an enterprise and also between enterprises along the logistic process chain (see Figure 1 and [1][2][4]-[10][12]). In addition to this time bridging structure, inventory management becomes more and more important which realises an efficient order related picking [2][3][5]-[8][12]. Particularly, with an almost fully occupied automatic warehouse, the performance necessary for the handling of goods is not reached for picking in the warehouse.

Attempts are often made to improve the performance of warehouses by elaborate storage and handling measures [1][2][4][5][12]. In addition, in very highly automated companies, special approaches from research, as described in [14], can be used. An important performance criterion is the maximization of the handling of goods in the warehouse, i.e. the warehouse should be able to transfer to stock or to remove from stock as many storage units as possible within a given time span (e.g., an hour) [1][2][5]-[8][12][13].

Figure 1. View of a highbay warehouse – provided by Klug GmbH integrated systems.

The rest of the paper is structured as follows. Section II describes storage in large warehouses, Section III presents the key performance indicators, Section IV describes some storage strategies, followed by the testbed problem in Section V. Section VI presents the simulation study, with the results in Section VII. An analysis of the results is done in Section VIII and we conclude the work in Section IX.

II. STORAGE

With automatic warehouses, the product is stored in free-mounted racks. Figure 2 shows a model of a rack of the length L, height H and depth T (see [1][2][5]-[8]) and a Rack Feeder (RF). The RF is used to access the stored product.

The RF accesses the stored product usually stacked on palettes. A RF is an automated conveyor which simultaneously drives through a lane in a warehouse, heads for a certain rack shelf of height H about a lifting device and moves its load suspension device (LSD) into the rack shelves of depth T in order to pick or lay bins.

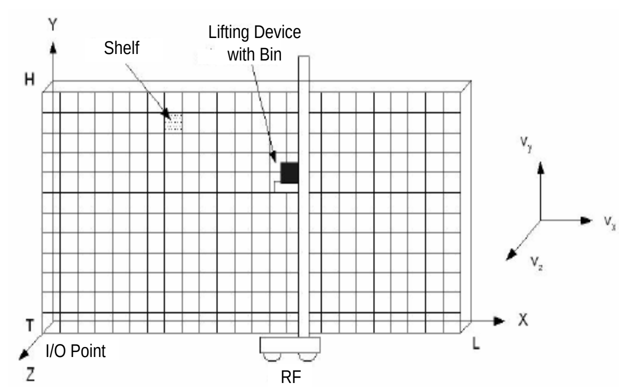

Figure 2. Model of a rack with rack feeder (RF) and entry (I) / exit (O) point (I/O point); speed (v) – see e.g. [8]

A rack feeder [1][2][4][8] can be used with single cycle or double cycle. With a single cycle, the rack feeder in the entry (I) / exit (O) point (I/O point) of the rack waits for a transport order. In the case of a transfer to stock, a bin is laid in the nearest free rack shelf. Afterwards, the rack feeder returns to the transfer point. In the case of a removal from stock, the needed rack shelf is headed and the bin is provided in the transfer point. With a double cycle, however, the rack feeder after an occurred storage (transfer to stock) can head immediately for another rack shelf from which a retrieval (remove from stock) should be affected.

III. KEY PERFORMANCE INDICATORS

The rack feeder operation has an effect on storage and retrieval times. These times are determined by the trajectory for the carriage and for the lift, because the number of goods which are transferred to stock or removed from stock are to be held steady during the analysis period. Such a trajectory is called working cycle, and the required time is called cycle time. The trajectory of the rack feeder consists of these phases: accelerating, driving at steady speed, braking, positioning at the destination. At the destination, a load suspension device cycle is carried out to take up or to deliver a bin. Such a cycle consists of extending the telescopic fork or table, lifting the lift truck, retracting the telescopic fork and lowering the lift truck – with a belt conveyor, there is no lifting and lowering.

Working cycles have variable driving times. The real speed is shown in Figure 3 (see also [1][2][5][7]). In most publications, times for accelerating, braking and positioning are not regarded. Instead, the well-known Tschebyscheff metric is applied on the constant speed in x and y directions.

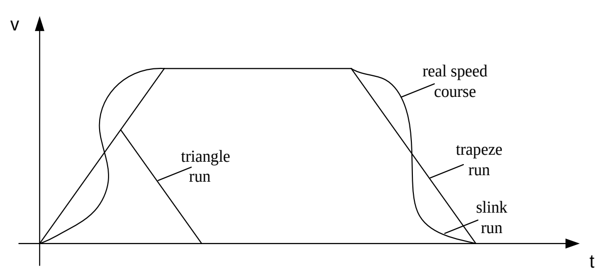

Figure 3. Real and simplified speed course (v).

Beside these variable driving times, a load suspension device cycle has constant times for positioning, for controlling that the correct shelf was reached and for switching as well as controlling operations. These times depend on specific technical data of a rack feeder. Altogether, this time is called "dead time".

In [1] and [7], for each single time, a formula is deduced in detail. The used simulation system calculates the single times by these formulas and their sum is the (total) cycle time. For the test problem which is described below, cycle times were measured and compared to the calculated ones. In each case, the difference between these times was less than one second. Therefore, the simulation of storages and retrievals of goods in a warehouse by a rack feeder corresponds to reality.

IV. STORAGE STRATEGIES

In today's industrial warehouse processes, the following storage strategies are applied [1][2][5]-[7]:

1. Accidental (storage):
   By an accidental storage, any free shelf is selected for the bin to be stored. Only restrictions about the size of a shelf and the allowed weight are considered.
2. (Storage after) Zones:
   The shelves in the warehouse are divided into zones. Each item is stored in exactly one zone. Therefore, each product has a so-called zone flag. For storing a product with zone flag F, a free shelf near to the I/O point with zone flag F is chosen.
3. (Strategy of the) Fastest neighbour:
   With double cycles, a storage shelf A to a retrieval shelf B is selected so that A can be reached from B as quickly as possible. With single cycles, the shelf for storage is chosen so that it can be reached from the storage track as quickly as possible.
4. Channel (optimized storage):
   In a multiple-depth warehouse, the bins are stored in a channel from two consecutive shelves. A free channel is searched so that:
   - as many bins as possible of the load suspension device fit – different bin types are often excluded for channels – and
   - the beginning of the allocation of a channel is avoided.
5. Combination of different storage strategies: A strategy is the combination of the strategies zones and fastest neighbour. In the case of single cycles, the strategy after zones is used. With double cycles, the strategy of the fastest neighbour is applied. In addition, various combinations of the strategies zones and channel – with various channels – are regarded.
   In a multiple-deep warehouse, various combinations of the strategies zones and channel are investigated. Normally, bins are stored by strategy zones. Only in special cases a specific type of strategy channel is used. These are:
   - Combination of strategies zones and channel 1:
     If all bins on the Load Suspension Device (LSD) have the same zone flag and in this zone no channel with suitable depth is free, then a suitable channel in an adjacent zone is chosen.
   - Combination of strategies zones and channel 2:
     a channel with the zone Flag (F) of the bin at position 1 in the LSD is chosen. This ensures that at least one bin is in the correct zone z. If the zone z is occupied, then a free shelf nearby zone z is chosen.
   - Combination of strategies zones and channel 3:
     The normal procedure that the bins are stored by strategy zones is used if all bins on the LSD have the same zone flag. Otherwise, strategy channel is applied.
     If the suitable zone is occupied, then strategy channel is applied.

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V. TEST PROBLEM

The problem is a modification of a small sized highbay warehouse at Leopold Fiebig GmbH in Karlsruhe, Germany. It consists of one aisle and two racks. Each rack has 10 fields in x direction (compare with Figure 2) and 32 fields in y direction. In z direction, there are two shelves, one behind the other. Each shelf can carry a bin. If both shelves are used and only the bin in the second shelf is taken, a stock transfer is necessary. Altogether, the warehouse has 1280 shelves. A rack is 4.5 m long, 8.5 m high and 1.30 m deep. The fields are started by a rack feeder which owns a load suspension device with two shelves. By a lifting bar construction of the rack feeder, high speeds in x and y direction are realized. Loading aids are stored twofold-depth or fourfold-depth. Such types of highbay warehouse are discussed in the literature under the name Commissioner (see, e.g. [4][9][10]).

VI. SIMULATION STUDY

For the simulation study, common commercially available simulation tools such as Plant Simulation from Siemens were first evaluated against a proprietary development. The tools allow extensive visualisations of the processes. However, they cannot significantly reduce the development effort required to control the handling of randomly arriving orders in and out of storage.

A tool is developed to simulate and analyse various highbay warehouses and storage strategies. It is implemented in C++. The tool uses an Oracle database for permanent data storage and to support the search for bays.

To validate the model, log files of the rack feeders in the highbay warehouse at Leopold Fiebig GmbH in Karlsruhe, Germany, were evaluated. These files were used to determine the driving time between the coordinates approached. With the help of a test module, the driving times of the rack feeders are calculated in the simulation for the same coordinates. Positioning times and grinding times are added to the calculated driving times and these are then compared with the real driving times. The differences in the driving times are less than one second. The simplifications mentioned above are likely to have a certain impact. This deviation is acceptable for the simulation. Thus, the simulation model and reality are identical if the simulation runs only slowly enough.

Due to the above-mentioned log files, accidental storages and retrievals appear – as typical in warehouses. In this case, they are normally distributed.

VII. NUMERICAL RESULTS

In industrial warehouses, the storage and retrieval of orders vary based on their importance described by an ABC indicator. For the simulations of an ABC indicator with the storage and retrieval orders 80% of A bin, 15% of B bin and 5% of C bin was chosen. With the single cycles or with the single and double cycles, 15 is the number of storages and retrievals per simulation experiment and 5 is the standard deviation. With pure double cycles, the standard deviation is put on 0 to receive the same number of storage and retrieval orders for every simulation experiment. The highbay warehouse in the test problem has three channels. Therefore, there are three combinations of the strategy zones and optimized channel, namely “combination of zone and channel 1”, “combination of zone and channel 2” as well as “combination of zone and channel 3”.

In the case of single cycles, Figure 4 shows the mean cycle times for the different storage strategies. These cycle times increase with the warehouse utilization. The increase is about 5 to 10% if the warehouse utilization rises from 50% to 99%. The strategy “channel” is mostly influenced by the warehouse utilization. With a warehouse utilization of 50% and 80%, the strategy “zone” delivers the maximum mean cycle times. With a warehouse utilization of 99%, the strategy “channel” has the worst value. The strategy “combination of zone and channel 3“ always delivers the minimum mean cycle times. The percental deviation of the best strategy to the worst strategy amounts with a warehouse utilization of 50% to 7.96%, with a warehouse utilization of 80% to 6.96 %, and with a warehouse utilization of 99% to 5.08%. So, the increase in output by the application of the best storage strategy with rising warehouse utilization becomes smaller.

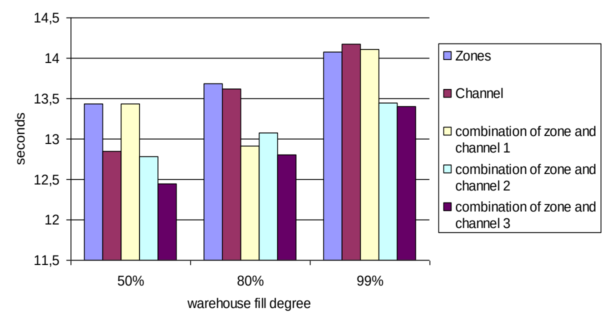

Figure 4. Mean cycle times with single cycles.

The use of the strategy “combination of zone and channel 3“ causes the least stock transfers, see Figure 5. The decrease of the number of stock transfers arises by accidental determination of the number of bins for retrievals – in this case, the number of bins for retrievals decreases. The probability of stock transfers is between 44% and 52%. The smallest values are reached for every warehouse filling degree by the strategy “combination of zone and channel 3“.

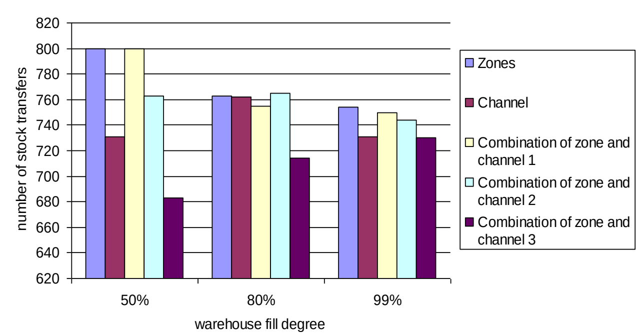

Figure 5. Number of stock transfers with single cycles.

Single cycles and double cycles give the same results structurally like with the single cycles; they are shown in

Figure 6. The percental deviation shows that the relative difference decreases between the best strategy and the worst strategy with rising warehouse filling degree and also the improvement in performance decreases by the use of the most favorable strategy. Also, in this case, the mean cycle time correlates with the warehouse filling degree.

Figure 6 shows the stock transfers to the single warehouse filling degrees for every storage strategy. The strategy "combination of zone and channel 3" has the smallest number of stock transfers at the warehouse filling degrees of 50% and 80%. With a warehouse filling degree of 99%, the strategy "channel" causes the smallest values.

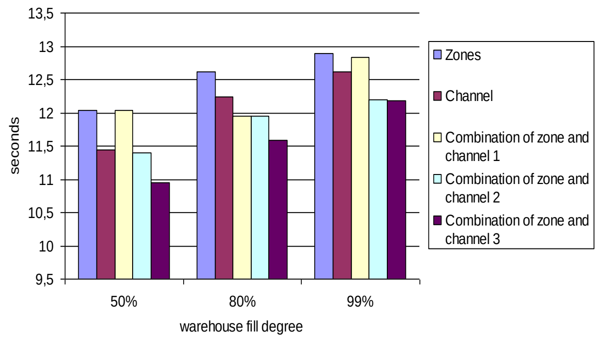

Figure 6. Mean cycle times with single and double cycles.

Comparing Figure 6 and Figure 7 shows that the strategy with the highest mean cycle times does not always have the most stock transfers and vice versa. Also, the strategies with the smallest mean cycle times do not always have the least stock transfers. Therefore, based on the number of stock transfers, one cannot make a statement about the quality of a strategy.

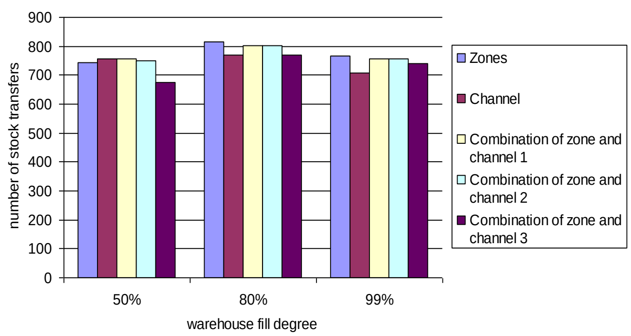

Figure 7. Number of stock transfers with single and double cycles.

The results for double cycles are essentially the same as the ones with single cycle and double cycle. They are shown in Figure 8 and Figure 9. Also, here, the strategies of type "combination of zone and channel" react most clearly to the increase of the warehouse filling degree. A comparison of these deviations with the deviations from both previous simulation runs shows that with double cycle the relative profit is the largest by the most favorable storage strategy. Indeed, the improvement in performance here also decreases with the warehouse filling degree.

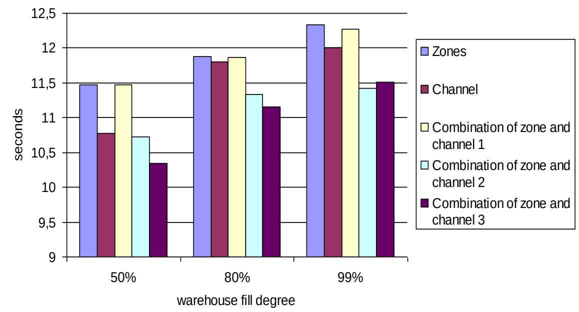

Figure 8. Mean cycle times with double cycles.

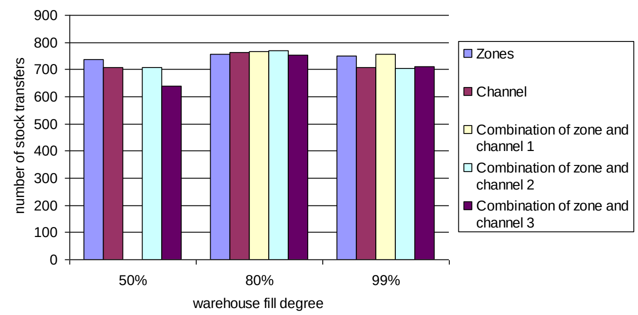

Figure 9. Number of stock transfers with double cycles.

There is no warehouse strategy that always generates the most or the least stock transfers. With a warehouse filling degree of 50%, there is a correlation between the number of stock transfers and the mean cycle time. Such a correlation does not exist with other warehouse filling degrees. Hence, the number of stock transfers cannot be inferred from the mean cycle time and vice versa.

VIII. IMPROVED ANALYSIS COMPARED TO LITERATURE

Lipplot and Blunck specify in [11] the increase of the handling of goods in warehouses with zones compared with warehouses without zones is between 15% and 20%. Gudehus says in [4] that the increase of the handling of goods by using zones is limited to 15%. The simulation shows that the mean cycle times by strategy zones is lower about 40% than by strategy channel in the case of a warehouse utilization of 50%. With increasing warehouse utilization the relative reduction is lower; in the case of a warehouse utilization of 99% the general proves that the improvement in performance depends on the ABC indicator of orders, the warehouse utilization as well as the sequence of storages and retrievals.

Seemüller regards in [7] the strategies chaotic storage, which fits with the strategy accidental (storage), storage close to retrieval, which is comparable to the strategy of the fastest neighbour, and multiple storage in which several bins are stored side by side. In his calculations, Seemüller regards a rack feeder with three load suspension devices (next to one another). In a single-deep warehouse, the performance of the strategy chaotic storage is independent of the warehouse utilization and significantly lower than using the other two strategies. This investigation exposes the same results. Seemüller approves a reduction in the mean cycle times by using double cycles which is approved by this investigation as well. But, this investigation in particular and a simulation in general, show concrete values.

There are no quantitative results published about the improvement in performance of multiple-deep warehouses by storage strategies. Nevertheless, investigations about storage strategies for multiple-deep warehouses were published.

Seemüller regards in [7] the strategies chaotic storage, storage close to retrieval and multiple storage for multiple-deep warehouses. So, the most effective strategy in this investigation is not investigated by Seemüller.

The probability of stock transfers is analyzed in [6]. The authors describe the run of the probabilities of stock transfers in a twice-deep warehouse as a function of the warehouse utilization by a curve. For a warehouse utilization of 50%, the probability of stock transfers is 32%, for a utilization of 80%, the probability for stock transfers is 45% and at a utilization of 100% the probability is 50%. The probabilities for stock transfers in this investigation are higher. With a warehouse utilization of 50%, the probability for stock transfers is already 44%. Furthermore, probabilities for stock transfers of more than 50% appear. The number of stock transfers is determined by the retrievals. The retrievals depend on the orders. Hence, a stochastic process is given which is not considered in the static curve in [6]. By allowing the beginning of the allocation of a channel even if this can be avoided, the probability for stock transfers should become smaller. This will be analyzed in further investigations at the IPF.

IX. CONCLUSION

The state of the art in the literature comprises non-quantitative statements. By the simulation introduced here, quantitative results for concrete enterprises and warehouses, respectively, are delivered. Compared with the published results, the investigation proves partly clearly higher performance in the handling of goods and probabilities of stock transfers.

For a specific small highbay warehouse, the one of Leopold Fiebig GmbH in Karlsruhe, Germany, actual driving times were used by simulation. The results differ significantly from those results published in the literature. Finally, such an effective and efficient implementation is a good basis for newer approaches, which are elaborated in [15], among others.

For the concrete storage strategies, it was proven that all together, a combination of the strategies zones and channel causes the best results.

Preliminary measurements suggest that similar results are observed in other warehouses. Further development of this into significant measurements and results is one of the tasks at the IPF.

Methodically quite demanding, but very interesting, is a generalization of these results for as many warehouse types as possible. The IPF will also continue to research this problem in the future.

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