Optimization of order batching in a picking system with a Vertical Lift Module: 6th International Conference on Information Systems, Logistics and Supply Chain (ILS International Conference)

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Abstract. Order picking is one of the main warehousing activities. It deals with the retrieval of products from their storing location in order to fulfil customers' orders. This paper focuses on Order batching, namely, how to regroup customers' orders into batches before collecting. This practice has proven to be a critical operation for the order picking efficiency. We provide an optimization model for orders batching, when items are stored in a Vertical Lift Module in order to minimize the total completion time. The Vertical Lift Module is an Automated Storage and Retrieval System that is widely used in warehouses. Numerical results from real case studies have been conducted to prove the efficiency of our model.

Keywords: Order Batching, Vertical Lift Module, Order picking, Warehouse Management

1. Introduction

In order to improve efficiency and reduce cost in the warehouses, managers are increasingly interested in optimizing the process of order picking. The Order Picking can be defined as the operation of retrieving products from their storage location to fulfill customers' orders. It is the most labor intensive operation in manual warehouses with about 55 % of all operating costs [1] , and a primordial one in warehouses equipped with automated systems [2] .The order picking is clearly one of the operations that has the most important impact on the warehouse global performance.

1.1. Technology used

The Automated storage and retrieval systems (AS/RS) are increasingly used by both manufacturing and distribution companies. Such systems have several advantages such as, basically, the space saving and the increase in productivity. The use of AS/RS implies that the machine brings the products to the operator (picker) who stays in front of it and does not need to move from one storage location to another. Such a system is referred to in the literature by "Part to Picker" system as opposite to "Picker to Part" system where pickers have to retrieve products by walking down alleys until the location where the product is stored. The picking area is composed by a picker who retrieves products from a given machines.
Among the wide variety of AS/RS, Vertical Lift Modules (VLMs) is a set of insertion/extraction storing trays where products are stored on (see Fig.1 for an illustration). Our study focuses on VLMs system. These systems are widely used in practice. In this paper, we consider the case of one picker operating on one VLM.

Figure 1: VLM illustration (picture from SouthWest Solution [5])

1.2. Order Batching

Achieving a higher throughput, which is the number of orders that are collected by a picker within a certain period, is currently one of the main objectives of companies [3]. One strategy that could lead to a higher throughput is to regroup customers' orders into batches and, then, to retrieve the orders of the same batch together at the same time instead of retrieving each order alone. According to [4], this practice has many advantages. For instance, when products from several orders have to be retrieved from the same tray, it is more efficient to retrieve them simultaneously instead of having to call this tray several times. Indeed, this leads to reducing the total number of visited trays, hence implying a time and cost saving.
On the demand side, a customer's order is represented by a set of lines, each line corresponds to a required quantity of a given product. Clearly, each product is stored on a given tray of the VLM. After receiving a set of customers' orders, the first decision is to regroup them into batches. A batch is composed by a set of orders and, consequently, by the set of lines composing these orders. Note that a given order cannot be split between different batches. In other words, the lines of a given order must be put in the same batch. The rest of the operations can be described as follows. A succession of batches have to be picked from the VLM. For each batch, the picker receives a certain quantity of bins representing the number of orders included in the considered batch as all order lines of one order have to be placed in one bin. Each time the picker retrieves an order line from a tray, he places it in the bin associated with the order requiring this product. Then, he continues with the next product until no other products have to be retrieved from this tray. When all the products of the current batch, and stored in this tray, are retrieved, the current tray is then returned to its location and the next tray is extracted. The operator repeats the process until all products belonging to the current batch are collected. At this time, the bins leave the picking area and new bins, associated with a new batch, are received by the picker. The picker repeats this process until all batches are picked.
The orders batching is currently performed by most companies using VLM systems. However, in spite of the critical impact of batching decisions on the orders picking performance for VLM systems, the literature did not give adequate interest to this decision problem. Unlike the case of VLMs, the order picking and order batching problems are widely studied in the literature dedicated to picker to part systems. A review of such systems is given by [2] while [6] provides a review of order batching problem and describes the existing solutions approaches.
In the existing literature, the papers focusing on VLMs aim basically to develop throughput models i.e. the expected time to pick several items from a VLM. For instance, in [7] throughput models for one or several VLMs are developed by using a two server queuing model approach. Dukic et al. [8] developed a throughput model for a VLM having a dual tray opening. This particular type of VLM has two trays that can be waiting at the opening point and is a different technology compared to the one studied in this paper. The method used for the throughput calculation is similar to the one used in [7]. To our knowledge, papers dealing with the order batching for VLM systems are missing in the literature. In addition, most practitioners are using basic tools for batching, such as the first come first served, which are generally very far from optimality.
This paper contributes to the literature and practice by providing a batching optimization model for VLMs. The objective of our model is to minimize the total completion time for picking a set of customers' orders. We first evaluate the total completion time of a given number of batches for one VLM. This evaluation will

help us determining the criterion that should be optimized. Our optimization model is designed to be used in practice by warehousing managers.
This paper is organized as follows. In section 2, we describe the evaluation of the total completion time for the case of one VLM. In section 3, we provide the optimization model followed by the experiments and the numerical results. Note that all the experiments are based on real data collected from companies. We finally conclude and give future work directions.

2. Orders Batching with 1 VLM

As explained previously, the picker has to retrieve several batches of orders from a VLM. We consider the case of one VLM with one picker. Our objective is to minimize the total completion time, which is the time taken by a picker to collect all orders. First, we present the notation and the adopted assumptions. Then, we will evaluate the completion time for a given set of orders.

2.1. Notation and Assumptions

We consider the following sets:
- $\mathcal{K}$= {Set of the index of the K trays of the VLM} and k=1,…,K: index of trays of the VLM
- $\mathcal{B}$= {Set of the index of the batches} and b= 1, …, B: index of batches
- $\mathcal{Kb}$ = {Set of the Kb trays visited by the VLM for the batch b} and l=1,…, Kb : the index of the l-th tray visited by the VLM for batch b.

The set $\mathcal{K}$ represents the trays available in the VLM. So K trays are actually storing goods in the VLM. In order to evaluate the completion time, we need to know the trays visited for a given batch. $\mathcal{Kb}$ is the set of the trays to visit for the batch b. So if $\mathcal{K}$ ={1,2,3,4}, therefore K=4 and if $\mathcal{Kb}$ ={2,4}, it means that there are 2 trays to visit for batch b over the 4 trays of the VLM. In this case Kb=2 and l=1,Kb. l=1 means that we visit the first tray of $\mathcal{Kb}$ which is the tray 2 and l=Kb=2 means that we consider the second tray of $\mathcal{Kb}$ that is tray 4.
We denote by C the total completion time for all batches. This completion time C includes the total time during which the picker waits in front of the VLM, denoted by W, and the total picking time, denoted by P. The waiting time corresponds to the time when the VLM stores a tray and releases the next one. Meanwhile, the picker has to wait. Clearly, we have the following relation: C=W+P.
We use the following notation:
- $\boldsymbol{C_b}$: the completion time for batch b.
- $\boldsymbol{W_b}$: waiting time for batch b
- $\boldsymbol{P_b}$: the picking time for batch b. Thus, we have: $\boldsymbol{C_b = W_b + P_b}$

We now introduce the notation used for each tray:
- $\boldsymbol{W_{l\,b}}$: the waiting time for the l-th tray associated with batch b
- $\boldsymbol{P_{l\,b}}$: Time to pick items from the l-th tray associated with batch b

The time required to wait and collect items from the l-th visited tray is given by $\boldsymbol{C_{l\,b} = W_{l\,b} + P_{l\,b}}$
Clearly, we also have the following relations between the different lead times

$$C = \sum_{b=1}^{B} C_b \qquad W = \sum_{b=1}^{B} W_b = \sum_{b=1}^{B}\sum_{l=1}^{K_b} W_{l\,b} \qquad P = \sum_{b=1}^{B} P_b = \sum_{b=1}^{B}\sum_{l=1}^{K_b} P_{l\,b}$$

Consequently, the general formula of the total completion time C is:

$$C = \sum_{b=1}^{B} (W_b + P_b) = \sum_{b=1}^{B}\sum_{l=1}^{K_b} (W_{l\,b} + P_{l\,b})$$

We now introduce the following system parameters:
- **PU**: the unit picking time, i.e. the time required to collect one order line (i.e. a given quantity of a given product associated with a given customer order).
- **TR**: the time required by the VLM to retrieve the current tray and to present the next one. In practice, this time does not depend on which trays have to be retrieved or presented.
- $\boldsymbol{NL_{l\,b}}$: the number of order lines that have to be collected on the l-th tray visited by batch b.

We recapitulate hereafter the different modeling assumptions. We firstly recall that one picker is present in front of the VLM. We assume that the picker starts collecting the products associated with a given batch by waiting for the first tray.
We consider that the time required by the VLM to retrieve a given tray and extract the next one is constant (does not depend on the involved trays) and equals to TR. This is a realistic assumption since the vertical moving speed of the VLM is high (up to 2 meters per second) whereas the horizontal speed is much slower (up to 0.7 meter per seconds) (according to [9]). Hence the time required for the vertical movement can be neglected with comparison to the time required for the horizontal movement. Thus, the time required to release a given tray consists essentially of horizontal movement. Consequently, the release time is constant and is the same for all trays.
We consider that the picking time required to collect one order line is constant and equals to a unit picking time PU. In practice, this depends mainly on the dimension of the product, the number of items to collect and the different operations that have to be done while collecting (such as labeling or scanning items before putting them into bins). The time required to collect an order line is in practice lower than the time to retrieve a tray and extract the next tray.
In order to simplify the presentation of the problem for such a complex real-world situation,, we begin our paper by studying the simplest case and then move to a more complex situation. We therefore investigate two different cases: (1) the picking time is considered negligible with comparison to the time required by the VLM to store a tray and retrieve the next tray, and (2) the picking time for the l-th visited tray depends on the number of lines that have to be picked on this tray: $P_{l\,b} = NL_{l\,b} * PU \quad \forall b \in \mathcal{B}$ and $\forall l \in \mathcal{K}\mathcal{b}$.

2.2. Evaluation of Completion Time

We now evaluate the completion time for B batches. This will be used later as an optimization criterion to develop our model for batching decisions.
Recall that we will characterize the completion time for two different situations: (1) the picking time on a given tray is supposed to be negligible and (2) the picking time on a given tray depends on the number of lines (items) to be picked on this tray. For easier understanding, we firstly present an example of each situation and then propose the general formulas.

Case with negligible Picking Time

When no additional operations are required with picking and the quantities of orders lines are small enough, one can assume that the picking time is negligible compared to the time required to retrieve a tray and extract the next one.

Here, the picking time on each tray can be neglected with comparison to the other lead times, hence implying that it is not considered in the calculation of the batch completion time. We have $P = 0$. We consider the following example with one VLM having to visit 3 trays (1, 2 and 3) associated with a given batch b. The following representation (Fig. 2) shows how the completion time of batch b is composed. As explained, before the waiting time is equal to TR for each visited tray.

TR	TR	TR
$W_{1\,b}$	$W_{2\,b}$	$W_{3\,b}$
$C_{1\,b}$	$C_{2\,b}$	$C_{3\,b}$
C_b		

Figure 2: Illustration of the completion time for case (1)

From this example we can see that
$C_b = W_b = \sum_{l=1}^{K\,b} W_{l\,b} = 3 * TR$
The time to collect this batch is 3*TR.
Now, we present the general formulas for a given number of batches and a given number of trays visited per batch. For a given batch b:

$$C_b = W_b = \sum_{l=1}^{K\,b} W_{l\,b} = K_{\,b} * TR$$

The total completion time is given by:

$$C = \sum_{b=1}^{B} C_b = \sum_{b=1}^{B} K_b * TR = TR * \sum_{b=1}^{B} K_b \qquad (1)$$

Case with a Picking time proportional to the number of lines

We consider here a more realistic case where the picking time per tray is proportional to the number of lines to be collected on this tray. We consider the following example for one VLM that has to visit 3 trays for a given batch b with $NL_{1\,b} = 2; NL_{2\,b} = 1; and\ NL_{3\,b} = 3$. Recall that $NL_{l\,b}$ is the number of product lines that must be collected on the l-th tray visited for batch b. The following representation (Fig.3) shows how the completion time depends on the Picking and waiting times associated with the visited trays

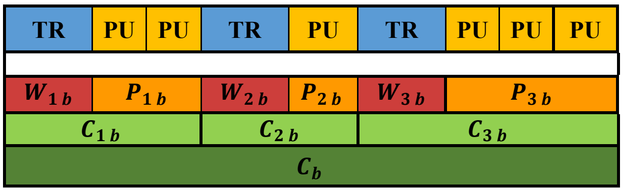

Figure 3: Illustration of the completion time for case (2)

In this example, the picker has to wait until the first tray is available, then he picks the two lines on the first tray. He waits until the second tray becomes available, collects one line and waits again the last tray to collect three lines, which finishes the collecting process for batch b. Hence, the completion time to retrieve all items from this batch is:

$$C_b = W_b + P_b = \sum_{l=1}^{K_b} (W_{l\,b} + P_{l\,b}) = 3 * TR + P_{1\,b} + P_{2\,b} + P_{3\,b} = 3 * TR + 6\,PU$$

The general formula is presented below:

$$C_b = W_b + P_b = \sum_{l=1}^{K_b} (W_{l\,b} + P_{l\,b}) = K_b * TR + \sum_{l=1}^{K_b} NL_{l\,b} * PU$$

Thus, the completion time for all batches is given by:

$$C = \sum_{b=1}^{B} C_b = \sum_{b=1}^{B} \left(K_b * TR + \sum_{l=1}^{K_b} NL_{l\,b} * PU \right) = TR * \sum_{b=1}^{B} K_b + PU * \sum_{b=1}^{B} \sum_{l=1}^{K_b} NL_{l\,b} \qquad (2)$$

As observed in the two previous examples and in the mathematical formula, the time required to complete all batches depends on the number of visited trays and on the number of collected lines. However, the picking time ($PU * \sum_{b=1}^{B} \sum_{l=1}^{K_b} NL_{l\,b}$) is constant since it is given by the total number of lines to be collected multiplied by another constant parameter PU.
Given in addition that TR is a constant parameter then, in both cases, minimizing the total completion time is equivalent to minimizing the number of trays visited by the different batches.
Consequently, the objective of our optimization model is: Minimize $\sum_{b=1}^{B} K_b$

3. Optimization model for the Order Batching Problem

We dedicate this section to developing and experimenting our model.

3.1. Optimization Model

The main decision of our model is to build the different batches from a set of customers' orders. We let $\mathbb{N} = \{Set\ of\ the\ index\ of\ the\ N\ orders\ to\ batch\}$ denote the set of customer's orders, and $n = 1, \ldots, N$: the index of the set. We firstly need to know the batch size i.e. the maximum number of orders to put in a batch. In practice, this number is generally constant and depends on the number of bins fitting in the picking area i.e. the batch size. We denote by Bmax the batch size. Given the batch size Bmax and the number of orders, we know the number of batch $B = Ceil\,(\frac{N}{Bmax})$ with Ceil the ceiling function.

The input parameter $U_{k\,n}$ is equal to 1 if order n visits tray k, 0 otherwise.
The decision variables are the following:
$x_{n\,b}$=1 if order n is included in batch b; 0 otherwise
$T_{k\,b}$ =1 if tray k is visited by batch b; 0 otherwise
As explained earlier, our objective function is:

$$Minimize \sum_{b=1}^{B} \sum_{k=1}^{K} T_{k\,b}$$

The model constraints are presented hereafter:

$$\sum_{n=1}^{N} x_{n\,b} \leq Bmax,\ \forall\, b \in \mathcal{B} \qquad (1)$$

$$\sum_{b=1}^{B} x_{n\,b} = 1\ ,\ \forall\, n \in \mathbb{N} \qquad (2)$$

$$T_{k\,b} = \sum_{n=1}^{N} x_{n\,b} * U_{k\,n}\ , \forall b \in \mathcal{B};\ \forall k \in \mathcal{K} \qquad (3)$$

$$x_{n\,b} \in \{0;1\};\ T_{k\,b} \in \{0;1\};$$

Constraints (1) impose that the maximum number of orders per batch is equal to Bmax. Constraints (2) ensure that an order must be included in only one batch. Constraints (3) serve to compute variable $T_{k\,b}$: a tray k is visited by batch b if at least one order of this batch visits the tray.

3.2. Case Study

Numerical experiments have been carried in order to determine the gain obtained by using our model instead of the FIFO, which is the current approach used by the considered companies. Two companies are concerned by this study: a Hospital in France and a manufacturing company based in Switzerland. The data used in our experiments are real data extracted from the databases of these companies. They correspond to the customers' orders received by these companies in one day. The main difference between the data of these companies comes from the number of orders per day and the number of order-lines per order. In case of the French hospital there are fewer orders per day and fewer number of order lines per order than for the case of the Swiss company. The extraction of data was possible with the help of company KLS Logistic Systems. This French company is an editor of WMS and WCS inventory management software.

The FIFO works by including into a batch the orders according to their preparation due date until the batch is full (Bmax is reached) and we continue by filling the next batch until we finish placing all orders. We let CT1 denote the total completion time in the case where the picking time is negligible compared to TR and assume, without loss of generality, that TR is equal to one time unit. CT2 is the total completion time in the case where the picking time is proportional to the number of visited lines. In this case, we use the following extreme parameters: TR = PU=1 meaning that the unitary picking time is equal to the unitary time to change a tray for the VLM. For these two cases, we evaluated the gain obtained by using our model instead of FIFO. Our model was solved to optimality with CPLEX on an Intel Core i3 dual 2.27 GHz with 3Go Ram and running under the environment windows 7 professional 32 bits.

Case 1: French hospital

The following tables summarize the results of comparison between FIFO and our model in the case of the French hospital. According to the hospital practice, Bmax was set to 6 orders per batch.

In table 1, 7 different scenarios are considered. Each scenario corresponds to a given day and represents the customer's orders received in this day. We compare the number of extracted trays obtained with FIFO to the number of trays extracted with our model. In the sixth column, we show the saving obtained by using our model. As one can observe, this saving ranges from 25% to 52%. The larger is the number of considered orders the more important is the gain obtained by using our model instead of FIFO. Indeed with more orders, we increase the number of possible combinations, which increases the interest of using an optimization approach as the one developed in this paper. Furthermore, the solving time with CPLEX did not exceed one minute for most scenario, only the scenario with 63 orders required a relatively long solving time with 109 seconds.

Table 1: *Savings of the number of trays visited for the French Hospital*

Scenario	NB Orders	NB lines	NB tray FIFO	NB tray CPLEX	Saving	Computation time (seconds)
A	19	53	40	29	28%	1,52
B	20	44	36	33	25%	1 ,63
C	20	54	44	27	25%	1,57
D	20	57	47	34	28%	1,02
E	35	79	66	43	35%	3,52
F	43	81	66	38	42%	7,31
G	63	130	121	58	52%	109,03

Table 2 summarizes the results for the total completion time. We have a saving ranging from 25 to 52% with an average saving of 33 % for CT1. Concerning CT2, we observe a saving ranging from 11% to 25% with an average of 15%.

Table 2: *Savings of the completion times for the French Hospital*

Scenario	CT1 FIFO	CT1 CPLEX	Saving CT1	CT 2 FIFO	CT2 CPLEX	Saving CT2
A	40	29	28%	93	82	12%
B	44	33	25%	98	87	11%
C	36	27	25%	80	71	11%
D	47	34	28%	104	91	13%
E	66	43	35%	145	122	16%
F	66	38	42%	147	119	19%
G	121	58	52%	251	188	25%

Case 2: Swiss company

The second example corresponds to the case of a Swiss company specialized in the manufacturing of precision measuring instruments. As the previous case, we considered 7 scenarios, each of them corresponds to one day. We stopped CPLEX after 30 minutes if no optimal solution is found. In this case, we take the best obtained feasible solution.
Table 3 represents the comparison between our model and FIFO. We can notice that the company's data show an increased number of orders and lines per orders compared to the previous case. Bmax is here equal to 8, according to the order picking strategy in this company. We observe that the savings are from 24% to 33% compared to FIFO with an average of 27%. Concerning the computational time, we observed that it becomes very long when the number of orders is greater than 60. This is due to the combinatory explosion.

Table 3: *Savings of the number of trays visited for the Swiss company*

Scenario	NB Orders	Nb lines	NB tray FIFO	NB tray CPLEX	Savings	Computation time (seconds)
A	31	269	170	127	25%	3,40
B	50	224	169	125	26%	78
C	60	307	217	157	28%	1190
D	81	352	275	209	24%	1800*
E	103	329	248	166	33%	1800*
F	116	490	327	250	24%	1800*
G	145	364	281	187	33%	1800*

Table 4 shows the saving in terms of total completion time. We obtain a saving ranging from 24 to 33% with an average saving of 27 % for CT1. Concerning CT2, we observe a saving ranging from 9% to 15% with an average of 11%.

Table 4: *Savings of the completion times for the Swiss company*

Scenario	CT1 FIFO	CT1 CPLEX	Saving CT1	CT 2 FIFO	CT2 CPLEX	Saving CT2
A	170	127	25%	439	396	10%
B	169	125	26%	393	349	11%
C	217	157	28%	524	464	11%
D	275	209	24%	627	561	11%
E	248	166	33%	577	495	14%
F	327	250	24%	817	740	9%
G	281	187	33%	645	551	15%

From these two cases, we can deduce that the drop of saving between CT1 and CT2 is due to the fixed time ($PU * \sum_{b=1}^{B} \sum_{l=1}^{K\,b} NL_{l\,b}$) that we add to the waiting time. As this picking time cannot be optimized and is fixed, we can only optimize the batches by reducing the waiting time.

4. Discussion and Conclusion

This paper dealt with the order batching optimization in a warehouse with one Vertical Lift Module, which is a critical operation in warehouse management. First, an evaluation of the total completion time has been made in order to identify the objective of the optimization model. We considered two situations according to the estimation of the picking time, either negligible or proportional to the number of order lines to be collected. In both cases, we showed that minimizing the total completion time is equivalent to minimizing the number of visited trays. We used this result to develop our batching optimization model. We used real companies' data to evaluate the performance of our model with comparison to the actual batching strategy used by the considered companies. We found that our model outperforms the actual strategy in both cases. In particular, the numerical experiments show that, in average, our strategy leads to reducing the completion time by about 33%, in case of the French hospital, and 27%, in case of the Swiss company, when the picking time is assumed to be negligible. For the second situation where the picking time is proportional to the number of collected order lines, the average reduction of the completion time is about 15% in case of the French hospital and 11% in case of the Swiss company.
Our research could be extended to the case multiple VLMs. The warehouses are generally implemented with several VLMs in order to allow one VLM to store a tray and extract the next tray while the picker is picking items on another VLM. This is called working in masked time. The benefits of working under masked times are multiple as the withdrawal of several products at the same time on a tray implies shorter waiting time in front of the other VLMs. We are working on this issue and our preliminary results are very promising.

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