Dual-tray Vertical Lift Module for order picking: a performance and storage assignment preliminary study

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Abstract: Among all the warehouse operations, order picking is the activity that always attracts a lot of interest in research, since it presents a complex combination of several interacting factors, often involving human operators. Considering the system overall performance improvement, it has been proved that it can be achieved by reducing the distances travelled by the pickers, as well as by improving their ergonomics working conditions, also through the adoption of automated solutions. In small parts order picking, the need of reducing travelled distances and improving ergonomics turn out to be even more important. The present paper proposes a preliminary study concerning a particular automated parts-to-picker, small objects picking system, called Vertical Lift Module (VLM). Although the value of such a solution is already acknowledged in industry, its evaluation from a scientific point of view is still lacking. Here a first simulation model for the performance study of a VLM is introduced. Then, this simulation model is applied for the comparison of three different storage assignment strategies: random storage, class-based storage with the product classes divided per trays and class-based storage with the product classes divided within all trays.

Keywords: warehouse picking, vertical lift module, throughput model, storage assignment

1. Introduction

Warehouse picking is often described as the most time and cost consuming activity in a warehouse. In fact, the most widespread picking solutions usually require the presence of human operators, travelling within the warehouse aisles to retrieve the items needed to fulfil the orders of the customers. Hence, the travelling component can become predominant, even arriving to represent the 60% of the total picking time, as demonstrated by Tompkins et al. (2010). Moreover, as far as the picking of small objects is concerned, such aspect can become even more critical, considering that also small objects are often stored in pallets, requiring a high amount of space (Bartholdi and Hackman, 2011; Battini et al., 2014). On the contrary, an alternative smart solution can be the creation of a separate area for small objects picking, with the main benefit of reducing the total needed space and, hence, the travelled distances, leading to a higher system throughput (Choe and Sharp, 1991; Tompkins and Smith, 1998; Battini et al., 2015a).

The present paper represents a preliminary study on Vertical Lift Modules performance evaluation. In particular, it proposes a simulation model that has been used to estimate the system overall performance and, then, to compare different possible storage assignment strategies. Considering the characteristics of such storage and retrieval system, which will be detailed in the following sections, it has been studied which storage assignment strategy, among random storage, class-based storage per trays and class-based storage within trays, warrants a higher system throughput. The remainder of the paper is organized as follows. The following section proposes a general presentation of the existing literature concerning small objects picking, Vertical Lift Modules and storage assignment strategies. Then, the subsequent section focuses on the description of Vertical Lift Modules and on the explanation of the simulation model, proposed to evaluate such storage systems and to compare different possible items assignment strategies. Then, Section 4 reports the different performed simulations, together with the corresponding results. In the final section, the conclusions and some ideas for further research are presented.

2. Literature overview

Focusing on small dimensions items, the most common systems used for their storage and their picking can be divided into two main categories: static, referring to picker-to-parts solutions, and dynamic, referring to the parts-to-picker ones (Choe and Sharp, 1991; Tompkins and Smith, 1998). Static solutions are 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, often equipped also with particular devices (containers, dividers etc.), modular drawer cabinets, movable aisle systems, flow rack systems. On the other hand, dynamic solutions concern an 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 (Wurman et al., 2008).

As already stated in the introduction, the present paper focuses on Vertical Lift Modules, also called VLMs. Thanks to their recent evolutions, these storage systems find interesting applications in different warehouse contexts. In particular, they turn out to be useful in case of small objects picking with the need of reducing the occupied space and, hence, the distances travelled by the operators. Although some researches are available on vertical carousels systems dimensioning and performance evaluation (Van Den Berg, 1996; Park et al., 2003; Hassini, 2009), very few proposes models for vertical lift modules. However, it is important to point out that, 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 particular attention on how the items are stored inside the trays in terms of loads distribution (Tompkins and Smith, 1998). 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. Then, the only work that has been developed so far specifically dealing with vertical lift modules design is by Meller and Klotz (2004). Moreover, another recent research by Dukic et al. (2015) is exactly focusing on dual-tray VLM systems, proposing a throughput model for the dimensioning of such storage solutions.

In a warehouse, as well as in a warehouse picking area, the storage assignment issue deals with the decision on how and where to store the various items or SKUs that have to be kept inside the storage area (Petersen et al., 2005; De Koster et al., 2007). Of course, such choice depends on the characteristics of the considered warehouse (only for bulk storage vs. also for picking activity), on the kind of products stored, and on the priorities expressed by the warehouse managers (i.e., space high utilization, pickers’ travelled distances reduction, storage and retrieval time lowering etc.). There are several storage assignment strategies (De Koster et al., 2007); here the authors describe only the two that will be subsequently applied to the vertical lift modules: random storage and class-based storage. As suggested by its name, in the random storage strategy every incoming pallet is assigned to a location that is selected randomly from all the available empty locations with the same probability (Petersen et al., 2004; Bartholdi and Hackman, 2011). On the other side, a class-based storage (CBS) assignment requires the grouping of all the product codes according, for example, to the picking frequency, based on Pareto’s principle (the 20% of the stored products contributes to the 80% of the picking activities). Then, the warehouse is divided in as many areas as the number of products classes and the classes are assigned to the different warehouse areas: the products with higher picking frequencies (belonging to class A) are stocked to the locations that are nearer to the input/output point, the class B products are assigned to the intermediate area and the class C products are dedicated to the farther stocking locations (De Koster et al., 2007). Several interesting contributions have evaluated the potential benefits of class-based storage with respect to random storage ( Larson et al., 1997; Petersen et al., 2004; Reddy Muppandi and Kumar Adil, 2008). However, a precise study focused on storage assignment evaluation for vertical lift modules is still missing; the only similar research refers to carousel systems and considers different ways of class-based storage assignment, but only applying it within every single tray (Ha and Hwang, 1994).

3. Dual-tray Vertical Lift Module study

A VLM configuration 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 line (Figure 1). The moving device is guided by an automated control system, which in some cases is also interfaced with a software system, so that to set the correct order of trays retrieval. Such VLM solutions represent an interesting combination of several benefits of other dynamic parts-to-picker systems. In fact, a VLM assures small layout and 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), modularity and throughput comparable to the ones of horizontal carousels, as well as the security and the storage density of miniloads (Tompkins and Smith, 1998). However, traditional VLMs present also some weaknesses, 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 are leading these systems to the gaining of growing success in several warehouse applications. For example, an interesting VLM configuration 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.

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**Figure 1: Dual-tray Vertical Lift Module (Modula website)**

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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 (Grosse et al., 2015); in fact, in such systems the picker stands in front of the picking bay, without assuming postures that could lead to musculoskeletal disorders (Neumann and Medbo, 2010; Dukic et al., 2015; Calzavara et al., 2015). Another interesting aspect concerning VLMs is the potential reduction of picking errors (Battini et al., 2015b): the error probability decreases since the picker has in front of him just one tray at a time, with the further possibility of signalling the correct item to pick for example with a system of lights or laser pointers. Finally, it is important to point out that the specific configuration of the VLM assures a safe storage of the products, preventing possible goods thefts or damages.

![Figure 2: References grouping profile according to picking frequency](image-url)

**Table 1: Simulation model input parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLM Width</td>
<td>W</td>
<td>4.0 m</td>
</tr>
<tr>
<td>Depth</td>
<td>D</td>
<td>2.4 m</td>
</tr>
<tr>
<td>Height</td>
<td>H</td>
<td>11.2 m</td>
</tr>
<tr>
<td>No. of trays</td>
<td>N_t</td>
<td>60</td>
</tr>
<tr>
<td>Tray width</td>
<td>W_t</td>
<td>4.0 m</td>
</tr>
<tr>
<td>Tray depth</td>
<td>D_t</td>
<td>0.8 m</td>
</tr>
<tr>
<td>Tray height (including interspace)</td>
<td>H_t</td>
<td>0.35 m</td>
</tr>
<tr>
<td>Horizontal speed</td>
<td>v_h</td>
<td>0.30 m/s</td>
</tr>
<tr>
<td>Vertical speed</td>
<td>v_v</td>
<td>0.65 m/s</td>
</tr>
<tr>
<td>Single line net picking time</td>
<td>t</td>
<td>20 s</td>
</tr>
<tr>
<td>Picked items per line</td>
<td>Q_t/Z_t</td>
<td>1</td>
</tr>
<tr>
<td>No. of references</td>
<td>N_r</td>
<td>1,200</td>
</tr>
<tr>
<td>No. of references per tray</td>
<td>N_r/N_t</td>
<td>20</td>
</tr>
<tr>
<td>No. of orders</td>
<td>N_o</td>
<td>400</td>
</tr>
<tr>
<td>No. of lines per order</td>
<td>N_l,o</td>
<td>25</td>
</tr>
<tr>
<td>Total number of lines</td>
<td>N_o ∙ N_l,o</td>
<td>10,000</td>
</tr>
<tr>
<td>ABC grouping</td>
<td>A 20/80, B 30/15, C 50/5</td>
<td></td>
</tr>
</tbody>
</table>

3.1 Performance study set up

It has been already described that in a dual-tray VLM the storage/retrieval device can work in parallel to the picker, since it retrieves the requested tray from the racks, it leaves it in front of the picker and immediately retrieves back the previous tray from which the picker has just picked some items. In such a scenario, it becomes important the understanding of the mutual interactions that could emerge between the human picker and the VLM system. Among the others, the authors consider useful to evaluate the system overall throughput, expressed in picked items per hour, together with the picker idle time and the VLM idle time. Moreover, it is important to highlight how such throughput can change according to the variation of some input parameters values, also to understand which are the factors that have a greater influence on system performance. The approach that has been implemented starts with a simulation analysis. Table 1 reports the starting characteristics of the assumed system, as far as the VLM, the picker and the products are concerned. The parameters highlighted with a grey background are the ones that have been changed in the subsequent parametrical analysis.

In order to perform the simulations, a time-based map of a virtual Vertical Lift Module has been set up, in which for each one of the trays a storage and a retrieval time (that are assumed to be equal) have been associated. Then, 400 different picking orders have been randomly generated, considering products divided in three classes, according to their picking frequencies: for A-class items, 20% of the references moving the 80% of the picks (and, since Q/Z_t = 1, also of the picking lines), another 30% moving a further 15% for B-class products and the last 5% of picking lines for the C-class items (Figure 2). Within each one of the randomly generated orders, the picking lines have been ordered for tray; that is, if two different picking lines of the same order require products that are located in the same tray such tray is moved only once. Another important hypothesis concerning the simulation model is that every reference occupies the same space inside the VLM (each product code is supposed to be contained in a 0.4 ∙ 0.4 m² space). Finally, the last step of the procedure has dealt with the observation of the interactions between the activities of the picker and the operation of the VLM, arriving to the calculation of the idle time (total and average per picking line), both for the picker and for the VLM; of the single line average picking time, of the picking lines processes per hour and of the moved trays per hour. All the formulas are reported below.

**Overall system idle time per picking line**

\[ t_{Ltot} = t_{LP} + t_{VLM} \] \[ \text{[s]} \]

**Picker idle time per picking line**

\[ t_{LP} = \frac{\text{picker total idle time}}{N_o ∙ N_{l,o}} \] \[ \text{[s]} \]

**VLM idle time per picking line**

\[ t_{VLM} = \frac{\text{VLM total idle time}}{N_o ∙ N_{l,o}} \] \[ \text{[s]} \]

**Single line average real picking time**

\[ t_{p,real} = \frac{\text{Total picking time}}{N_o ∙ N_{l,o}} \] \[ \text{[s]} \]

**Picking lines per hour**

\[ N_{LB} = \frac{3600}{t_{p,real}} \] \[ \text{[lines/h]} \]

**Moved trays per hour**

\[ N_{TB} = \frac{\text{Total moved trays}}{\text{Total picking time}} \] \[ \text{[trays/h]} \]
3.2 Comparison of different assignment strategies

Figure 3 shows a representation of the different assignment strategies that have been considered in the simulations. In particular, the proposed model allowed the overall system performance comparison of a VLM with a random storage and two alternative applications of class-based storage. As can be seen in the left of Figure 3, in case of random storage, the various products are stored randomly in the different trays, without considering their different picking frequencies. Then, the first CBS option considers the storage of the items belonging to the same class in the same trays. That is, there are trays dedicated to the storage of the A-class products, and that are located closer to the picking bay, some other ones are for the B-class products and are in a medium-distance position with respect to the picking bay, while the C-class items are in the farthest trays. The third storage assignment policy is still based on ABC items grouping, but in this case the items of the three classes are equally divided in the various trays. The scheme of Figure 3 represents only a possible division of the stocking locations for the different products (for example it can be supposed that in the left part of the VLM there is the barcode scanner, or a printer). However, the mutual position of the different classes within the trays does not influence the here introduced analysis, because this is only focused on the general movement of the trays, without considering the precise position of each reference within them (Ha and Hwang, 1994).

In order to understand the potential benefits of class-based storage in a VLM, as well as to evaluate the eventual more suitable fields of application of the different storage assignment policies, some of the input parameters reported in Table 1 have been varied. In particular:

- the average single line picking time $t$ has been put equal to 10 s, 20 s, 30 s, 40 s;
- the number of picking lines per order $N_{l,o}$ has been considered to be equal to 10 lines, 25 lines and 50 lines per order;
- the three cumulated picking lines percentages for classes A, B, C: A 20/50 B 30/35 C 50/15, A 20/60 B 30/30 C 50/10, A 20/80 B 30/15 C 50/5, A 20/90 B 30/9 C 50/1 (leading to a change in the slope of the cumulated percent picking lines curve, as shown in Figure 2).

The first set of graphs reported in Table 2 refers to the parametrical analysis of the single line net picking time $t$. As far as the idle times are concerned, it can be seen that by increasing the net picking time the picker idle time decreases, while the VLM idle time tends to increase, for all considered storage assignment policies. Hence, focusing on the overall system idle time, the trend is increasing for the CBS per trays policy, while it decreases and, then, it increases for the random policy and for the CBS within trays strategy. It derives that, from an idle time point of view, the CBS per trays strategy is more suitable for low single line net picking time. For $t=20$ s the three assignment strategies are similar, while for higher values of $t$ the random policy and the CBS within trays are better than the CBS per trays policy. However, it is interesting to integrate these considerations with the performance analysis, represented in the further three graphs reported in the lower part of Figure 4. In fact, it is easy to see that in this case the CBS per trays policy generally warrants the best results: the single line real picking time is always the lowest one (hence, the number of picking lines processed per hour is the highest). The difference is more evident for lower values of net picking time, while for $t=40$ s the performance are equal for all the three assignment strategies. Another interesting graph is the one reporting the number of moved trays per hour. The number of trays is about 100 for all the analysed assignment strategies for $N_{l,o}=20$ s, while for $t=10$ s the CBS within trays and the random policies require a lower number of trays movements. On the other side, for $t=20$ s, the movements are fewer for the CBS per trays strategy.

The second set of graphs of Table 2 shows the parametrical analysis of the number of picking lines per order $N_{l,o}$. Considering the overall system idle time, by increasing the number of picking lines per order it has a decreasing trend for the random and for the CBS within trays policies, and an increasing one for the CBS per trays strategy. Moreover, it results to be comparable for the three assignment strategies for $N_{l,o}=25$ lines, even if the picker idle time contribution and the VLM idle time one are different: in case of CBS per trays policy the VLM has a higher idleness than the picker, while for the other two

### Table 2

<table>
<thead>
<tr>
<th>Assignment Strategy</th>
<th>Graphs Reported in Figure 4</th>
<th>Graphs Reported in Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Random storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. CBS per trays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. CBS within trays</td>
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</tbody>
</table>
storage assignment policies the proportion is the opposite. As far as the throughput of the system is concerned, it can be noticed that the dimension of the order is less influential, above all for the CBS per trays strategy. For the CBS within trays strategy, instead, the single line picking time decreases for a higher number of picking lines per order, although the number of moved trays per hour remains almost constant. On the other side, in case of CBS per trays the number of moved trays decreases when the number of picking lines per order increases.

<table>
<thead>
<tr>
<th>Varying parameter</th>
<th>Graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single line net picking time</strong></td>
<td><img src="image1" alt="Graphs" /></td>
</tr>
<tr>
<td><strong>Number of picking lines per order</strong></td>
<td><img src="image2" alt="Graphs" /></td>
</tr>
<tr>
<td><strong>A, B, C products picking lines percentages</strong></td>
<td><img src="image3" alt="Graphs" /></td>
</tr>
</tbody>
</table>

**Legenda**

- Random
- CBS per trays
- CBS within trays

**Table 2: Performance evaluation, varying **$t$, $N_{lo}$ and the A, B, C picking lines frequencies**

The last interesting analysis concerns the evaluation of the products characteristics, referring to their picking frequencies (lower part of Table 2). In this case, from the first plots it can be seen that the overall system idle time remains constant and equal for all the different assignment strategies. Anyway, the overall idle time is again composed in a different way for CBS per trays policy with respect to the random and CBS within trays ones. Furthermore, for the CBS per trays strategy both the picker idle time and the VLM idle time are influenced by the variation of the picking frequencies per product class: by increasing the percentage referring to the A-class products the picker idle time decreases while the VLM idle time is higher. This is due to the fact that if the 20% of the products is picked for the 80% or 90% of the times, and these products are all stored in the same trays, the VLM has to move a lower number of trays, as can be seen from the graph reporting the trend of the moved trays per hour. Also in the throughput graphs (single line net picking time and number of picking lines per hour) the CBS per trays policy has a variable trend according to the value of the x-axis parameter. In fact, by increasing the
picking frequency of the A-class products the number of processed picking lines is higher. Since more picking lines require the same trays, the tray-change is reduced and the real picking time reflects the single line net picking time.

Another aspect that emerges from the results and that it is important to underline is that the random strategy and the CBS within trays one generally tends to have a very similar behaviour. Indeed, as can be observed in Figure 3, in the analysis reported in the present paper the random strategy assignment can be comparable to the CBS within trays one. In fact, at this stage of the study, the picking time refers only to the moving of the trays, considering an average picking time from the tray which is equal for all the storage assignment strategies, without focusing on the position of the references inside the tray.

5. Conclusions and further research

The present paper has introduced a preliminary analysis on Vertical Lift Modules. After having explained the general operation of these systems, and having described the existing related literature, the simulation model used for the performance evaluation has been shown. Moreover, the proposed model has been applied to compare three different storage assignment strategies: the random strategy and two different applications of the class-based strategy (CBS per trays and CBS within trays). As far as the results of the presented preliminary analysis are concerned, it has been observed that the CBS per trays assignment strategy generally warrants the best performance in terms of single line real picking time and, hence, picking lines processed per hour. Moreover, in this case the picker has very few idle time, while the VLM has no problems in moving the requested trays. However, in order to have a full understanding of the benefits and of the limits of the compared assignment policies, further deep research is absolutely needed.

Next steps of the research about this topic will deal with a more detailed parametrical analysis, by changing more parameters and in wider value ranges. Among the others, it will be changed the number of references per tray; the space dedicated inside the VLM will be considered to be different according to the characteristics of the various products; the VLM performance will be changed to see when it could be useful to have a faster system or, instead, when this is not needed. Moreover, the simulation model will be integrated with a further part, to allow the consideration of the impact of storage assignment also within the trays, then, to compare different storage assignment strategies (Ha and Hwang, 1994). Finally, the results of all the simulations will be used to obtain a general mathematical model, which in an easy way will help the understanding of the most suitable storage assignment for the particular considered context.

6. References


