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Investigating the impact of heavy products allocation on picker routing policies in a warehouse setting

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Abstract

In department stores, heavier products, such as water, are assigned to specific areas, placing them first in pallets to avoid the damage of lighter products that complete the picking order and are put over these heavier products. This study analyses the impact of the allocation of heavy products and of the size of relating areas on picker routing policies, and compare this scenario with a situation in which an area dedicated to heavy product does not exist in the warehouse. S-Shaped and S-Shaped Advanced policies are implemented to respond to picking orders for different products to be allocated in pallets following rules dictated according to their weight. Through a simulative approach, conducted with MS Excel™ software, their joint implementation was simulated by distinguishing various allocation areas within the warehouse to simulate the different types of products to be picked; the objectives functions cover the minimization of routes to fulfil orders, and the minimization of the total travelled distance. Warehouse storage capacity, picking list size, and the size of the specific allocations were the variables considered. The results of the two scenarios are presented separately and in aggregate form to appraise: (i) the impact of heavy product-specific allocation, (ii) the efficiency of the proposed solutions in terms of the total distance travelled by the pickers, and (iii) the achievable optimization margins. Finally, a possible future research proposal is presented.

Keywords: Heavy Products; Order Picking; Simulation Approach; Routing.

1. Introduction

Order picking is a fundamental process within the warehouse, and it accounts for approximately 55% of its total operating costs (Fumi et al., 2013; Andjelkovic & Radosavljevic, 2017). Under this assumption, optimizing the routing policy of pickers is a crucial aspect of the picking process in manual warehouses.

Efficient order processing time and reduced picking duration are essential goals for process optimization. Numerous studies have focused on finding the optimal route, minimizing the time required by the picker to fulfil the entire picking list, and reducing the total distance travelled during the process. For a complete overview on this topic, readers can refer to Casella et al. (2023).

More into detail, Zhou et al. (2022a) have evaluated, within a leaf warehouse, the performance resulting from the separate usage of Return and S-Shaped policies, rather than that resulting from their joint implementation. Specifically, given two storage locations to be visited, the best policy to adopt is recursively evaluated.

In another study, Zhou et al. (2022b) have divided a warehouse with a fishbone layout into three classes A, B, and C according to the proximity of the warehouse area to the input/output (I/O) points. Then, they evaluated the performance of the Return and S-Shaped routing policies in terms of the distances travelled by the pickers during order processing.

In real-world scenarios, picking operations must consider specific product characteristics, such as its weight and fragility, to be executed effectively (Chabot et al., 2017). During picking operations, the different weight of various products must be evaluated for a proper pallet formation to avoid damage of products or stability problems of the whole pallet. In the study by Zhang et al. (2021), items were distinguished into food and non-food products and through this category constraint, the joint order batching and picker routing problem was analyzed, meeting the constraint that non-food products must be placed below food products.

Žulj et al. (2018) have developed a solution method that considers product weight constraints when determining the picker routing strategy based on a real case of a German household product manufacturer. Again, Matusiak et al. (2014) have proposed a joint order-batching and picker routing method to address the combined precedence-constrained routing and order-batching problem.

Weight constraints also play a role in selecting and evaluating the optimal allocation storage policies, as demonstrated by Trindade et al. (2021). Additionally, Trinidade et al. (2022) have developed an alternative heuristic procedure, in which product weight is one of the four main parameters for making allocation decisions.

On the bases of these short premises, this paper introduces a dedicated area at the front of the warehouse, specifically designated for heavy products, which will be the initial stop of pickers during their picking tasks, given the fact that heavy items should be place at the base of a pallet.

The objective of this paper is to determine the impact of heavy product allocation on the optimization of picking routing policies. Two scenarios are taken into account and reproduced using a MS Excel™ software named "FORMULA 59". In the first scenario, three layouts without a dedicated area are defined, with variations in the number of cross-aisles. The picking policy adopted is the S-Shaped Advanced (SSAD) so that the presence of cross - aisles, if any, can be exploited. The only area where a SSS was performed is the dedicated area for heavy products in the Scenario B. Of course, in both scenarios, the prior constraints of heavy products were applied.

The S-Shaped policy (SSS) implies no use of cross-aisles during picking, making it the simplest routing strategy for pickers (Al-Shboul, 2023). Consequently, the picker must travel through the entire corridor when necessary. The S-Shaped Advanced policy (SSAD), allows for the effective usage of cross aisles and is selected based on its superior performance in various warehouse configurations (Montanari et al., 2022).

The results are presented for each scenario in terms of the average distance traveled by the pickers to fulfill picking orders and its standard deviation. Finally, a comparison between the two scenarios is conducted to determine the percentage of performance improvement achieved through the reduction of the distance travelled.

The remainder of the paper is structured as follows: the next section (section 2) details the material and methods, including the methodology; section 3 presents the results of the simulations and discusses them, followed by a conclusion section (section 4).

2. Materials and Methods

2.1. Nomenclature

The nomenclature adopted in this study is presented in Table 1, below.

Table 1. Nomenclature.

Symbol	Description	Unit
R	Storage Capacity	-
SL	Size of the storage slot	m×m
Xf	Shape factor of the warehouse	-
W_a	Aisles width	m
I/O	Input/output position of pickers	-
H_v	Number of storage locations dedicated to heavy products	-
O_v	Number of storage locations dedicated to non-heavy products	-
C_a	Number of cross-aisles	-
LO	Number of products (order lines) in each picking task	-
LO(H)	Number of order lines characterizing each mission covered only by heavy products	-
N	Number of picking tasks in each simulation	-
M	Number of simulations replicates	-
M_A	Number of simulations replicates in Scenario A	-
M_B	Number of simulations replicates in Scenario B	-
Rout_H	Routing policy implemented in the heavy products area	-
Rout_O	Routing policy implemented in the non-heavy products area.	-
d_m	Average travel distance for each mission	m
SD(d)	Standard Deviation of the travelled distance	m
Red_%	Percentual reduction of the distance travelled (from Scenario A to Scenario B)	%

2.2. Layout

As already stated, for this study, two different scenarios were simulated, and each one involved various configurations of the warehouse layout. The different layout configurations used in the study are summarized in Figure 1 below.

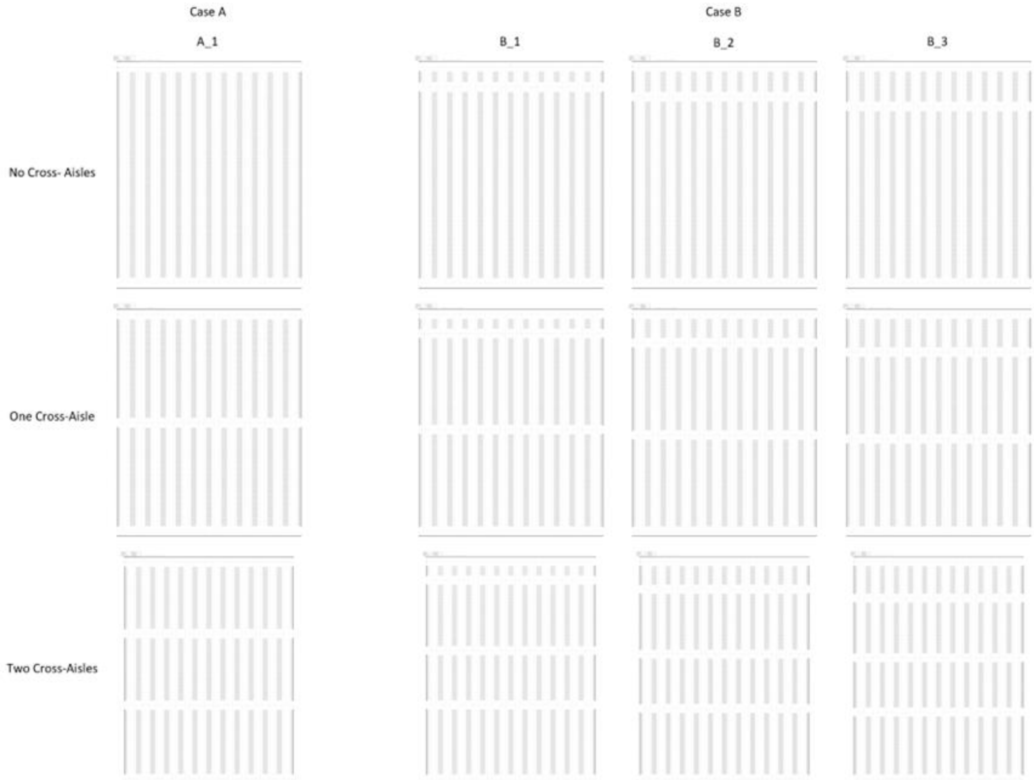

Figure 1. Layouts adopted in the simulation campaign.

2.3. Preliminary Assumptions

In each scenario, various parameters were defined for setting the simulative campaign carried out through the software, as summarized in Table 2.

Table 2. Fixed settings and values of the simulations.

Symbol	Value/Setting	Unit
R	2 400	-
SL	1.00 × 1.25	m×m
Xf	1	-
W_a	5.40	m
I/O	Opposite Lateral Picking Same Side (OLPSS)	-
Rout_H	S-Shaped Simple (SSS)	-
Rout_O	S-Shaped Advanced (SSA)	-

It is important to point out that the value of Xf set at 1 is to be seen as a "nominal" value. Due to the size constraints to be satisfied and being a parameter closely related to the specific layout, Xf may be subject to variation in a range of values. Efforts were made to maintain this range as close to 1 as possible while keeping the value of R fixed and adjusting the remaining parameters accordingly.

The value of W_a was determined to enable two order picking trucks to travel in opposite directions simultaneously without causing congestion. This decision was made to ensure that the layout closely resembles real-world warehouse contexts.

The rationale behind the choice of an OLPSS-type I/O policy is instead the physical flow of pickers within the warehouse. In scenario B, the layout consists of two distinct areas, one exclusively designated for heavy products and the other dedicated to all other types of products. The picker is thus required to pick the heavy products first in the mission order lines, and only after completing these picks, he/she will proceed by picking the remaining order lines. Extensive evaluations revealed that an OLPSS-type I/O policy provides the best access to both areas, considering the specific characteristics and constraints of the study.

This thoughtful selection of parameters and policies allows for a robust and realistic simulative analysis of the impact of heavy product allocation on the optimization of picking routing policies in the warehouse scenarios under examination. The following section will delve into the details of the software used and the methodology employed for conducting the simulations.

2.4. Simulation Tool Description

To achieve the research objective, an adaptable tool called "FORMULA 59" was customized for warehouse design and management. The "HEAVY PRODUCTS add-in" was integrated into the tool to allow for the creation of layouts tailored for stocking heavy products and to handle picking activities involving heavy products at the beginning of the order list. The following is a brief overview of "FORMULA 59" (Figure 2), highlighting its analytic capabilities and its role in developing the simulation campaign in the logistics domain. Although the simulation campaign makes use of a subset of "FORMULA 59"'s functionalities only, this section aims to provide a clear understanding of its potential, facilitating future extensions and developments. As shown in Figure 2, "FORMULA 59" consists of two interconnected components:

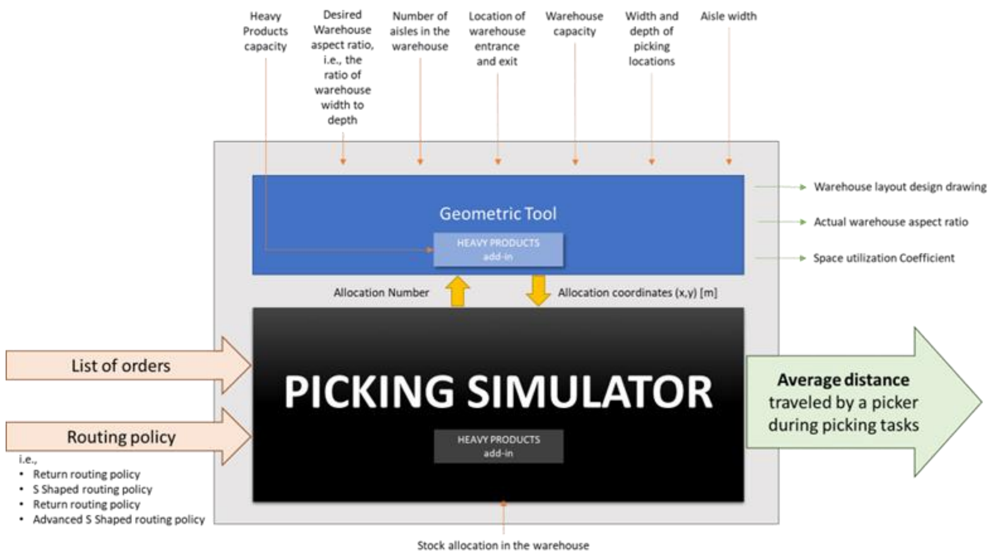

Figure 2. FORMULA 59 Simulation Model.

- **Geometric Tool** (in blue): this component is responsible for creating an abstract model of the warehouse, generating picking points for each allocation within its boundaries. The geometric tool uses various data, including warehouse capacity, the number of transversal corridors, allocation width and depth, corridor width, desired aspect ratio of the warehouse, and entrance and exit positions for the picker. The virtual representation of the entire warehouse, produced by the geometric tool, determines the warehouse size, the surface saturation coefficient surface coefficient rate, the shape factor, and, when needed, the layout design of the warehouse. Notably, the system adheres to integer variables, which means that fractional allocations or corridors are not considered. Consequently, the actual shape factor may slightly deviate from the user's desired shape factor, considering the integer constraints while closely approximating the desired shape factor. The virtual warehouse model, created by the geometric tool, associates each allocation with the corresponding picking point, where the picker executes routine order fulfillment tasks. The picking simulator accesses this model to calculate picking mission distances within the warehouse.
- **Picking Simulator** (in black): before utilizing the picking simulator, instructions regarding product allocation in the warehouse are required. This involves defining which product is stored in each allocation, characterized by a rotation index linked to the market demand for that specific product. This paper assumes an equal rotation index for each product, with the rule that heavy products are picked first during the procedure, ensuring they are placed at the bottom of the pallet. Future extensions can explore the impact of varying rotation indices on the results.

As shown in Figure 2, the Geometric Tool has been enhanced by integrating the "HEAVY PRODUCTS add-in", which plays a crucial role in delineating the dedicated region for storing heavy products. This "heavy products" zone is strategically located at the forefront of the warehouse, close to the I/O. During the design phase, users have the flexibility to specify the storage capacity of this area. For Scenario B, as depicted in the previous Figure 1, this study allocates 5%, 10%, and 15% of the warehouse capacity, respectively, for the "heavy products" zone. The "Geometric Tool's heavy products add-in" assists in defining this specific area for storing heavy products.

Using all the available data, the tool calculates the average distance covered by the picker during picking missions, considering the list of market-requested orders and the selected routing policy for warehouse picking. The user can choose from a selection of routing policies, including the Return Routing Policy, SSS Routing Policy, Advanced Return Routing Policy, and SSAD Routing Policy. Based on previous research insights, the SSAD Routing Policy is preferred for normal products due to its commendable performance compared to the other three policies. This SSAD

Routing Policy is an extension of the SSS Routing Policy, incorporating the added capability to utilize cross aisles when beneficial.

2.5. Simulation campaign

As mentioned in the previous sections, the simulation campaign consists of two scenarios:

- **Scenario A:** in this scenario (A_1 in Figure 1), there is no dedicated area for heavy products; rather, they are stored randomly within the warehouse. In each mission an increasing percentage of order lines involves picking heavy products, which serves as a precedence constraint for the picker. The picker first picks the heavy products and then fulfils the remaining order lines.
- **Scenario B:** this scenario includes an area within the warehouse specifically dedicated to heavy products of different sizes. Three distinct layouts were analysed for Scenario B: B_1 (size of the dedicated area = 5% R), B_2 (size of the dedicated area = 10% R), and B_3 (size of the dedicated area = 15% R).

In all the scenarios, three further cases were identified resulting from the presence of a different number of cross-aisles within the area for non-heavy products (in cases B_1, B_2 and B_3) rather than within the layout (case A_1). Specifically, layouts with 0 cross-aisles were considered, with 1 cross-aisle rather than 2 cross-aisles.

The simulation campaign leverages the following variables:

- **H_v**: the number of storage slots designated for heavy products in Scenario B is determined by three different percentages of the total R: 5%, 10%, and 15% of R, respectively. The Table 3 below summarizes the different values of H_v.

Table 3. H_v values for R=2 400.

H_v%	H_v
5%	120
10%	240
15%	360

- **O_v**: the number of storage slots designated for non-heavy products in Scenario B is computed as the complementary values to the respective Hv values (Eq.1).

$$O_v = (R - H_v) \quad (1)$$

- **C_a**: the number of cross-aisles in each layout analysed. Three different conditions are studied: 0 cross-aisles, 1 cross-aisle, and 2 cross-aisles. In Scenario B, the cross-aisles are inserted in the area dedicated to non-heavy products.
- **LO**: it represents the number of items per picking mission. Four different cases were considered, with 10, 20, 50, and 100 items picked per mission. This value includes both heavy and non-heavy products. In Scenario A, since there is no dedicated area for heavy products, a number of order lines including heavy products (LO(H)) has been set within each mission. These values are equal to the percentages used for H_v in Scenario B. In Scenario B, the need to set a specific number of order lines dedicated to heavy products (LO(H)) within each mission is not required due to the presence of the dedicated area for heavy products. All products in the warehouse share the same rotation index by assumption, which means they have an equal probability of being ordered. The percentage of warehouse capacity designated for heavy products (H_v) directly corresponds to the probability of encountering these heavy products in the order list during the picking process. For example, if 10% of the warehouse capacity is designated for heavy products (H_v = 10% R), then there is a 10% chance that any product in the order list will be a heavy product. This simplifies the simulation process in Scenario B, as the probability distribution of heavy and non-heavy products is already determined by the designated percentage of H_v. As a result, the simulation campaign in Scenario B focuses on analysing the impact of different layouts, cross-aisle configurations and the size of the dedicated area for heavy products on the picker's routing policies and travelled distance, without the need to explicitly set a specific number of order lines dedicated to heavy products in each mission. The presence of the dedicated area ensures that heavy products are readily available for picking, and the simulation explores how different factors affect the efficiency of the picking process in this specific scenario.

In each M^{th} simulation, a total of 10 000 picking missions were simulated. The total number of simulations performed (M) is determined as the sum of the number of simulations performed in Scenario A (M_A) and the number of simulations performed in Scenario B (M_B). Each scenario includes various combinations of layouts, cross-aisles and heavy product area sizes, leading to a total of 72 simulations (36 in Scenario A and 36 in Scenario B).

The equations for calculating the total number of simulations are as follows:

$$M = M_A + M_B = 36 + 36 = 72 \qquad (2)$$

where:

$$M_A = n°C_a \cdot n°LO(H) \cdot n°\text{LO} = 3 \cdot 3 \cdot 4 = 36 \qquad (3)$$

$$M_B = n°H_v \cdot n°C_a \cdot n°\text{LO} = 3 \cdot 3 \cdot 4 = 36 \qquad (4)$$

Finally, a comparison between the two scenarios was carried out and the percentage reduction of the distance travelled by the picker (Red%) moving from the Scenario A to the Scenario B was calculated according to the Equation 5.

$$Red\% = \frac{dm_B - dm_A}{dm_A} \cdot 100 \qquad (5)$$

The next Table 4 summarizes the numerical values of each variable considered.

Table 4. Values of the variables adopted for the simulative campaign.

Symbol	Value/Setting
H_v%	5% - 10% - 15%
O_V%	95% - 90% - 85%
C_a	1 - 2 - 3
LO	10 - 20 - 50 - 100
LO(H)	5%LO - 10%LO - 15%LO
M	72
M_A	36
M_B	36
N	10 000

3. Results and Discussion

The simulation campaign involved 36 simulations for each scenario, with each simulation comprising 10 000 picking missions to calculate the mean distance (d_m) travelled by the picker for a mission and its Standard Deviation (SD(d)). Results are presented in Tables 5, 6 and 7. In each table the results of the two Scenarios are presented but Table 5 refers to no cross-aisles layout, Table 6 refers to single cross-aisle and Table 7 refers to the layout characterized by the presence of two cross-aisles.

Table 5. d_m e SD(d) values - Case with 0 Cross-Aisles.

Scenario			A							B			
LO(H)	5%		10%		15%		H_v	5%		10%		15%	
LO	d_m [m]	SD(d)	d_m [m]	SD(d)	d_m [m]	SD(d)	LO	d_m [m]	SD(d)	d_m [m]	SD(d)	d_m [m]	SD(d)
10	868.47	118.29	918.91	115.86	938.55	114.23	10	785.38	96.07	746.93	93.52	711.02	87.13
20	1 379.69	142.35	1 442.27	138.52	1 483.02	136.39	20	1 189.38	121.42	1 125.84	114.13	1 073.24	107.71
50	2 206.49	178.62	2 345.05	175.44	2 458.51	179.22	50	1 840.64	154.01	1 766.81	140.83	1 705.93	131.82
100	3 114.27	257.14	3 335.27	256.20	3 501.33	254.99	100	2 550.49	232.89	2 438.02	213.95	2 361.15	199.06

Table 6. d_m e SD(d) values - Case with 1 Cross-Aisle.

Scenario			A							B			
LO(H)	5%		10%		15%		H_v	5%		10%		15%	
LO	d_m [m]	SD(d)	d_m [m]	SD(d)	d_m [m]	SD(d)	LO	d_m [m]	SD(d)	d_m [mt]	SD(d)	d_m [m]	SD(d)
10	709.29	101.53	753.74	100.27	768.40	100.30	10	647.44	79.64	621.04	75.50	600.15	72.52
20	1 124.26	118.45	1 169.13	114.61	1 197.28	113.63	20	969.18	96.18	924.97	91.68	890.17	85.30
50	1 865.55	113.04	1 939.35	117.15	2 013.14	121.26	50	1 542.56	92.84	1 491.43	87.75	1 454.43	85.00
100	2 493.60	139.15	2 666.08	142.65	2 803.29	146.09	100	2 048.29	118.45	1 997.68	108.17	1 965.31	103.69

Table 7. d_m e SD(d) values – Case with 2 Cross-Aisles.

Scenario			A							B			
LO(H)	5%		10%		15%		H_v	5%		10%		15%	
LO	d_m [m]	SD(d)	d_m [m]	SD(d)	d_m [m]	SD(d)	LO	d_m [m]	SD(d)	d_m [m]	SD(d)	d_m [m]	SD(d)
10	693.76	106.97	736.41	106.88	751.95	106.33	10	637.75	85.30	612.28	82.46	592.72	77.43
20	1 093.36	126.33	1 134.57	120.91	1 181.31	123.91	20	950.87	102.63	908.95	96.79	876.55	88.94
50	1 756.19	110.79	1 848.70	114.90	1 922.26	122.00	50	1 485.11	84.23	1 439.01	82.51	1 407.04	80.66
100	2 331.89	112.64	2 499.46	122.94	2 638.66	127.35	100	1 923.16	85.07	1 885.67	81.75	1 862.58	78.82

From the data analysis, it is evident that the placement of a dedicated heavy products area in Scenario B impacts the average distance travelled by the picker to fulfil missions, irrespective of the number of cross-aisles. The inclusion of the dedicated area in the front part of the warehouse reduces the average distances travelled in all the simulated configurations. As shown in detail in Figures 4a-4b-4c, in Scenario A, as the number of heavy products to be processed increases, the distance travelled by the picker also increases. On the other hand, *ceteris paribus*, in Scenario B the trend is naturally the same, but the distance is much lower than in Scenario A.

In addition, having heavy products all located in a specific area of the warehouse also minimizes the impacts of the routing policy used (SSS), which does not allow cross-aisles to be used to reach warehouse locations. This is evident in the layout without cross-aisles (Figure 4a). In fact, it can be seen that the discrepancy is generated between the dark blue line (H_v = 5%) and the light blue line (H_v = 15%) as order lines increase, while as the number of cross-aisles increases (Figure 4b and 4c) this discrepancy tends to disappear.

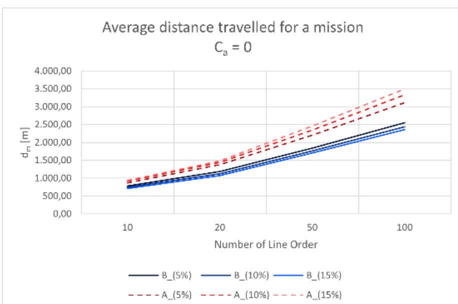

Figure 4a. Case with 0 cross-aisle: Trend of d_m.

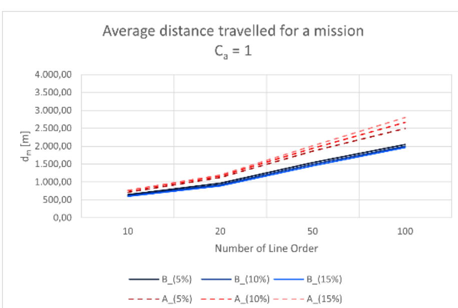

Figure 4b. Case with 1 cross-aisle: Trend of d_m.

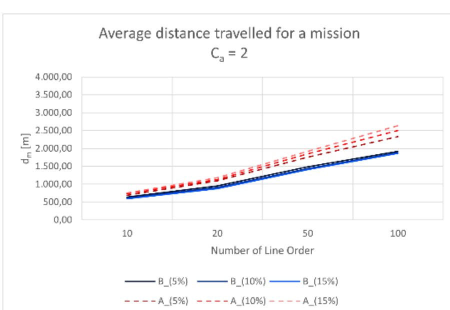

Figure 4c. Case with 2 cross-aisle: Trend of d_m.

The impact of the routing policy (SSS) on the distance travelled is also mitigated when heavy products are concentrated in a specific area. This is particularly evident in layouts without cross-aisles. As the number of heavy products to be processed increases in Scenario A, the distance travelled by the picker increases as well. However, in Scenario B, the trend is opposite, and the distance travelled decreases as the size of the dedicated area increases. The next Figures 5a -5c illustrate these opposite trends between these two scenarios, represented for the case of 100 LO each mission.

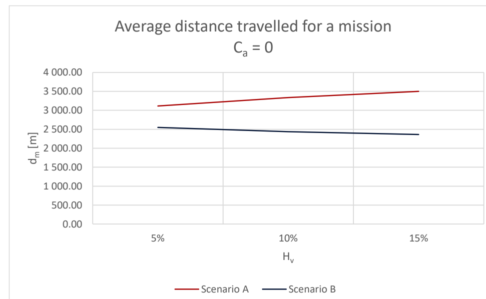

Figure 5a. Case with 0 cross-aisle and 100 LO: Trend of d_m.

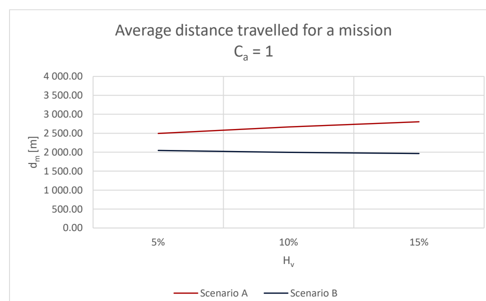

Figure 5b. Case with 1 cross-aisle and 100 LO: Trend of d_m.

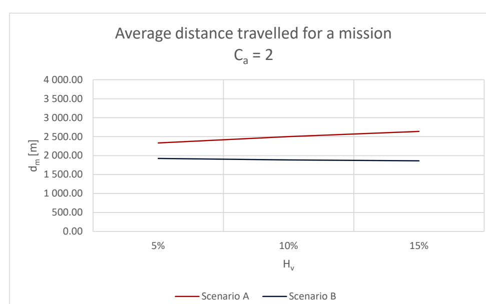

Figure 5c. Case with 2 cross-aisles and 100 LO: Trend of d_m.

This reduction in distance can be justified with the presence of a precedence constraints for picking heavy products. With the dedicated area located near the I/O points, all heavy products are concentrated in a specific area of the layout. This minimizes the distances travelled for picking these products, leading to an overall efficiency gain. The reduction in distance becomes more pronounced as the size of the dedicated area and the number of heavy products increase. This is an important result, as the same products affect in an opposite manner the performance just by changing their position inside the warehouse.

Furthermore, the inclusion of cross-aisles in the non-heavy products area of Scenario B attenuates their impact on the distances travelled. Figure 6a shows that adding a single cross-aisle has a more significant impact on d_m than adding another cross-aisle, even with different H_v values (Figures 6b and 6c).

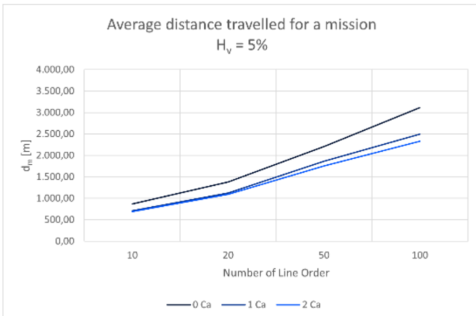

Figure 6a. Scenario B: H_v 5%: Trend of dm varying C_a and LO.

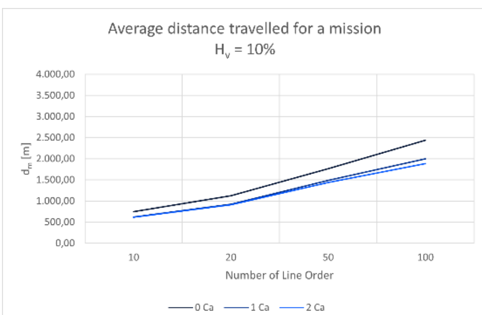

Figure 6b. Scenario B: H_v 10%: Trend of d_m varying C_a and LO.

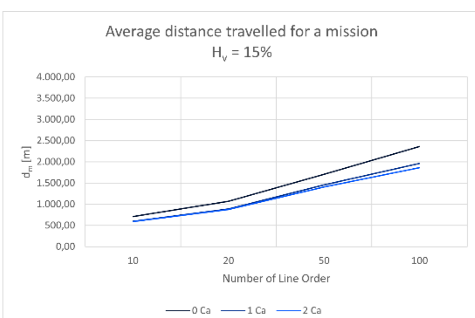

Figure 6c. Scenario B: H_v 15%: Trend of d_m varying C_a and LO.

Based on Figure 6a, i.e. a warehouse, with H_v of 5%, the inclusion of a single cross aisle into the non-heavy products area impacts the value of d_m much more significantly than the addition of another cross aisle, resulting in the layout with two cross-aisles in the non-heavy product area. In fact, the gap between the dark-blue line (0 cross-aisles) and the blue line (1 cross-aisle) is much more relevant than the gap between the blue line and the light-blue line (2 cross-aisles). This phenomenon is not affected by the size of the areas, as it is also found in Figures 6b and 6c characterized by different H_v values.

The benefits achieved when shifting from Scenario A to Scenario B are summarized in Tables 8, 9 and 10, where the percentage reduction of d_m (Red%) was calculated for different numbers of cross-aisles. These tables confirm that the greatest increase in performance is achieved in layouts without cross-aisles due to the concentration of products in a limited area.

Overall, the results indicate that dedicating a specific area for heavy products in the warehouse has a positive impact on the efficiency of the picking process. This allocation strategy reduces the average distances travelled by pickers and minimizes the impact of routing policies and cross-aisles. It thus offers valuable insights for optimizing order picking operations in manual warehouses and highlights the importance of considering product characteristics and layout design in logistics management.

Table 8. Red% Values: Case with 0 cross-aisles layout.

	H_v		
LO	5%	10%	15%
10	-9.6%	-18.7%	-24.2%
20	-13.8%	-21.9%	-27.6%
50	-16.6%	-24.7%	-30.6%
100	-18.1%	-26.9%	-32.6%

Table 9. Red% Values: Case with 1 cross-aisle layout.

	H_v		
LO	5%	10%	15%
10	-8.7%	-17.6%	-21.9%
20	-13.8%	-20.9%	-25.7%
50	-17.3%	-23.1%	-27.8%
100	-17.9%	-25.1%	-29.9%

Table 10. Red% Values: Case with 2 cross-aisles layout.

	H_v		
LO	5%	10%	15%
10	-8.1%	-16.9%	-21.2%
20	-13.0%	-19.9%	-25.8%
50	-15.4%	-22.2%	-26.8%
100	-17.5%	-24.6%	-29.4%

Once again, the assumption that the greatest increase in performance is achieved in the absence of cross-aisles is confirmed by these outcomes, precisely because of the concentration of products in a limited area.

4. Conclusions

In conclusion, optimizing the routing policy of pickers in manual warehouses is essential for reducing the total travel time and distance covered by the operators. Product characteristics and constraints must be considered when determining the best routes for operators to efficiently execute picking operations.

In this study, two separate warehouse scenarios were simulated in the presence of heavy products and with a precedence constraint for the operator to comply with during the picking phases. In a first scenario (scenario A) there is no dedicated area for this type of products, which are included in variable percentage in the order lines of picking missions. A second scenario (Scenario B), on the other hand, involves the inclusion of a dedicated area of variable size, located at the front of the layout. Further simulated variations concern the number of cross-aisles included in the layout, as well as the size of each picking mission, in terms of number of lines order. The simulation campaign as a whole featured 72 different configurations, with 10 000 picking missions to be fulfilled in each scenario.

An analysis of the results obtained showed a relevant impact on the performance deriving from the inclusion of the dedicated area. In fact, concentrating heavy products in a restricted area close to the I/O depot allowed for shorter travel distances of the pickers. As the size of the dedicated area increases, the decrease in the distance travelled becomes even more pronounced. The presence of cross-aisles in the layout showed instead an opposite effect. While cross-aisles improve the accessibility to non-heavy products, their presence also increases the overall distance travelled, especially when heavy products are spread throughout the warehouse. Overall, the benefit of having no cross-aisles was most significant when the dedicated area for heavy products existed.

In addition, in the absence of cross-aisles in the layout, an effect of the size of the area itself was also observed. Specifically, as the size increases, the average travelled distance reduces further. This result is evident for picking missions with a high number of LO (50 or 100). Under these conditions, the distance travelled by pickers can be reduced by more than 32%.

The inclusion of cross-aisles lessens this effect, as the impact of cross-aisles is lower than proportional to the number of cross-aisles inserted. In fact, in terms of benefits, the maximum reduction occurs with the inclusion of the first corridor, while increasing the number of aisles has a progressively decreasing effect. Moreover, this phenomenon does not depend on the presence of the dedicated area or the size of the same, as it has been observed in both scenarios.

Future research could investigate the presence of a "threshold" in the size of the dedicated area, beyond which the cost-effectiveness of that area becomes low and does not justify its implementation. Exploring different warehouse layouts and additional parameters such as variable turnover index could also provide valuable insights.

Ultimately, this study highlights the importance of tailored warehouse design and order picking strategies. By properly placing dedicated areas for specific product types and considering layout configurations, warehouse managers can optimize the picking process and improve the overall efficiency of the system.

References

Al-Shboul, M.A. (2023). Design and control order picking route of a retailer warehouse using simulation to increase labour productivity. Acta Logistica, 10(1), 121-133. doi:10.22306/al.v10i1.367

Andjelkovic, A. & Radosavljevic, M. (2017). Improving order-picking process through implementation warehouse management system. Strategic Management, 1 (23), 3-10. doi: 10.5937/StraMan1801003A

Casella, G., Volpi, A., Montanari, R., Tebaldi, L., & Bottani, E. (2023). Trends in order picking: a 2007-2022 review of the literature. Production & Manufacturing Research, 11(1), 2191115, doi: 10.1080/21693277.2023.2191115

Chabot, T., Lahyani, R., Coelho, L. C., & Renaud, J. (2017). Order picking problems underweight, fragility and category constraints. International Journal of Production Research, 55(21), 6361-6379. doi:10.1080/00207543.2016.1251625

Fumi, A., Scarabotti, L., & Schiraldi, M.M. (2013). The Effect of Slot-Code Optimization in Warehouse Order Picking. International Journal of Engineering Business Management, 5 (20), 1-10. doi: 10.5772/56803

Matusiak, M., De Koster, R., Kroon, L., & Saarinen, J. (2014). A fast simulated annealing method for batching precedence-constrained customer orders in a warehouse. European Journal of Operational Research, 236(3), 968-977. doi: 10.1016/j.ejor.2013.06.001

Montanari, R., Bottani, E., Volpi, A., Solari, F., Lysova, N., & Bocelli, M. (2022). Warehouse design and management: A simulative approach to minimize the distance travelled by pickers. Paper presented at the International Conference on Harbour, Maritime and Multimodal Logistics Modelling and Simulation, doi: 10.46354/i3m.2022.hms.005

Trindade, M.A.M., Sousa, P.S.A., & Moreira, M.R.A. (2021). Improving order-picking operations with precedence constraints through efficient storage location assignment: Evidence from a retail company. U.Porto Journal of Engineering,7(3), 34-52. doi: 10.24840/2183-6493_007.003_000

Trindade, M.A.M., Sousa, P.S.A., & Moreira, M.R.A. (2022). Ramping up a heuristic procedure for storage location assignment problem with precedence constraints. Flexible Services and Manufacturing Journal, 34(3), 646-669. doi: 10.1007/s10696-021-09423-w

Zhang, J., Zhang, Y., & Zhang, X. (2021). The study of joint order batching and picker routing problem with food and nonfood category constraint in online-to-offline grocery store. International Transactions in Operational Research,28(5), 2440-

2463. doi: 10.1111/itor.12926

Zhou, L., Liu, H., Zhao, J., Wang, F., & Yang, J. (2022). Performance analysis of picking routing strategies in the leaf layout warehouse. Mathematics, 10(17) doi: 10.3390/math10173149

Zhou, L., Zhao, J., Liu, H., Wang, F., Yang, J., & Wang, S. (2022). Stochastic models of routing strategies under the class-based storage policy in fishbone layout warehouses. Scientific Reports,12(1) doi: 10.1038/s41598-022-17240-w

Žulj, I., Glock, C.H., Grosse, E.H., & Schneider, M. (2018). Picker routing and storage-assignment strategies for precedence-constrained order picking. Computers and Industrial Engineering, 123, 338-347. doi: 10.1016/j.cie.2018.06.015