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Warehouse Design and Management: a simulative approach to minimize the distance travelled by pickers

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Abstract

In this work, we use a simulation approach to optimize the picking policy of a warehouse, with the aim to minimize the distance travelled by a picker, and thus to reduce the throughput time. The analysis was performed considering a traditional warehouse used for both storing and picking activities, with double-sided racks and a storage capacity of 1,200 pallets. We generated 50 different warehouse configurations by modifying the values of two input parameters (warehouse shape factor and location of the input-output depot) and adopting 4 different routing policy for each layout. Then we generated 10,000 different picking list of each scenario to gain statistical significance. The simulation results were recorded in a structured database and analyzed to determine the conditions that allowed for the minimization of the travel distance. The data analysis allowed also to evaluate the impact of the input parameters, both hardware (geometrical features) and software (management policies), on the distance covered by the picker and derive some managerial insights. One interesting result, referring to the combination of location of the picking input-output depot with a specific routing policy and a defined range of warehouse shape factors, is presented and discussed in greater detail. Finally, we suggest possible future research activities, including the analysis of different order sizes and rotation indexes.

Keywords: warehouse; routing policy; input-output configuration; simulation approach; picking distance.

1. Introduction

Order picking is one of the most time-consuming, labour and cost-intensive activities for most warehouses. This activity has a time constraint predefined by the customer, and any deficit in the picking process at the warehouse level has a significant impact on the entire supply chain (Amorim-Lopes et al., 2020).

The activities performed by the pickers mainly consist of travelling through the warehouse, searching for the items ordered, and picking them from their storage locations. Everything related to the general logistics of a warehouse, such as receiving, storing, order picking and shipping, has often high costs (Rouwenhorst et al., 2000). Therefore, an efficient organization of the warehouse activities is crucial to reduce the time required for the operator to travel through the warehouse and collect the items. In the case of manual processes, it is estimated that picking operations account for more than 50-75% of the total cost of warehouse management (Coyle et al., 1996; Tompkins et al., 1996; Bottani et al., 2015). A reduction in the travel time is therefore expected to result in a direct enhancement of the warehouse performance and management, e.g., a picker could process more orders during the working day or work shift, thereby increasing the productivity level. Methods for minimizing the distance travelled by the picker have been developed and published in the literature, leveraging mathematical models, decision support systems, heuristic algorithms, and multidimensional data mining techniques (Yener et al., 2019, Bottani et al., 2019).

In this study we use a simulation approach to optimize the picking policy of a warehouse, aiming to minimize the distance travelled by the picker, and thus reduce the throughput time and cost. We consider a warehouse with a traditional layout and equipped with double-sided racks. In literature, studies relating to non-traditional layouts are also available, such as fishbone configuration or Flying-V (Esmero et al., 2021). Unlike Ozden et al. (2020), we adopt the Manhattan metric, meaning that the picker is not able take shortcuts and cut corners. Furthermore, we assume that the items are stored according to a random allocation policy and a fixed number of items is collected by the picker during each mission (i.e., the picking list has a fixed length). We design a simulation campaign by sequentially modifying the values of three input parameters, including both hardware and software variables. In particular, the parameters considered are the type of *routing policy*, the warehouse *shape factor* and the location of the *input-output* depot from and towards the warehouse. Regarding the latter parameter, we start our analysis from the work developed by Petersen (1997), who considered only one single *I/O* configuration, and we expand this setting by increasing the number of *I/O* configurations to five. We then analyze the results of the simulation campaign to determine the system configuration that allows for minimizing the distance travelled by the picker, and to assess the impact of the warehouse parameters. Finally, we present and discuss the results we obtained, deriving some managerial insights.

2. Material and methods

2.1. Simulation campaign

We consider a traditional warehouse layout with double-sided racks, characterized by a storage capacity of 1,200 pallets. Each pallet location measures 1.25 m x 1 m, while the width of the aisles is 3 m.

In addition to the front and back aisles, two cross-aisles are also included in the warehouse, as shown in Figure 1., resulting in a 3-block layout.

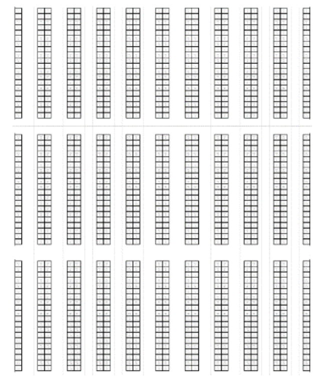

Figure 1. Layout of the warehouse with 2 cross-aisles.

To design the simulation campaign and generate the database useful for our analysis, the following assumptions were made:

- The warehouse can accommodate 1,200 pallets with standard "*Europallet*" size (0.80 m x 1.20 m);
- the warehouse is arranged with double racks, with predefined storage locations;
- each location can contain one stock-keeping unit only;
- two cross-aisles are located in the warehouse, in addition to the front and back aisles;
- the aisle width is not negligible and accounts for 3 m;
- the demand for the picking items has a uniform distribution, and each item has the same probability of being demanded by the market;
- a manual, picker-to-parts order picking strategy is adopted;
- each picking mission targets a fixed number of 50 items.

The random allocation policy was selected because it is easy to use and implemented in the management of many real warehouses (Petersen et al., 2004). With regards to the fixed number of items retrieved per mission, our assumption is based on the results of Petersen (2000), who has demonstrated that the decision makers could reduce the total picking time by 17-22% by grouping smaller orders in one single picking mission. Implicitly, in our analysis the number of items picked in each mission (50 items) could therefore belong to several orders of different sizes.

The simulation campaign was defined by evaluating all the possible configurations that can be generated by varying three input parameters, relating to both software and hardware features of the warehouse, according to the following scheme (the input factors considered are discussed in detail in the subsections that follow):

- 4 routing policies (*RP*);
- 10 shape factors (x_f);

- 5 input-output configurations (I/O).

The total number of configurations therefore results from the application of the formula below:

$$Configurations = n°RP \cdot n°x_f \cdot n°\,I/O = 4 \cdot 10 \cdot 5 = 200 \qquad (1)$$

In line with the above formula, we simulated a total of 200 warehouse configurations (Eq.1). To generate statistically significant results, we performed 10,000 simulations of each scenario, and computed the mean distance travelled by the picker for each warehouse configuration. Finally, we recorded the results obtained in a database and analyzed them to determine the best combinations of input factors, i.e., warehouse configurations minimizing the *average mission distance* (AMD) travelled by the picker during each mission.

2.2. Routing Policy

The purpose of a *RP* is to sequence the items in the picking list to ensure the minimum path of the picker through the warehouse. In this study, we considered four types of *RPs*:

- **Return Simple (RS)**: the cross-aisles are not utilized during picking activities, meaning that the picker always enters and leaves the aisles from the same side. The picker can visit the racks on one side of the aisle only at a time (Figure 2a);
- **Return Advanced (RAD)**: the policy is the same as that above, apart from the fact that the cross-aisles can be utilized during picking operations (Figure 2b);
- **S-Shaped Simple (SSS)**: no cross-aisles are used during picking operations, so the picker has to travels the whole aisle each time he/she enters it. As opposed to RS, the picker can visit the racks on both sides of the aisle (Figure 2c);
- **S-Shaped Advanced (SSAD)**: the policy is the same as that above, apart from the fact that the cross-aisles can be utilized during picking operations (Figure 2d).

As can be easily deduced from the description above, the *advanced* policies were developed to allow the picker to change aisle via the cross-aisles.

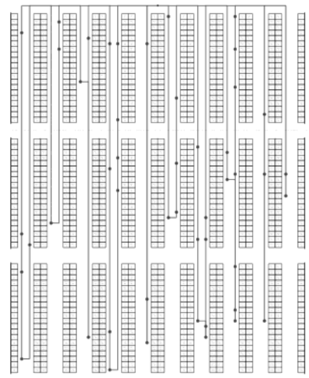

Figure 2a. RS Policy

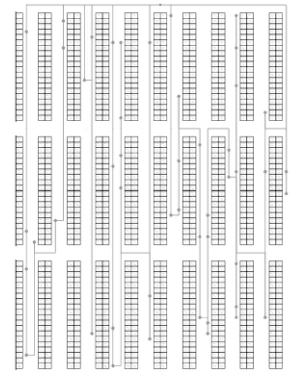

Figure 2b. RAD Policy

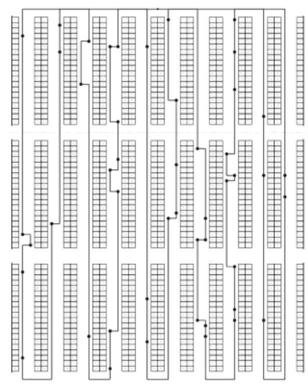

Figure 2c. SSS Policy

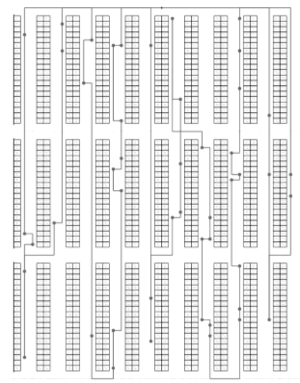

Figure 2d. SSAD Policy

2.3. Shape Factor

The layout of a traditional and regular (*rectangular*) warehouse consists of a number of parallel longitudinal aisles of equal length, divided by corridors, with the items stored in the storage locations on both sides of the aisle (de Koster et al., 1998). The shape factor (x_f) is defined as the ratio between the width (a) and the depth (b) of the warehouse (Eq. 2).

$$x_f = a/b \qquad (2)$$

Values of x_f greater than 1 refer to a warehouse that develops mainly horizontally (Figure 3a); values of x_f close to 1 denote a warehouse with a shape similar to a square (Figure 3b); finally, x_f values smaller than 1 refer to warehouses with a narrow and elongated shape (Figure 3c).

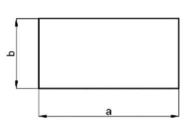

Figure 3a. $x_f > 1$

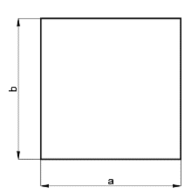

Figure 3b. $x_f = 1$

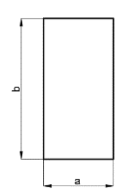

Figure 3c. $x_f < 1$

The values of x_f considered in our study are reported in Table 1, along with the corresponding *a* and *b* dimensions of the warehouse. The warehouse shapes evaluated were defined in accordance with the above-mentioned constraints on the number of aisles and cross aisles, and with the standard storage location dimensions.

Table 1. Shape factor employed in the creation of the database.

x_f	*a* [m]	*b* [m]
0.14	22	162
0.21	27.5	132
0.29	33	112
0.51	44	87
0.76	55	72
1.06	66	62
1.59	82.5	52
2.62	110	42
3.57	132	37
3.82	137.5	36

2.4. Input-Output Positions of pickers

The *I/O* configurations considered in our study are listed and described below:

- **Single Central Picking (SCP)**: single central entry and exit point (Figure 4a);
- **Single Lateral Picking (SLP)**: single lateral entry and exit point (*Figure 4b*);
- **Opposite Lateral Picking Same Side (OLPSS)**: lateral entry and exit points located on the same side of the warehouse, with the entry at the beginning and the exit at the end of the aisle (Figure 4c);
- **Opposite Central Picking (OCP)**: central entry and exit points, with the entry point at the beginning and the exit at the end of the aisle (Figure 4d);
- **Opposite Side Picking (OSP)**: lateral entry and exit points on opposite sides of the warehouse (Figure 4e).

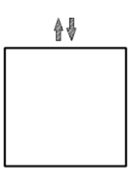

Figure 4a. SCP

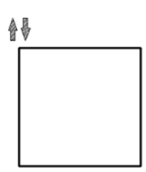

Figure 4b. SLP

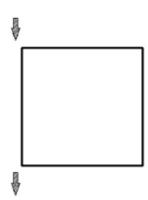

Figure 4c. OLPSS

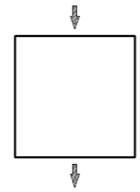

Figure 4d. OCP

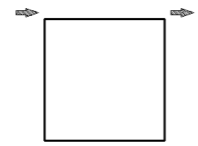

Figure 4e. OSP

3. Results and Discussion

We ran 10,000 simulations for each previously defined configuration and computed the mean value of the distance travelled by the picker for each scenario.

In Figures 5a–5d, relating to the different *RPs* considered, AMD is plotted as a function of x_f. Each figure contains five plots, representing the five different *I/O* configurations. Overall, the best *I/O* configuration resulted to be OSP, regardless of the *RP*.

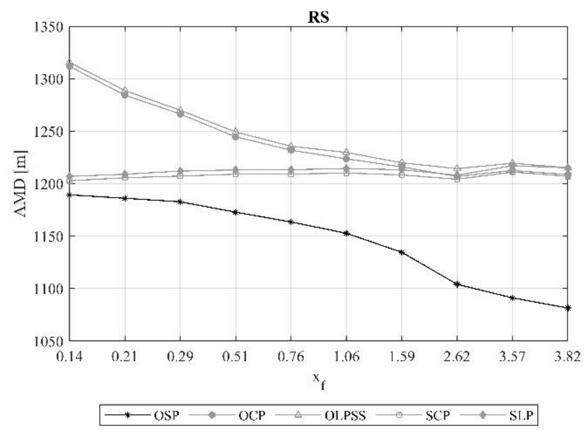

Figure 5a. Distance covered by the picker with RS Policy

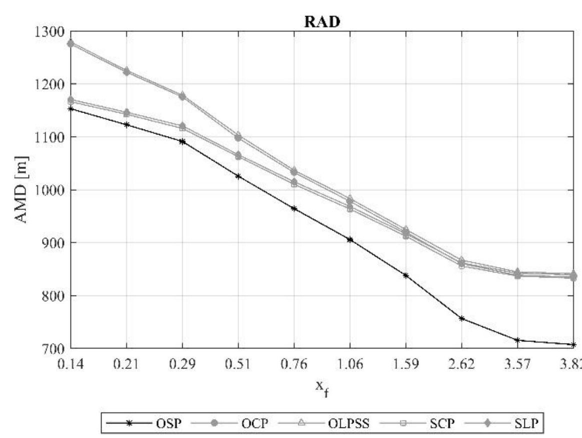

Figure 5b. Distance covered by the picker with RAD Policy

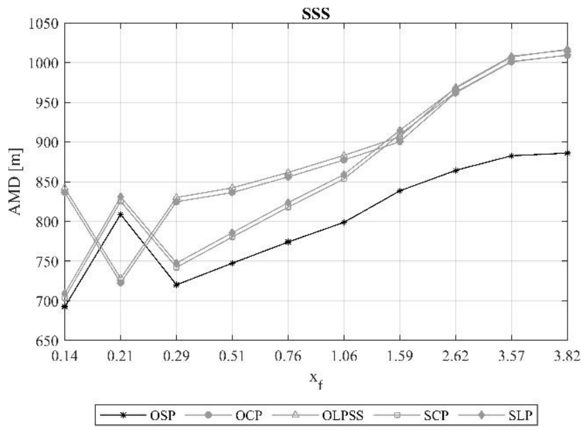

Figure 5c. Distance covered by the picker with SSS Policy

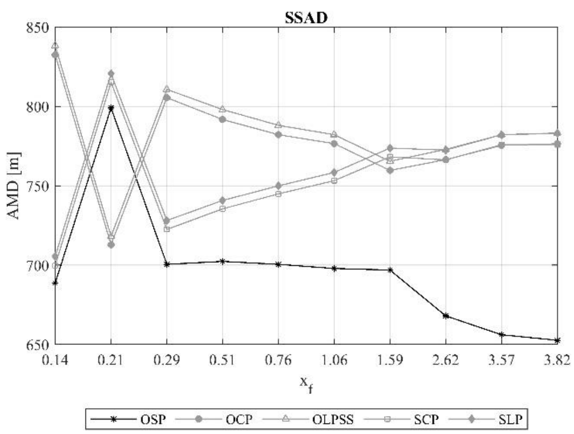

Figure 5d. Distance covered by the picker with SSAD Policy

The most advantageous *RP* for minimizing the AMD turned out to be the SSAD, regardless of the *I/O* configuration adopted. In particular, it can be observed that by changing the *RP* and keeping the remaining settings unchanged, the AMD decreases by 37% (on average). The distance travelled, indeed, decreases from 1315 m (RS policy, OLPSS *I/O* position, $x_f = 0.14$) to 838 m (SSAD, OLPSS, $x_f = 0.14$). This outcome suggests that for optimizing the management of an existing warehouse (in which the shape factor is obviously defined), interventions should be made at software level, by leveraging the *RP*. Consequently, as the picking activities become more efficient, it would be possible to choose whether to reduce the working time during the day and process the same number of orders, or to increase the number of orders while keeping the number of working hours unaltered.

An interesting result that we derived is that under particular conditions, the distance travelled by the picker appears to be almost independent upon the warehouse shape factor. This result can be observed in Figure 5d for the SSAD policy, OSP configuration and x_f ranging from 0.29 to 1.59.

This behavior can be also appreciated looking at Figure 6, in which the AMD travelled in the case of four different *RPs* is plotted against x_f, considering an OSP *I/O* configuration. By considering the SSAD plot, a striking result shows a wide range of x_f values where the impact of the warehouse shape on the AMD is negligible. This condition of indifference of the warehouse shape is presented in greater detail in Table 2 and Figure 7.

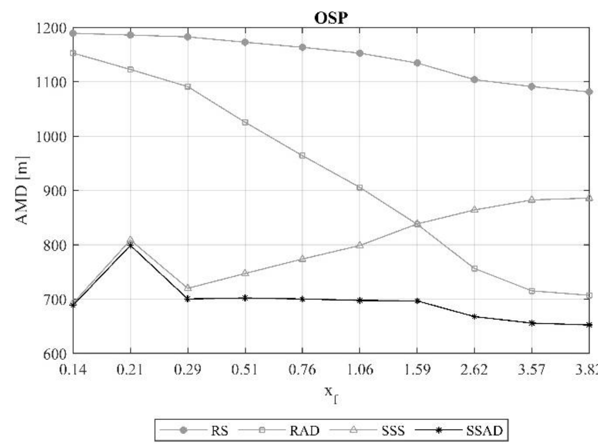

Figure 6. Distance covered by the picker with the OSP configuration

In the range of x_f considered, the AMD is overall 700 m, with a difference between the longest and the shortest distance route of less than 6 m (<1%). An increment in standard deviation (*std*) can also be observed as the value of x_f increases. This trend can be attributed to the correlation that exists between the shape factor and the characteristic geometry of OSP *I/O* configuration, meaning that the distance between the entry and exit points varies as the shape of the warehouse changes.

Table 2. AMD and the corresponding std in the x_f range considered

x_f	*AMD* [m]	*std* [m]	*a* [m]	*b* [m]
0.29	700.53	22.78	33	112
0.51	702.36	30.07	44	87
0.76	700.52	34.44	55	72
1.06	697.90	37.68	66	62
1.59	696.92	47.22	82.5	52

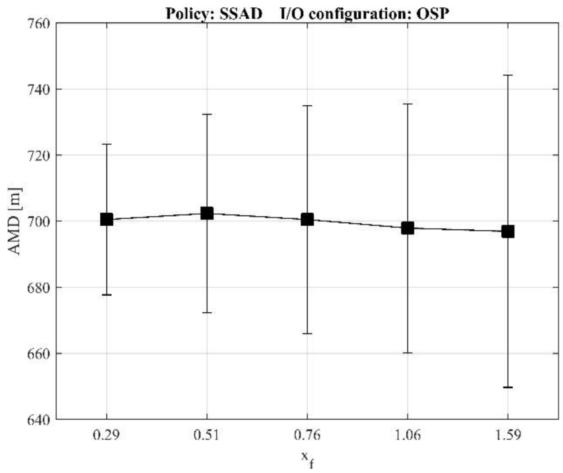

Figure 7. AMD in the case of OSP with 0.21<x_f<1.59 and its *std*

It is also important to point out that the range of x_f values in which this condition of indifference occurs reflects plausible and feasible geometries of warehouses, that can be easily encountered in real cases. On the contrary, scenarios with very high or very low warehouse shape factors are to be considered as case studies at academic level only.

4. Conclusions

The present work contributes to defining a preliminary simulation approach for the optimization of the picking policy of a warehouse with fixed storage capacity and a predefined number of cross-aisles. The optimization of such a warehouse can be performed both at management and design levels by leveraging the three input factors considered in this study, namely the routing policy, the input-output configuration and the warehouse shape factor. Furthermore, we identified a particular condition in which, using a specific routing policy and input-output configuration, the distance travelled by the picker appears to be almost unaffected by the warehouse shape in a wide range of plausible x_f values.

The outcome of this first analysis is of great interest from both the scientific and practical points of view. Regarding the research side, we included several input-output configurations in our study, extending the analysis of its impact with regards to the present state-of-the-art. Regarding the practical contribution of this study, it is two-fold. First, we showed how the management of an existing warehouse can be improved by acting at software level and adopting the SSAD routing policy. Second, we demonstrated how, with SSAD policy and OPS input-output configuration, the distance covered by the picker remains the same for a feasible range of warehouse shape factors. This important result can be leveraged both in the design of a new warehouse and in the optimization of an existing one.

Furthermore, starting from the database built using our simulation results, it will certainly be interesting to include additional variables in future studies, such as different numbers of items retrieved per picking mission, and/or the presence of products with different probabilities of being ordered.

By including these additional variables, it will be possible to further enrich our database, and thus extend the analysis to other case studies, possibly closer to real industrial conditions.

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