INVESTIGACIÓN E INNOVACIÓN EN INGENIERÍAS

Combination of a heuristic and simulation approach for route evaluation in order picking in a distribution center

Combinación de un enfoque heurístico y de simulación para la evaluación de rutas en la preparación de pedidos de un centro de distribución

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Abstract
Objective: This study focuses on the optimization of order picking in distribution centers (DC), a task that involves significant time, labor, and costs. **Methodology:** A mathematical model based on mixed integer linear programming (MILP) was used to minimize the total distance traveled during order picking. This model was applied to a Colombian case and complemented with a simulation model to evaluate improvement scenarios. **Results:** The mathematical model generated four optimal routes for order picking. Two of the routes used S-shaped routing, one used return routing, and another combined both policies, thus reducing the total distance by 5% to complete the order-picking process. Subsequently, the simulation model was used to evaluate three improvement scenarios: i) increasing the capacity of the picking carts, ii) increasing the number of picking carts, and iii) increasing both parameters simultaneously. **Conclusions:** The best result was obtained by increasing the capacity of the picking carts by 33%, which reduced the distance traveled by 49.5% and had a positive impact on other defined operational indicators. This innovative combined approach to the routing problem can be used to explore further improvements.

Keywords: Order Picking, Heuristic Model, Simulation, FlexSim.

Resumen
Objetivo: Optimizar recolección de pedidos en los centros de distribución (CD), una tarea que implica tiempo, mano de obra y costos significativos. **Metodología:** Se utilizó un modelo matemático basado en la programación lineal entera mixta (MILP) para minimizar la distancia total recorrida durante la recolección de pedidos. Este modelo se aplicó a un caso colombiano y se complementó con un modelo de simulación para evaluar escenarios de mejora. **Resultados:** El modelo matemático generó cuatro rutas óptimas para la recolección de pedidos. Dos de las rutas utilizaron un enrutamiento en forma de S, una utilizó el enrutamiento con retorno y otra combinó ambas políticas, reduciendo así la distancia total en un 5% para completar el proceso de recogida de pedidos. Posteriormente, el modelo de simulación se utilizó para evaluar tres escenarios de mejora: i) aumentar la capacidad de los carros de picking, ii) aumentar el número de carros de picking, y iii) aumentar ambos parámetros simultáneamente. **Conclusiones:** El mejor resultado se obtuvo al aumentar la capacidad de los carros de picking en un 33%, lo que redujo la distancia recorrida en un 49,5% y tuvo un impacto positivo en otros indicadores operativos definidos. Este innovador enfoque combinado del problema de las rutas puede utilizarse para explorar nuevas mejoras.

Palabras claves: Selección de Pedidos, Modelo Heurístico, Simulación, FlexSim.

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Introduction

At distribution centers (DCs), manufacturing organizations strive to implement good practices for picking and preparation; these steps, which are also referred to as order preparation, represent approximately 45 to 75% of the total cost of warehouse management operations [1]. Order picking is the process of retrieving a set of items from their storage locations and classifying or consolidating them for subsequent packing and shipping in response to a customer order [2]. This process has always been considered intensive and can consume between 50 and 60% of all work activities in a DC [3]. For these reasons, improving productivity within DCs is of the highest priority and is also the most effective way to reduce costs by 10 to 35%, increase profits and optimize the use of resources [4]. According to [5], important decisions are made in DCs regarding product storage, picker routing, order batching, picking zone configuration, order assignment, and selection of the order picking method [6, 7]. The main objective of preparing orders is generally assumed to be minimization of the travel distance or picking time, and these activities are carried out through a routing policy that determines the sequence of item picking. The most common policy is the picker to parts system, which consists of picking items from a storage area [6]. In this system, picking is performed manually using a picking cart with a defined capacity. If the orders are grouped by batches, the maximum batch size is determined by the capacity of the cart [8].

Several researchers have investigated order picking policies in various types of DCs and the optimization of routes in warehouses. Several routing policies are used in practice, and their efficiency usually depends on the particular conditions of the storage system [9]. Most previous research has mainly focused on the S-shaped routing policy and random storage assignment [10].

In this context, [6] validated that order picking and routing policies represent the key planning problems for the efficient operation of DCs. Likewise, to determine the distance traveled by the picker, it is necessary to decide in which sequence items are picked.

To minimize the distance traveled by the picker, researchers have combined the picker routing problem (PRP) and the vehicle routing problem (VRP), and this approach offers theoretical support for the approach proposed in this research. The VRP represents one of the most researched combinatorial optimization problems due to its complexity and its potential impact on real world applications, especially in logistics [11]. In the VRP, a set of closed routes to and from a depot is constructed, and each routed is served by a vehicle with a certain capacity. In addition, a vehicle is used for each route to achieve the tasks specified by customers [11].

In this study, a mathematical model was used to minimize the total distance traveled, a simulation model was used to evaluate route scenarios and the capacity of alternative picking carts based on performance indicators of the system, and these two models were combined. The combined model was applied to a DC in the city of Popayán, Colombia as a case study. According to [12], the combination of heuristic models and discrete event simulations for the optimization of order picking has not been addressed in depth, and the existing implementations are only applicable to a general type of warehouse.

The solution corresponding to the heuristic model was formulated based on mixed integer linear programming and approaching the PRP as a VRP problem. [13] proposed an alternative formulation for the traveler problem that reduces the number of complicated constraints such as time windows and does not involve special conditions. This model was solved using the CPLEX solver of GAMS software version 24.4. By simulating the discrete events in the FlexSim 2020 software, order picking scenarios were evaluated in a virtual environment through performance indicators, thereby mitigating the risk of committing costly errors before the actual implementation [14].

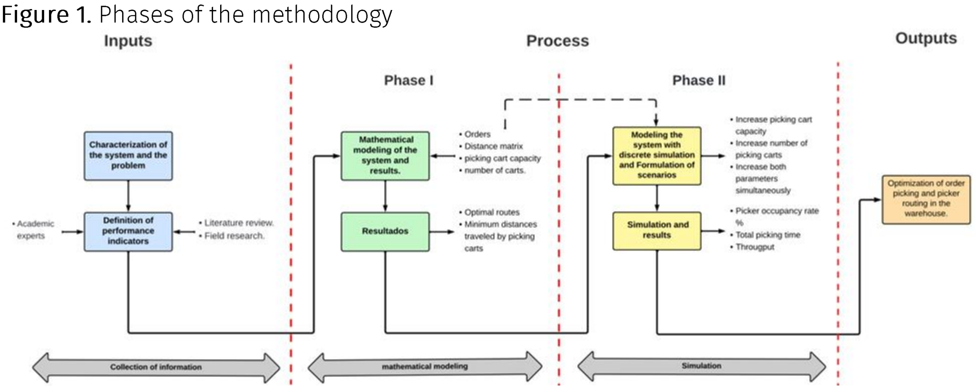
According to [12], the combination of these two methodologies to evaluate improvements in the distance traveled and in other indicators of the logistics performance of DCs has not been addressed in depth, with less than 30% of published articles deemed relevant to this approach. Existing implementations are only applicable to a general type of warehouse and ignore the specific conditions that may occur in specific cases, such as the conditions considered in the present study.

This paper's main contribution and objective are to present a mathematical framework for modeling the dynamic decision-making that occurs during warehousing and picking operations. Due to operational decision-making's emotional aspect and complexity, most current practices and research are based on high-level decision rules evaluated by simulations or analytical models. Often, these real-time problems lack a rigorous mathematical framework. We believe that formalizing the decision process with a heuristic dynamic model facilitates the development of more advanced solutions.

Metodology

The modeling procedure for addressing the PRP in the picking system proposed in this research is shown in Figure 1.

Figure 1. Phases of the methodology



Source: Own elaboration

Results

Characterization of the system and the problem

For the application of the methodology developed in this research, the DC of an organization dedicated to the online sale of electronic items in the retail sector was selected; this company is located in Popayán, Colombia.

Identification of the structure of the CD under study

The area of the storage zone and the picking zone were calculated as follows:
Area of the storage zone:

$$Z_{Sto} = M * N \quad (1)$$

Where, $\boldsymbol{Z_{Sto}}$ represent the area of the storage zone, M Width of the storage zone [m] and N Length of the storage zone [m].

Area of the picking zone:

$$Z_{Pick} = M * N \quad (2)$$

Where, $\boldsymbol{Z_{Pick}}$ represent the area of the picking zone, M width of the storage zone [m] and N length of the storage zone [m].
Total Area:

$$A_{Total} = Z_{Sto} + Z_{Pick} \quad (3)$$

Where, $\boldsymbol{A_{Total}}$ represent the total Area, $\boldsymbol{Z_{Sto}}$ area of the storage zone and $\boldsymbol{Z_{Pick}}$ area of the picking zone. Table 1 shows the results of the work area.

Table 1. Total work area calculation

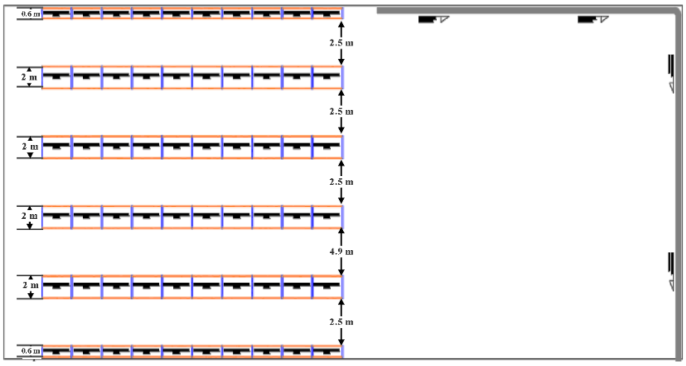
Area	Measure [m2]
Storage zone area	418
Picking zone area	413
Total Area	831

Source: Own elaboration

The distribution of the storage zone has a traditional configuration (Figure 2). The widths of the central aisles and the side aisles of the storage zone are 2.5 m and 0.6 m, respectively, and their length is 20 m, which allows the pickers to move freely.

There is a low-level manual order picking system. This area has 50 stations, distributed in 5 aisles so that the 4 pickers can pick the orders with the picking carts. Replenishment has not been analyzed in this study.

Figure 2. Picking zone layout

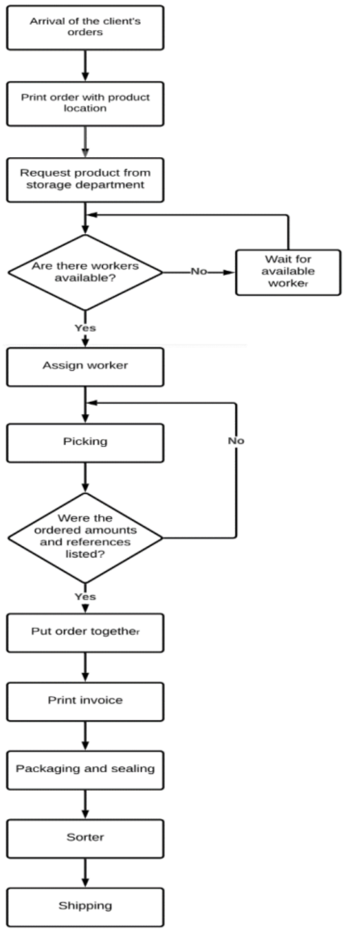


Source: Own elaboration

The SKUs are stored one per rack, in alphanumeric order. The picking zone is equipped with a conveyor band that transports boxes to the shipping dock. There is a table for the picking process, invoice printing, labeling for each order and sealing.

The current flow of the order picking process in the DC is as follows: the pick lists are generated according to the aisle and shelf level to be visited, with the intention of collecting several orders at the same time without having to go to the same location several times. The picker moves to the first location indicated by the pick list, verifies that the requested code coincides with the existing storage unit, takes the number of boxes indicated, and finally goes to the next location in the list. Once the picker finishes collecting in the locations corresponding to an aisle, he goes to the next aisle and this process continues until he finishes collecting all the products from the assigned list. Another picker in the picking zone assembles the boxes for packing the products and prints a label with the codes and quantities for the items in the boxes. The boxes are also classified according to their destination. Finally, the boxes are sealed at the conveyor belt and taken to the loading docks (Figure 3).

Figure 3. Flow line of the picking process



Source: Own elaboration

Definition of performance indicators

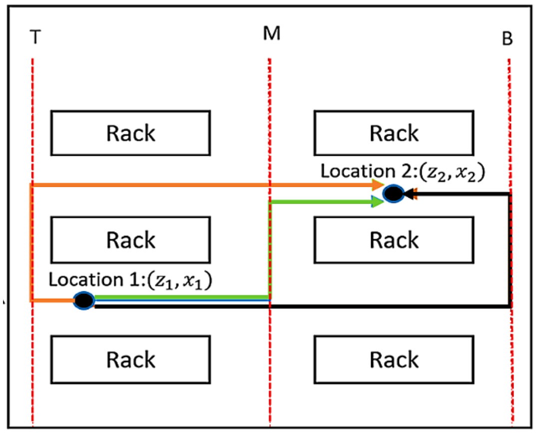
The results of the developed approach were evaluated based on five performance indicators: i) distance traveled in the picking zone (Equation. 4), ii) throughput as the output rate of the boxes per unit of time (Equation. 5)., iii) Total picking time (Equation. 6), and iv) picker occupancy (%) (Equation. 7).

Total distance traveled

The distance between a pair of nodes is provided by means of a distance matrix. The shortest distance between any two nodes is calculated as follows. Let x be the across aisle coordinate and z be the coordinate along the aisle as shown in Figure 4. If x1 = x2, the two nodes are located in the same aisle, the distance between the two nodes can be easily calculated: t12 = z2 - z1 where t12 is the distance between node 1 and 2. Otherwise, the distance between the two nodes can be calculated as follows [15]:

$$D_{12} = (|Z_1 - B| + |X_2 - X_1| + |Z_2 - B|, |Z_1 - M| + |X_2 - X_1| + |Z_2 - M|, |Z_1 - T| + |X_2 - X_1| + |Z_2 - T|) \quad (4)$$

Figure 4. Distance between two nodes



Source: Adapted [15]

where T, M, and B are the z-coordinate of top cross aisle, middle cross aisle, and bottom cross aisle, respectively. The top cross aisle, middle cross aisle, and bottom cross aisle locations are shown in Figure 4. The distance matrix calculated this way is used for the optimization model, alternative policies, and simulation.

Throughput

$$Throughput = \frac{Us}{Tr + Ta} \quad (5)$$

Where, $\boldsymbol{Throughput}$ represent the Rate of box output [units/second], $\boldsymbol{Us}$ units subtracted [units], $\boldsymbol{Tr}$ retrieval time [s] and $\boldsymbol{Ta}$ picking time [s].

Total picking time

$$Ttv = \frac{D_{ij}}{VP_{ij}} \quad (6)$$

Where, $\boldsymbol{Ttv}$ represent the total travel time [s], $\boldsymbol{D_{ij}}$ distance from i to j [m] and $\boldsymbol{VP_{ij}}$ average speed of vehicle traveling from i to j [m].

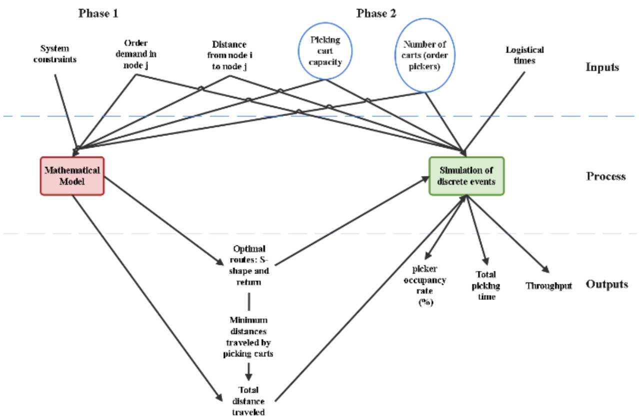
Picker occupancy rate (%)

$$\%\ Occupancy = \frac{To}{To + Ti} \quad (7)$$

Where, % $\boldsymbol{Occupancy}$ represent the picker occupancy rate (%), $\boldsymbol{To}$ Picking time [s] and $\boldsymbol{Ti}$ idle time [s].

The characterization of the problem and its solution, including the indicators, are outlined in Figure 5. In this figure, the two approaches are combined in a process structure (input-process-output) for each phase of modeling. The first phase shows the structure of the mathematical modeling of the system, and the second phase shows that of the simulation. This structure can also be seen as a function F (X) = Y, where X is the set of input parameters, F is the combined model, and Y is the set of output indicators.

Figure 5. Characterization of the problem



Source: Own elaboration

Phase 1 modeling: Mathematical modeling of the system and results.

Mathematical modeling

The general assumptions for the model were defined based on the characterization of the VRP and the case study. The VRP integrates combinatorial optimization and mixed integer programming to ask "What is the optimal set of routes for a fleet of vehicles that must satisfy the demands of a given set of customers" The model designed by [16] addresses the PRP as a VRP and applies the Miller-Tucker-Zemlin (MTZ) formulation [17]. To complement the model and as theoretical support, references were taken into account, notably [13] and [18], who addressed the problem by considering the capacity of the picking cart and the routing policies. The characteristics of the DC in the case study were analyzed to describe the picking problem. The assumptions for the model are as follows:

- The sum of the units subtracted by the picker to complete the order must not exceed the capacity of the picking cart.
- All picking carts that start from the "put wall" or zero node must return to it.
- The racks must be visited only once by the assigned picking cart.
- The distance matrix is symmetrical and is associated with the conditions of the DC (width and length of the aisles).
- All picking carts have a capacity of thirty (30) units.

- The supply of products is given in units.

The elements of the model are described below:

Objective function: minimize the total distance traveled to complete the order picking process.

Parameters: The distance between the source nodes to the destination nodes is determined. For the development of the distance matrix, the parameters taken into account by the DC, including the rack numbers and the width and length of the aisles, were taken as a reference.

Constraints: The equations associated with the capacity of the picking carts, the elimination of subtours, a sufficient inventory and the VRP model were written.

Mathematical model:

Set

N= {1,2, 3 … n} Set of all nodes formed by i and j, excluding node zero.
No= {0} U N: {1,2, 3 … n} Set of all nodes formed by i and j, including node zero.
K= {1,2, 3 … k} Set of the picking cart.

Parameters

Tij Distance in meters from the starting point i until arrival j.
Dj Demand in units at node j.
Qj Number of items in units stored at node j.
CK Capacity in units of picking cart k.

Binary variables

XijK Binary decision variable that takes the value of 1 if the route is traveled by picking cart k from node i to node j and the value of 0 otherwise.
UjK Binary decision variable that takes the value of 1 if assigned to node j to be served by picking cart k and the value of 0 otherwise.

The equations used in this model are listed below:

Objective function:

$$Min \sum_{i \in N0} \sum_{j \in N0} \sum_{k \in K} T_{ij} * X_{ijk} \tag{1}$$

Subject to

$$\sum_{i \in N_0} X_{ijk} \leq 1 \forall j \in N, k \in K \tag{2}$$

$$\sum_{j \in N_0} X_{ijk} \leq 1 \forall i \in N, k \in K \tag{3}$$

$$\sum_{i \in N} \sum_{k \in K} X_{i0k} = \mathrm{C}_k \tag{4}$$

$$\sum_{j\in N}\sum_{k\in K} X_{0jk} = C_k \tag{5}$$

$$\sum_{i\in N} X_{ijk} - \sum_{j\in N} X_{jik} = 0 \forall i \in N, k \in K \tag{6}$$

$$\sum_{k\in K} U_{jk} = 1 \forall j \in N \tag{7}$$

$$\sum_{i\in N} X_{ijk} = U_{jk} \forall j \in N, k \in K \tag{8}$$

$$\sum_{j\in N} D_j * U_{jk} \leq C_k \forall k \in K \tag{9}$$

$$O_{iK} - O_{JK} + C_k * X_{ijk} \leq C_k - D_j \tag{10}$$

$$D_j \leq O_{jk} \leq C_k \tag{11}$$

The objective function seeks to minimize the distance resulting from completing the order picking process for an established set of orders.

Constraints (2) and (3) limit the number of routes per picking cart. The first constraint refers to the number of times a cart leaves from node i, and the second constraint refers to the number of times it reaches node j. Constraints (4) and (5) are used to ensure that all picking carts end and begin their travel through the put wall or zero node. To ensure the continuity of the model, that is, to ensure that the picking cart leaves node j once it makes an established visit to and moves to another node, constraint (6) is used. Constraint (7) ensures that each node is assigned exactly one picking cart for an order. In constraint (8), node j is assigned to picking cart k, which passes through that node, for an order. Constraint (9) ensures that the picking cart capacity is not exceeded. Finally, constraints (10) and (11) eliminate subtours.

Results of the mathematical model

The computational execution time to obtain a solution was 1,020 seconds. The model suggested jointly carrying out 4 simultaneous routes for a total distance traveled of 293.6 meters. Table 2 summarizes the results of the mathematical model.

Table 2. Routes generated by GAMS

# Route	Distance (m)	Positions visited	Picker occupancy (%)
1	67.4	P0-P19-P17-P15-P13-P11-P9-P7-P1-P33-P31-P0	77.2%
2	83.2	P0-P5-P21-P43-P61-P63-P67-P69-P71-P73-P75-P85-P87-P0	95.3%
3	82.2	P0-P3-P39-P37-P35-P59-P57-P41-P81-P83-P89-P91-P93-P95-P97-P99-P0	93.7%

4	60.8	P0-P25-P27-P29-P55-P53-P51-P49-P47-P45-P79-P77-P65-P0	70.6%
Total	293.6		84.2%

Source: Own elaboration

This solution shows that the highest occupancy rate for the picker was obtained with routes 2 and 3. This allowed us to propose two S-shaped and return order picking policies for optimal CC operation. Authors such as [19],[20],[21],[22],[23] support the proper use of routing policies in the warehouse allows minimizing the distance traveled, which has a direct impact on improving picking performance.

Phase 2 Modeling: Modeling the system with discrete simulation

For the construction of the simulation model, a plane model from AutoCAD version 2020 was imported to the FlexSim software to spatially identify the software objects that represent the elements of the DC.

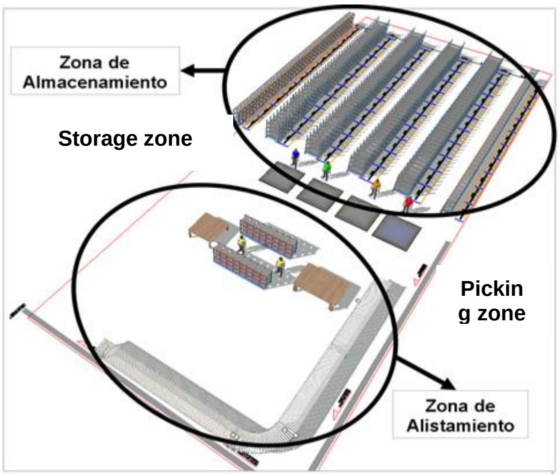
In the simulation, a process flow was used to assign colors or simulation attributes to the boxes, create articles and position the ABC classification. The codes of the 50 references managed by the DC were used as input data.

The process flow assigns the pick lists to the pickers, uses input data corresponding to customer demand, and allows the picking of stored items after having verified the SKU in the destination position. Once an item is located, it is eliminated from the system. Finally, the order is classified, consolidated, and shipped to the customer.

Formulation of scenarios, simulation and results Modeling of the discrete simulation

The discrete event simulation was performed in the FlexSim software version 20.2.3. Figure 6 shows a 3D layout of the DC.

Figure 6. Layout of the DC in the simulation model

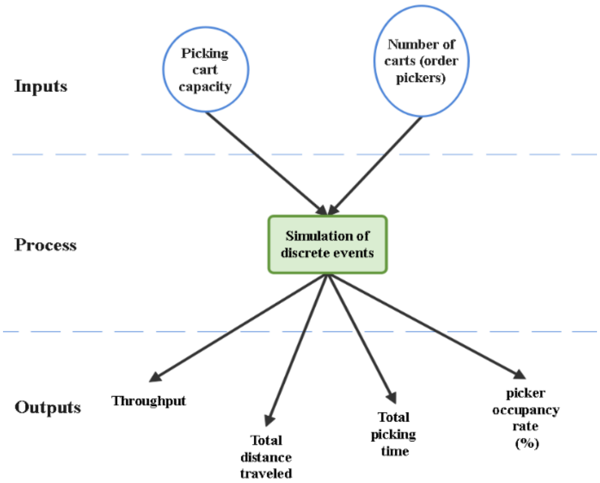


Source: Own elaboration

Initially, the results of the mathematical model were used to validate the simulation model for the 50 nodes (Pi positions), using the four picking carts as part of the zero scenario, which provided the value of the total distance traveled and the

following logistical performance indicators for the DC: throughput, total picking time, and picker occupancy percentage (Figure 7).
This ability, which is based on combining the two approaches, is one of the contributions of this study. Based on two sensitive improvement parameters, scenarios were defined based on the problem map shown in Figure 7. The input parameters or Xs are the capacity of the picking cart and the number of carts (pickers). The output indicators or Ys related to performance were selected.

Figure 7. Map of problem for modeling with simulation



Source: Own elaboration

In Table 3, after combining the two approaches, the total distance traveled by the pickers was 293.6 meters.

Table 3. Results of the simulation model for the zero scenario

Pickers	Total distance traveled [meters]	Throughput [units/ second]	Total picking time [seconds]	Picker occupancy [%]
1	81	23/595	595	58.32%
2	59.94	21/544	544	79.15%
3	82.71	15/388	388	77.51%
4	69.95	15/388	388	68.09%
Total	293.6	74/1,915	1,915	70.77%

Source: Own elaboration

The throughput was 74 boxes every 1.915 seconds. The occupancy of the four pickers was 70.77%, this when compared with the result of Table 2, 91.67%, are different, since the results of the mathematical model do not take into account specific movements of the operator such as turns or curves, the simulation allows to analyze this type of movements, allowing to obtain a slightly more accurate result and in real time.

Based on the simulation model, the map of the problem and the determination of the two sensitive parameters to be improved, three scenarios were formulated, evaluated and compared with the zero scenario to determine the robustness of scenario 0 and to identify possible improvements in the performance of the picking process. Table 4 describes the additional scenarios formulated.

Table 4. Description of the formulated scenarios

Scenario	Description	Data
1	Increase picking cart capacity	40 units
2	Increase number of picking carts	6 picking carts
3	Increase both parameters simultaneously	40 units y 6 picking carts

Source: Own elaboration

Results of the simulation modeling. Table 5 summarizes the overall results obtained.

Table 5. Results of the three simulated scenarios

# Scenario	Total distance traveled [meters]	Throughput [units/ second]	Total picking time [seconds]	Picker occupancy (%)
0	81.00	23/595	595	58.32%
	59.94	21/544	544	79.15%
	82.71	15/388	388	77.51%
	69.95	15/388	388	68.09%
Total	293.60	74/1,915	1,915	70.77%
1	57.26	23/595	595	76.46%
	61.21	22/569	569	75.26%
	50.66	17/440	440	74.18%
	27.27	24/621	621	79.98%
Total	196.40	86/2,226	2,226	76.47%
2	46.07	13/337	337	69.45%
	45.17	12/311	311	59.05%
	48.05	16/414	414	76.92%
	47.16	15/388	388	76.55%
	47.02	14/362	362	72.78%
	46.21	14/362	362	70.02%
Total	279.68	84/2,174	2,174	70.80%
3	45.12	15/388	388	87.72%
	42.05	14/362	362	87.03%
	41.03	14/362	362	86.46%
	40.08	13/337	337	74.18%
	39.23	13/337	337	73.98%
	38.15	11/285	285	71.26%
Total	245.66	80/2,071	2,071	80.10%

Source: Own elaboration

Results of scenario 1: The total distance traveled by the pickers was 196.4 meters. The throughput was 86 boxes every 2,226 seconds. The total picking time was 2,226 seconds. The picker occupancy was 76.47%.

Results of scenario 2: The total distance traveled was 279.68 meters. The throughput was 84 boxes every 2,174 seconds. The total picking time was 2,174 seconds. The average picker occupancy was 70.80%.

Results of scenario 3: The total distance traveled was 245.66 meters. The throughput was 80 boxes every 2,071 seconds. The total picking time was 2,071 seconds. The average picker occupancy was 80.10%.

Analysis of results

Table 6 shows the results of the four scenarios simulated and compared using the performance measures. Each indicator or measure was assigned a weight. The total picking time was the indicator that was most related to the value added to customers and thus had the largest weight. Weights were then determined by the value added to the company, with the throughput being assigned the next largest weight value. The first column of Table 6 contains all the weights. Then, an overall index per scenario was obtained; for example, to compare scenario 1 with scenario zero, the following procedure was performed: for the picker occupancy indicator, scenario zero yielded a value of 70.77%, scenario 1 yielded a value of 76.47%, and the relative value of scenario 1 in this indicator was 76.47-70.77/76.47.

Table 6. Comparison of the results of the three proposals for one day of work

Weighted performance measures	Performance measures /Scenarios	Scenario 0 (baseline)	Scenario 1	Scenario 2	Scenario 3
20%	Picker occupancy (%)	70.77%	7.4%	0%	11.6%
35%	Total picking time [seconds]	1.915	14%	11.9%	7.5%
30%	Throughput [units/ second]	74	14%	11.9%	7.5%
15%	Total distance traveled [meters]	293.6	49.5%	1%	15%
	Total		13.7%	6.7%	7.4%

Source: Own elaboration

When the simulation was combined with the mathematical model, the overall performance of all scenarios in relation to the zero scenario or baseline was improved, which verifies the complementarity of the two methodologies for the particularities of this problem.

From this analysis, it is evident that scenario 1 yielded a greater jump in the overall performance of the picking process, delivering a weighted average index of 13.7%, while scenario 3 did not offer a substantial improvement, and scenario 2 did not offer a relatively significant improvement.

Based on these results, a policy of pick by order system, in which S-shaped and with return routing policies are combined and the picking cart capacity is increased from 30 to 40 units or by 33%, is preferred for the case study.

Conclusion

In logistics management, picking is the strategic process of preparing orders. It consists of collecting units of one or more products stored in different locations. This article addresses the problem of picker routing for picking in a conventional DC by combining mathematical modeling and discrete event simulation. One of the contributions of this approach is the addition of the resulting optimal route (output) of the mathematical modeling, to other input parameters needed to run the simulation and to calculate the outputs of this second phase, which were the performance indicators of the process.

The results of the mathematical model show that for the optimal functioning of the DC, S-shaped and with return routing policies should be combined; likewise, a picker occupancy of 91.67% and a distance traveled of 293.6 meters were obtained.

The simulation model was developed in a complementary manner to validate the robustness of the solution obtained through mathematical modeling and evaluate additional scenarios based on an additional set of performance indicators that are useful in the management of DCs.

The best result shows that by increasing the capacity of the picking carts, the total distance traveled could be reduced by 49.5%, the throughput could be increased by 14%, the total picking time could be increased by 14% and the picker occupancy could be increased by 7.4% .

Finally, for subsequent studies, it would be interesting to analyze the consistency of the results obtained in this research, using metaheuristic algorithms for the resolution of the proposed mathematical model, and to consider vehicles with heterogeneous capacities, cross aisles and picking policies.

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