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Dual-tray Vertical Lift Modules for Fast Order Picking

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Abstract

In the last years, new solutions for order picking systems have been developed both from industry and academics, especially for small items. They include innovative flexible automatic parts-to-picker systems and optimized picker-to-parts ones. One of these solutions consists in the use of Vertical Lift Modules (VLMs), a storage column in which small items are stored in extractable trays. In this paper, we study a new system composed by dual-tray VLMs where the operators perform picking and sorting activities. We propose several actions in order to improve the productivity of the entire system: 1) class based storage assignment of items inside the VLMs; 2) batch retrievals of items and 3) batch orders and batch retrievals with pick-and-sort activity. The impacts of these actions are evaluated with a simulation of the system using real data from an industrial case.

1 Introduction

Warehouse picking is one of the most time and cost consuming activities in a warehouse, often requiring the presence of human operators, who travel within the warehouse aisles to retrieve the items that are needed to fulfill the various orders of the customers [1]. As a consequence, the travelling activity can become predominant, even arriving to represent 60% of total picking time, as demonstrated by Tompkins et al. [2]. Moreover, this aspect can become even more critical when the picking of small objects is considered, since small objects are often also stored in pallets, occupying a high amount of space [3; 4]. An alternative smart solution for small objects picking can be the creation of a separate storage area, with the main benefit of reducing the total needed space and, hence, the travelled distances, leading to a higher system throughput [5; 6; 7].

The most common systems used for the storage and the picking of small dimension items can be divided into two main categories: static, referring to picker-to-parts solutions, and dynamic, referring to the parts-to-picker ones [5; 6]. Static solutions are the ones characterized by the storage of goods in racks or other devices that are fixed in one place and, therefore, usually simple and not expensive. These solutions are particularly recommended for the storage of several different product codes with a low or moderate required throughput. Examples of static systems are: shelving, which can also be equipped with particular devices (containers, dividers etc.), modular drawer cabinets, movable aisle systems, flow rack systems. On the other hand, dynamic solutions concern equipment that brings the items to the picker, and that is usually supported by automated systems, as well as computer software tools. Dynamic solutions can assure higher space utilization, also taking advantage of normally unused vertical space. Examples of dynamic systems are: vertical carousels, horizontal carousels, vertical lift modules, miniload AS/RS systems, A-frames and picking machines, as well as the robots that have been recently employed, for example, in Amazon warehouses [8].

The present paper focuses on Vertical Lift Modules, also called VLMs (Figure 1). A VLM consists in a storage column in which small items are stored in extractable trays. These trays are inserted and extracted by a powered device, which travels vertically between the front and the rear shelving of the column, in order to make available in front of the picker the specific tray he needs to process his picking order. The moving device is guided by an automated control system, which is usually interfaced with a software system, so that to set the correct order of trays retrieval. Such VLM solutions represent an interesting combination of some benefits of other dynamic parts-to-picker systems. Indeed, a VLM warrants a small layout and a high volume utilization like vertical carousels, but avoiding the risk of damaging the stored products and without needing the balance of the loads inside each tray. This turns in a consequent reduction of the distances travelled by the operators, with a modularity and a system throughput which are comparable to the ones of horizontal carousels, and with the security and the storage density of miniloads [6]. However, traditional VLMs present some weaknesses as well, like the potential idle time for the picker who, once he performed a pick, has to wait the storage of the current tray and the retrieval of the following one. In this sense, the development of some recent smart VLM solutions is leading these systems to the gaining of growing success in several warehouse applications. For example, an interesting VLM configuration, often called dual-tray one, presents the possibility of having two different pick places: in this way, as long as the picker picks items from the tray he has in front of him, the retrieval system is able to store the previous tray and to retrieve the following one, resulting in a higher system throughput. Moreover, the employ of VLM solutions is encouraged also by the increasing attention that practitioners and researches are putting on human operators ergonomic working conditions [9]; in fact, in such systems the picker stands in front of the picking bay, without assuming postures that could lead to musculoskeletal issues [10; 11; 12]. Another interesting aspect concerning VLMs is the potential reduction of picking errors [13]: since the picker has in front of him just one tray at a time, the probability of making mistakes decreases. Furthermore, there is the possibility of signaling the correct item to pick for example with a system of lights or laser pointers. Finally, the specific configuration of the VLM assures a safe storage of the products, preventing possible goods thefts or damages.

Although some researches are available on vertical carousels systems dimensioning and performance evaluation [14; 15; 16], very few propose models for vertical lift modules [12]. However, even if the two systems may seem similar, they absolutely differ in terms of performance. In fact, in the traditional vertical carousel all the trays always rotate together, and during the picking of the products from a shelf all the moving system is stopped. This inevitably causes a slowing down of the system throughput, as well as the requirement of a particular care on how the items are stored inside the trays in terms of loads distribution [6]. On the other hand, in a VLM system the moving device extracts and moves only one tray at a time, bringing it in front of the picker. Moreover, there is the possibility of installing a dual-tray VLM system, able to retrieve and store trays during the picking of items from another tray. The only work that has been developed so far specifically dealing with vertical lift modules design is by Meller and Klote [17]. Another recent research by Dukic et al. [12] is exactly focusing on dual-tray VLM systems, proposing a throughput model for the dimensioning of such storage solutions.

To improve the productivity of this kind of system, batch retrievals can be performed, where the order lines are ranked based on the trays where items are stocked. This allows to reduce the number of delivered trays because there is a higher probability to pick different items from the same tray. Dukic et al. [12] and Meller and Klote [17] introduce the expression to estimate this probability based on the number of stocked items n and the number of trays m.

Figure 1. Vertical lift modules

2 Scope of the work

In the picker-to-parts warehouses, the pickers travel in the aisles, searching for the items and collecting them in order to complete their order list. In case of a traditional order picking warehouse where the items are stored on pallets that are positioned on the lower stocking locations of the shelves, the pickers use electric pallet trucks to move inside the aisles and to transport one or more mixed pallets, composed by the items collected during his order picking activity. The expected average time per order line of this system is typically about 40-50 s/line, where the main part is related to the travelling and searching activities [2]. Moreover, the items picking could have a relevant impact also on the ergonomics level, especially when the operators are picking the last items from the pallet.

In case of small products, a bin-shelving storage system is preferable, where the items are stocked in small bins and the operators walk inside the aisle to collect all the items of the order list. Here, the travel time is lower than in the previous situation due to the high storage racks, and the typical expected average time per order line can be about 20-30 s/line. The main issues in this case are related to the storage level of each item in the picking area, impacting on the refilling process and on the dimension of the area. More space is dedicated to each item in the picking area, lower is the number of refilling, but higher is the travelling time.

This work presents an interesting industrial solution involving vertical lift modules for fast order picking. In particular, since a dual-tray VLM allows the picker to work in parallel to the system, the paper considers the possibility of employing such a storing system for a fast processing of small-objects picking orders. Figure 2 represents the so-called *VLM fast picking system*. This system consists of a certain number of VLMs, with as many picking operators (it is supposed that one operator is needed for each VLM). Here, the pickers (VLM pickers) pick the items required by different customers' orders putting them into a pallet or box dedicated to each customer in a specific sorting area (pick-and-sort strategy).

The operators dedicated to the main order list (order pickers) stop in the sorting area to pick the box or the pallet containing all the items the VLM pickers prepare in advance. In this case, the order pickers do just one stop to pick all these items, sharing this picking time to all the lines contained in the box or pallet. This permits to significantly reduce the expected average time per order line. The main challenge in this system concerns how to obtain high productivity of the *VLM fast picking system*, combining the optimization of VLM storage and batch orders and retrievals.

In the next section, we illustrate several solutions to reduce the expected average time per order line spent in the *VLM fast picking system.* Thanks to a simulation based on real order lines, the performances of the system are estimated and evaluated. We do not consider the replenishment cycles, assuming they are performed in another shift, as done in similar previous research [12].

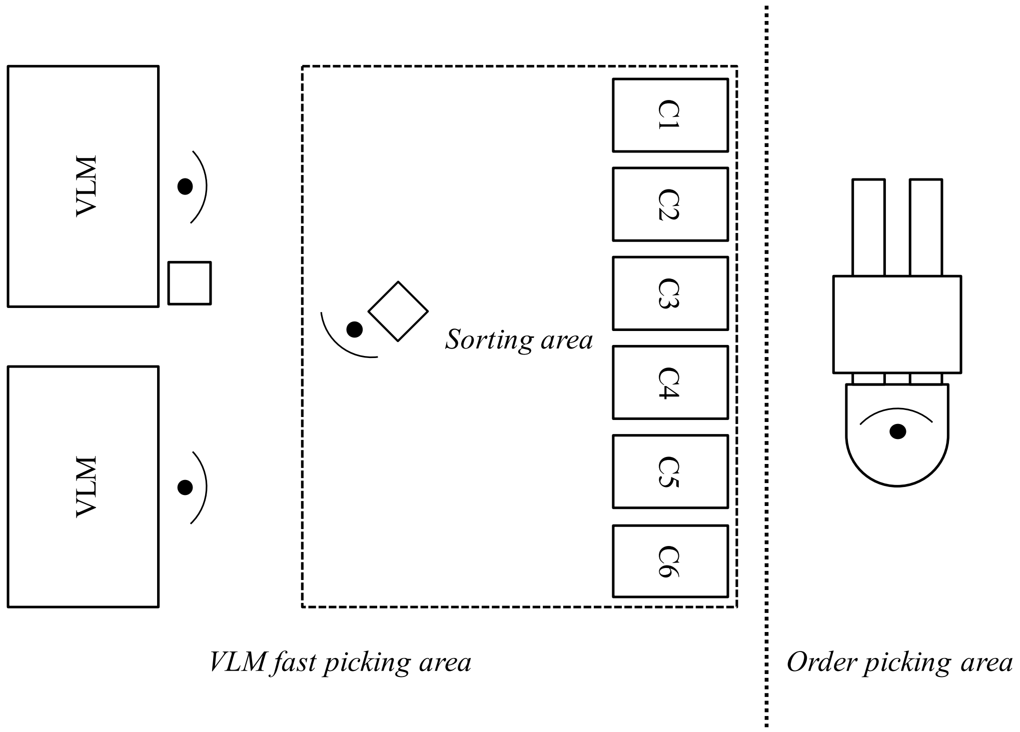

Figure 2. VLM fast picking system.

3 Analysis of VLM fast picking system

In order to understand the feasibility, together with the strengths and the weaknesses of this kind of implementation, the study deals with 2 main steps:

1. Study of the operation of a dual-tray VLM based on storage assignment policy and batch retrievals
2. Study of batch order picking based on a number of customers served in pick-and-sorting

The first step is focused on the analysis of the operation of the VLM in order to understand how its cycle time can be reduced. It is proposed to consider different storage assignment strategies and the possibility of ordering the retrieval of the VLM trays. On the other side, the second step considers the work of the pickers, and their cycle time. In fact, by introducing the pick-and-sort strategy, the pickers' impact can be reduced and the overall performance of the system improved.

Table 1 reports the input data used for the following analysis: it has been considered a VLM with m=60 trays and r=1,200 different stored references. The VLM has an average vertical velocity of 1 m/s, with a delay time per trip due to acceleration and deceleration equal to 2 s. The simulation has concerned the random generation of 10,000 picking lines, consisting in as many trays retrievals and considering also the association of the items to the customers. The picking lines generation followed real orders profiles, in terms of picked items and served customers at a time. For the running of the simulation it has been considered that the actual time needed to pick an item from a VLM tray (p_n) is on average equal to 20 s. As it will be shown in the results, this time is then affected by the interactions between the picker and the operation of the VLM.

Table 1. Input data of the analysis.

Description	**Notation**	**Value**
Height of VLM	H	11.2 m
Vertical velocity of VLM	$\bar{v}$	1 m/s
Delay time per VLM trip due to acceleration and deceleration	$t_{a/d}$	2 s
Delay time to pick up/deposit a tray	$t_{p/d}$	4 s
Average pick time per item	p_n	20 s
Total number of stored references	r	1,200
Total number of trays	m	60
Number of generated picking lines	l	10,000
Number of picking lines per picking list	l_p	25

3.1 VLM: storage assignment policy and batch retrievals

A possible way to increase the system throughput can consider the possible advantages deriving from the application of class based storage assignment strategy with respect to random one [18]. The comparison here studied and proposed is between random storage and class-based storage (CBS) per trays (Figure 3). In case of random storage all the products are stored randomly in the different trays, without considering their picking frequency; on the other side, in case of CBS per trays, the A-class products are stored in the trays that are closer to the picking bay, the B-class products are in an intermediate position, while the C-class products are in the furthest trays. Such a comparison is interesting to understand the possible interactions between the VLM and the picker. For the CBS per trays, four different curves are considered: 20/60, 20/70, 20/80 and 20/90.

Figure 4 shows some results of the performed simulation, with a graph that describes how the picking time changes according to the storage assignment strategy. Moreover, it shows the results for two different ways of processing the picking orders. The *"single orders"* strategy considers that a certain picking list is processed strictly sequentially, hence, by following the order of the picking list and by calling the respective trays containing the required products. On the other side, in the *"batch retrievals"* strategy the picking list is properly ordered by tray, so that if a tray contains more than one product that has to be picked, this is called only one time per picking list. The considered length of each picking list is of l_p=25 picking lines.

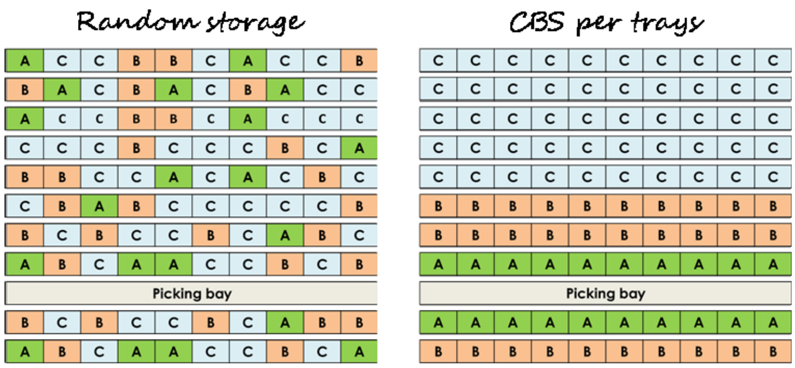

Figure 3. Comparison of different storage assignment strategies: random storage and class-based storage per trays.

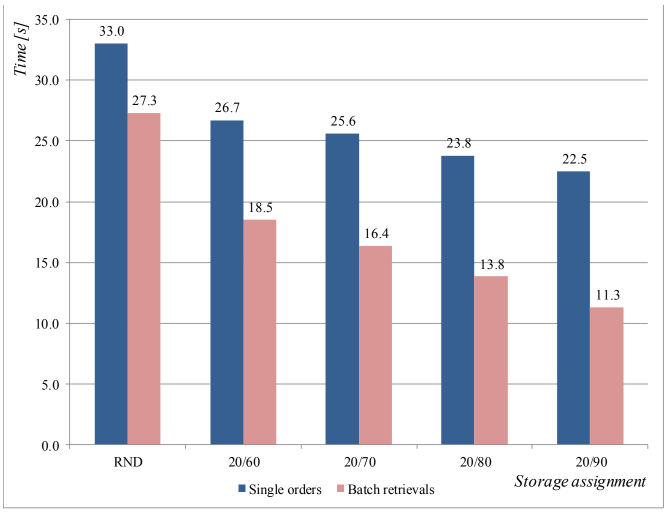

Figure 4. Simulation results: picking cycle time according to different storage assignment strategies.

The results of the simulation (Figure 4) show that storing the items according to their ABC classes leads to interesting benefits in terms of retrieval time and, hence, picking time reduction. In case of random storage, in fact, the overall picking time t_p is 33.0 seconds, corresponding to the highest value. This picking time decreases when the items are stored considering a class based storage, and it assumes the lowest value in case of a 20/90 curve.

As far as the *batch retrieval* approach is concerned, it can be seen that there is the same decreasing trend, starting from the random storage to the CBS per trays with a 20/90 curve. It is also interesting to notice that this processing approach of the picking lists always performs better than the *single order* one, with an improvement that increases from random storage to the class-based one, and that is always better with the increase of the class-curve slope.

3.2 Picker: batch order picking and pick-and-sort

The second step of the study considers the possibility of employing the VLM to do a pick-and-sort process, with a batch picking for various customers. Here, the picking lists of different customers are joined together, so that the trays retrievals are further reduced. Figure 5 shows the different combinations of the same two picking lists according to the three proposed approaches: *single order*, *batch retrievals* and *batch orders and batch retrievals*. In this last case, the picking lists of different customers are merged together and ordered per tray. In this way, the trays retrievals are reduced, and the pick of the same items can be done for more than one customer per time. Of course, a batch picking approach subsequently needs a sorting activity in order to divide the various items for the different customers. During the sorting activity the picker moves from the VLM to the sorting area that is organized per customer (Figure 2).

SINGLE ORDER

Code	Order	Tray
A	1	1
B	1	3
C	1	1
D	1	2
E	1	7

Code	Order	Tray
B	2	3
D	2	2
F	2	1
G	2	6
H	2	3

BATCH RETRIEVALS

Code	Order	Tray
A	1	1
C	1	
D	1	2
B	1	3
E	1	7

Code	Order	Tray
F	2	1
D	2	2
B	2	3
H	2	
G	2	6

BATCH ORDERS & RETRIEVALS

Code	Order	Tray
A	1	1
C	1	
F	2	
D	1	2
D	2	
B	1	3
B	2	
H	2	
G	2	6
E	1	7

Figure 5. Different approaches for picking lists processing: single orders, batch retrievals, batch orders and retrievals.

Section 3.1 has shown some possible solutions to reduce the time related to the VLM, through class-based storage strategies and batch retrievals; on the other side, batch order picking is more focused on improving the picking time from the picker perspective. Figure 6 shows the comparison between the picking time with *batch retrievals* already plotted in Figure 4 and the time needed to do the pick-and-sort activity. Of course, these times are not depending by the storage assignment strategy used for the items in the VLM.

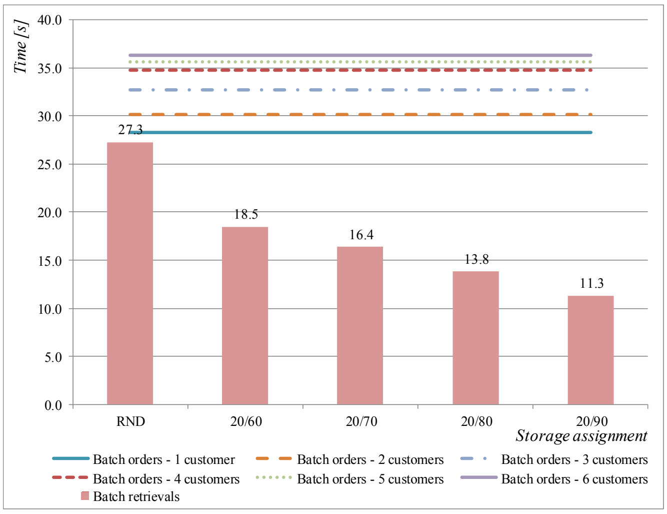

Figure 6. Impact of batch order picking.

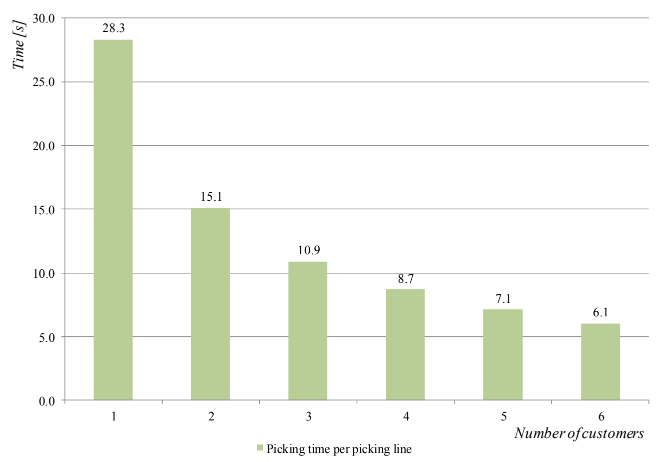

Figure 7. Total picking time per line varying the number of customers.

Figure 7 shows the total picking time per line, obtained by dividing the picking time in case of batch picking (Figure 6) by the number of simultaneously sorted customers. Hence, the time for batch order picking with six customers 36.3 s turns out in a picking time per line of 6.1 s, with an interesting improvement of the overall system performance.

Finally, Table 2 reports the data concerning the utilization rates both of the picker and of the VLM, in all the different scenarios. It can be seen that, apart of the case of single order processing and random storage assignment, the utilization rate of the picker is always 100%. So, the VLM does not represent a technological limit in such an implementation.

Table 2. Utilization rates of picker and VLM.

U_{picker}		RND	20/60	20/70	20/80	20/90
Single order		85.8%	100.0%	100.0%	100.0%	100.0%
Single order - Batch retrievals		100.0%	100.0%	100.0%	100.0%	100.0%
Batch orders - Batch retrievals	1 customer	100.0%	100.0%	100.0%	100.0%	100.0%
	2 customers	100.0%	100.0%	100.0%	100.0%	100.0%
	3 customers	100.0%	100.0%	100.0%	100.0%	100.0%
	4 customers	100.0%	100.0%	100.0%	100.0%	100.0%
	5 customers	100.0%	100.0%	100.0%	100.0%	100.0%
	6 customers	100.0%	100.0%	100.0%	100.0%	100.0%

U_{VLM}		RND	20/60	20/70	20/80	20/90
Single order		100%	94%	90%	84%	80%
Single order - Batch retrievals		96%	65%	58%	49%	40%
Batch orders - Batch retrievals	1 customer	96%	65%	58%	49%	40%
	2 customers	90%	61%	54%	46%	37%
	3 customers	83%	57%	50%	42%	35%
	4 customers	78%	53%	47%	40%	33%
	5 customers	77%	52%	46%	39%	32%
	6 customers	75%	51%	45%	38%	31%

3.3 System and performance discussion

The various analyses and comparisons that have been proposed in the previous sections suggest some interesting considerations about the possible operating characteristics of the innovative *VLM fast picking system*.

In case the picker has to pick the items only for one customer, the study can focus on the application of a class-based storage and on the performing of batch retrievals. In particular, such a strategy is also more effective when the picker's picking time is averagely lower than the VLM retrieving time. Moreover, the reported simulation has demonstrated that the *batch retrievals* strategy leads to interesting improvements in terms of trays retrieving time with a very low implementation effort. Also the application of the class-based storage brings some benefits in this direction, but with the need of a proper positioning of the items within the trays. Finally, the simultaneous application of batch retrievals and class-based storage can have a synergistic effect.

Starting from this first situation, the system overall performance can be further improved by acting on the picker time, hence, through the batch order picking approach. Here, the operator simultaneously picks the items for different customers, which are subsequently sorted in the sorting area. Then, in this case the throughput of the system depends on the picker, which has a higher working time with respect to the VLM retrieving time. However, this higher time is for the processing of various customers, and it can be seen that if the picker picks the items for more than one customer, the picking time per picking line is absolutely good (Figure 7).

4 Conclusion

This solution has been implemented in the small-objects picking area of a company which sells non-food products for large-scale retail network. The starting scenario was a traditional manual, picker-to-parts, piece-pick-from-carton warehouse. The fulfillment of the customers' orders required that the pickers entered all the various aisles by walking, while pushing a picking cart. In order to save space, reduce errors and improve the system productivity, the company decided to move to a parts-to-picker solution. It has then been studied the potential of using vertical lift modules, through the design of the *VLM fast picking system*.

This work represents an interesting alternative application for vertical lift modules. In fact, these systems are often used for the storage of slow-moving products, or for example of spare parts, obtaining the only aim of reducing the space occupied by these items within the storage area [12]. In this case, instead, the vertical lift module is intended to create advantage also by increasing the picking throughput (in terms of time per picking list and picking errors reduction) and improving the pickers' ergonomics working conditions.

In the next researches, we will extend the formulas introduced by Dukic et al. [12], modeling the class based storage assignment. Moreover, new models are necessary to estimate the time spent by the VLM-operator in picking and sorting activities. This will allow the understanding of the impact of batch order profiles (dimension, number of items per line, number of order per batch etc.) to the productivity of the system. Another aspect we need to consider is the refilling activity of the VLMs, in particular as far as its management, its frequency, and the number of items that have to be refilled are concerned.

Finally, it would be interesting to extend this work by introducing a preliminary step, with the aim of understanding which items are more suitable to be stored and picked with the VLM fast picking system instead of with a traditional picking system, according, for example, to the item physical characteristics (volume, weight) and its picking frequency.

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