

Three Simulation Cases of Automated Warehouse Picking Systems: A Comparative Analysis

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Abstract

Picking systems are great allies for companies that must manage a wide range of stock keeping units (SKU) and/or purchase order (PO) volume. The available systems allow optimization of the most valued resources within a company: time and labor; allowing organizations to gain greater competitiveness within their industry. Based on a descriptive and comparative scope design, this study focuses on the analysis of three automated simulation cases for order preparation systems to analyze its effectiveness within the warehouses: put-to-light, put-to-wall, and routing system. Likewise, it was sought to analyze the particularities of the three case studies in order to constitute a support framework for the management of the companies during their distribution center improvement process. The findings show that the first two simulation cases of the three chosen focus their study on solving makespan problems in picking, while the last case specializes in systemic preparations prior to the order preparation process; furthermore, these three selected cases have used the Gurobi Optimizer software to carry out the simulation.

Keywords

Picking, put-to-light, put-to-wall, routing system and makespan.

1. Introduction

Online shopping, also known as e-commerce, has become very popular due to the rapid development of the internet, even more so with the spread of COVID-19, where the social distancing implemented by the governments from different countries generated radical changes in life of people. Thus, this growth of information and communication technologies (ICT) has been key to replace activities such as face-to-face work with remote work, education with e-learning, purchases with e-shopping, among others. (Mouratidis and Papagiannakis, 2021).

In addition, referring to online purchases, Xuan (2022) considers that, with the progressive advance of ICT, consumers have become more demanding in the requirements for products and/or services that they request, because they seek greater personalization in them, causing companies to compete with each other using various strategies that require high investment to guarantee a level of service superior to their peers, since focusing only on the quality and price of products is no longer enough to obtain higher sales. However, these efforts to strengthen services must be balanced with the reduction of total logistics costs, in which the preparation of orders (picking) represents an important role.

Currently, there are multiple warehouses around the world that are constantly studying the possibility of making their picking operations more efficient and, as a result, the material handling industry has developed technological tools, such

as pick-to-light (PtL), picking-by-voice (PbV), terminal picking (RF), among others. These technological tools can help companies achieve major improvements, simplifying the collection task for workers and, thus, increasing productivity (de Vries et al., 2015). Therefore, this study aimed at answering the following research question: How are these three simulation cases of automated warehouse picking systems characterized and compared?

This objective was addressed through a comparative study of three successful cases in different parts of the world. The purpose of such study was to demonstrate the effectiveness of implementing automated systems in order preparation operations (picking) in warehouses, a decision that aims at aiding and providing support to the management or heads of different companies, which converge in the process of making a decision and choosing one of said systems for its distribution center.

1.1 Rationale for the research

In recent years, the safety and ease with which online consumers have been experiencing when making online purchases through their smart devices with high connection speeds, has caused gratifying results in electronic retail commerce (e-commerce), due to the large number of transactions they execute daily (Couri Boueri et al., 2021). This context is reinforced by the study carried out by Palomino Pita et al. (2020); who assure that, unlike previous years, where purchases in brick-and-mortar stores retained market dominance, with a 90.42% share; today, the statistics reflect the radical change that occurred after the appearance of COVID-19, because now purchases through online stores have increased by 51.77%, representing 61.35% of the entire market. Then, according to Marchet et al., (2015), when a high growing demand is generated, companies perceive multiple difficulties in order preparation operations (picking) in the warehouse, even more so due to the dilemma between maintaining low logistics costs and offer a high-level service to its consumers.

According to Babak Rasmi et al. (2022), order preparation (picking) is one of the warehouse activities that demands the greatest amount of time and money, so companies seek to reduce the delivery times of orders to the customer and the total logistics costs, considering as a basic strategy to seek to optimize the planning of the preparation of purchase orders. To this end, Kovac and Djurdjevic (2020) emphasize the importance of giving primary attention to the picking operation in the design process of a warehouse. This is because this order preparation operation can cover 55% of the total storage cost (Dujmesic et al., 2018). However, de Koster et al. (2007) highlight the innovations that the industry has developed, with the purpose of increasing the performance of the distribution center through picking productivity, which could achieve up to 1000 orders per hour, making said operation more profitable.

2. Literature Review

2.1 Some Automated Warehouse Picking Systems

Put-to-light:

According to Boysen et al. (2020), put-to-light or put-to-wall is a system that consists of changing the traditional order preparation approach, in which the worker usually goes through the entire warehouse in search of the shelf that contains the stock keeping units (SKU), which are specified in a selection list. This change of approach proposes the presence of a lane with bins arranged sequentially, emitting light signals and screens that project the number of items requested for each order. In this way, the collector moves along the lane a deposit with articles of the same SKU, by means of a fixed path equipment; and as the bin signals come on, it incorporates the number of items indicated on the screen. The process is repeated for each group of items of the same SKU. Füßler and Boysen (2017) conclude that the application of the put-to-light system is convenient as long as the items of the demanded SKUs are not characterized by their large size and/or weight, and are required by several orders at the same time.

Pick-to-light:

Unlike the put-to-light system, de Vries et al. (2015) mention that, in pick-to-light systems, the different items present in the warehouse are grouped according to their corresponding SKU in bins placed on shelves. The procedure consists of the collector recovering items from the bin that is emitting a light signal, to subsequently press a button that confirms the selection and turns off the signal. This is repeated until all the light signals of the bins are off; this will indicate the completion of the current order preparation and it will be possible to continue with the next one. Furthermore, Andriolo et al. (2015) state that, in order for each worker to be able to recognize which are the light signals corresponding to the order, it is essential that this type of system is carried out carrying: paper collection lists, digital screens attached to the bins or hand-held technologies; the same ones that will indicate the number of SKU items required per order.

Travel sequence:

According to Pinto and Nagano (2019), routing algorithms are a system that defines the configuration of the optimal route to be traveled by the worker to collect the products in the warehouse during picking. This route can be defined according to the product batch, proximity of the merchandise, unification of the order, among others. This system seeks to optimize order preparation time by eliminating makespan, generating shorter and more efficient routes according to the

characteristics of the warehouse, since after the implementation of the system it will not be the worker who performs the picking the one who defines the route to be traveled, neither WMS will make the picking order of the products applying these algorithms in order to reduce distances and times, considering the characteristics of the warehouse.

RFID:

Radio-frequency identification (RFID) technology, according to Liu et al. (2019), provides a novel solution for the design of storage centers, since it supports the objective of satisfying large-scale supply needs. Stopka and Lupták (2018) mention that this technology uses magnetic labels that do not require direct visibility when reading or entering the data in a system, which allows it to receive a greater volume of data at once. Thus, based on Motroni et al. (2021), the RFID reader can perceive the signal of a label attached to the packaging automatically, identifying its information to later compare it with the warehouse database. Along the same lines, Pane et al. (2018) comment that the implementation of RFID technology in a Warehouse Management System (WMS) simplifies and speeds up work processes and, at the same time, reduces the error rate in a warehouse.

WMS:

The WMS or Warehouse Management System, according to Kašparová and Dyntaxa (2021), is a system that provides information and allows to maintain control of the flow of merchandise within a warehouse from the moment of its reception until its dispatch; Likewise, this system serves as support for the operation of other business departments that use it, such as purchases and/or sales, which is why the integration of a WMS allows companies to increase efficiency, in response capacity, the various changes that may occur as a result of the warehouse or clients. Similarly, Caridade et al. (2017) mention that the implementation of this system always constitutes a challenge both for the company that develops it and for the company that benefits from the software; since, for the design to be tailor-made, it must take into consideration all the company's warehouse processes such as storage, stock management, picking, production, packaging, etc.

2.2 Other similar studies

Although no research focused on the comparative analysis of simulations such as the one proposed in the Scopus and Web of Science search sources has been found, general literature reviews have been compiled, such as those shown below. Jaghbeer et al. (2020) analyzed a total of 74 articles in search of a correct understanding of the aspects that influence the performance of an automated or semi-automated picking system, they also commented that the line of these literature reviews is of great benefit to simplify observing the links between the appearance and performance of the different PO models, as they offer a better understanding and description of the mentioned factors. Similarly, authors such as Nava Vargas and Quintero Moncayo (2019), show research supported by a bibliographic review that focuses on conceptualizing and defining the most relevant picking methods, including as an added value the analysis of four articles of simulated cases in which picking methods are applied in different sectors, in order to assess opportunities for improvement and increased picking productivity.

In other literature reviews such as Grosse et al. (2016), human factors are related to the use of order preparation systems in such a way that, as a conclusion of the research, it was determined that there are great opportunities for the development of research aimed at improving the processes of order picking. In addition, the authors encourage other studies to develop models that can support decision-making on the various planning systems for picking operations. On the other hand, in their study referring to the conceptualization of Order Picking 4.0, Winkelhaus et al. (2021) emphasize the contribution provided by the level of automation in the development of Order Picking Systems (OPS), but they also acknowledge that there are still certain limitations that occur in the traditional systems, for this reason they detail that there could be blind spots in research, so it is necessary to continue conducting an analysis on the subject in the future to avoid the trap of innovation by approaching it with new fields of research.

3. Methods

This simulation analysis study was carried out using the comparative method, which, according to Pérez Liñán (2008), is an analytical strategy that aims to describe and explain procedures that seek to answer the questions and general research intentions. In addition, according to Makón (2004), study cases, similarly related to the problems and research questions, must be chosen in order to correctly apply the comparative method while having material available and of a relevant nature for its analysis, comparison or generalization. Additionally, said comparison can be of a qualitative or quantitative nature.

For his part, Bartolini (1994) mentions that the most significant comparisons are those that consider the changes in the problem over time; that is why he recommends carrying out various analyses, measurements and observations, and comparing the transformations. In this way, the collection of information made it possible to delimit, assess and synthesize

the knowledge and experiences of academic or practical researchers, as expressed by Booth et al. (2012) and Randolph (2009) (as cited in Díaz-Bazo, 2017) in relation to three simulation studies on warehouse picking.

The review and selection of the published academic production of the three simulations of the implementation of automated picking systems in different warehouses around the world focused on the years 2016 and 2022. Subsequently, an exhaustive analysis was carried out using the comparative method, which was based on the following research questions: what characteristics do the three automated picking simulations present? What automated picking technologies have been tested in the simulation? What types of industries develop it? What are the objectives of the simulation? What type of methodology was implemented to simulate the automated picking system? And what results became evident when simulating automated picking systems?

The criteria for the selection of the three cases studied were the following:

- Empirical research showing one or more types of automated picking systems in the title, abstract or keywords.
- Research carried out in warehouses in different countries and/or contexts with identified industries.
- Cases published between 2016 and 2022.

The search for cases of implementation simulations of automated picking systems in warehouses was limited to the Scopus and Web of Science databases. Likewise, the following descriptors were used for their identification: warehouse management systems, put-to-light, put-to-wall, routing and travel sequence.

Based on the above, three reported cases of simulations were identified. Subsequently, a detailed reading of them was carried out and dynamic tables were used to organize the information according to the categories of analysis stemming from the research questions. Table 1 shows the categories and subcategories derived from the research questions.

Table 1. Research categories and subcategories

Question	Category	Subcategory
What characteristics do the three automated picking simulations present?	Origin and contextualization of simulation cases	Author(s) and year of publication.
		Country of origin.
What automated picking technologies have been tested in the simulation?	Technology applied for picking.	Technology applied.
		Type of transport of the merchandise.
		Type of merchandise to collect. Industry type.
What types of industries develop it?	Characteristics of the industry and company.	Warehouse characteristics
What is the initial scenario of the analyzed simulation?	Characteristics of the initial scenario.	Initial problem of the simulation study.
		Problem resolution hypothesis.
		Simulation goal.
What type of methodology was implemented for the simulation of the automated picking system?	Methodology used in the simulation.	Methodology applied.
		Characteristics of the applied methodology.
What is the final scenario of the analyzed automated picking systems simulation?	Final scenario of the simulation of the automated picking system.	Results obtained from the simulation.
		Conclusions.

4. Results

With the information collected according to the established methodological concept, the classification of the three selected simulation cases where warehouse picking automation is developed has been proposed. Table 2 below shows general information about the cases compared (Table 2).

Table 2. Selected picking simulation cases

Source	Title	Summary
Ardjmand, E., Eyad, M., Moyer, A, y Young II, W., Weckman, G., Shakeri, H. (2019)	A multi-objective model for minimizing makespan and total travel time in put wall - based picking systems.	In this case, three different algorithms are applied to ensure the operation of a put-to-wall system in warehouse picking in order to find the way to deliver the most accurate data for its implementation. In this way, the comparative-evaluative method is developed to confront the studied algorithms against each other and determine which of these three achieves greater efficiency in the representation of a real event.
Isler, C. A.; Righetto, G. M.; Morabito, R. (2020)	Optimizing the order picking of a scholar and office supplies warehouse.	This case analyzes the effects of the implementation of the automation of the routing of the workers of the order picking process through the Gurobi algorithm. Thus, it seeks to greatly simplify the transport times between the locations with the products requested by the customers through the optimization, simplification and decision regarding the automation of the design of the route to be carried out by the picking worker, thus reducing the preparation time. of an order attacking the focus of travel time and distance.
Boysen, N., Füßler, D., Sphan, K. (2016)	See the light: Optimization of put-to-light order picking systems.	In this case, picking is carried out using the put-to-light system, in which the picker walks along the lane where the order bins are placed. Three scenarios of problems related to the storage allocation of the order bins and the processing sequence of the SKU bins that influence the picking performance are proposed. Hence, a comprehensive computational study is carried out that applies algorithms in order to compare the performance of the three configurations.

The table above shows the three simulation cases of warehouse picking automation, through the use of different technologies such as: put-to-light, put-to-wall and routing. These converge in the search for the optimization of the picking process. However, each of the selected cases is characterized by providing a different approach to its main objective and the way to substantiate the results obtained in the simulation.


The results of the analysis of the three picking automation simulations in response to the research questions raised in the methodological section are presented below. The information has been sectioned according to the categories and subcategories of analysis.

4.1 Origin and contextualization of simulation cases

The three selected simulation cases are contextualized in the American and European continents, so that there are simulations originating in North America, South America and Central Europe. Table 3 details the country of origin, year of publication and author for each case study.

Table 3. Origin and contextualization of simulation cases

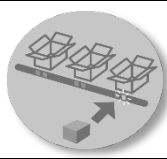
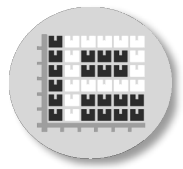
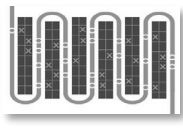
Simulation study	Year of publication	Authors	Country of origin
See the light: Optimization of put-to-light order picking systems	2019	Nils Boysen David Füßler Konrad Stephan	
A multi-objective model for minimizing makespan and total travel time in put wall-	2020	Ehsan Ardjmand Adam Moyer Heman Shakeri William A. Young II Eyad M. Youssef	

based picking systems			
Optimizing the order picking of a scholar and office supplies warehouse	2016	Cassiano Augusto Isler G. M. Righetto Reinaldo Morabito	

4.2 Technology applied for picking

To carry out the comparison of each automated picking system through simulation studies, the three cases apply a different technology, which are shown Table 4.

Table 4. Technology applied for picking

Simulation case	Technology applied		Transportation for merchandise	Type of merchandise to be collected
See the light: Optimization of put-to-light order picking systems.	Put to light		Bins and conveyor belts	Multi-SKU
A multi-objective model for minimizing makespan and total travel time in put wall-based picking systems.	Put to wall		Bins for SKUs	Multi-SKU
Optimizing the order picking of a scholar and office supplies warehouse.	Travel Sequence / Routing of Picking		Forklift with elevator	Multi-SKU

4.3 Characteristics of industry and company

The characteristics of the industry and company have not been explicit in the first two simulation cases. However, in the first case it only mentions that the picking automation process is developed in the retail sector. Regarding the third case, the picking system simulation is carried out in a lumber company warehouse. This warehouse has a vertical structure made up of 36 columns with 9 levels each and allows workers to have easy access inside the warehouse. Table 5 summarizes this description for each case with the objective of identify details of the warehouses used on the models.

Table 5. Characteristics of industry and company

Case study Sub-category	See the light: Optimization of put-to-light order picking systems	A multi-objective model for minimizing makespan and total travel time in put wall-based picking systems	Optimizing the order picking of a scholar and office supplies warehouse
Type of industry	Retailer	Non-specific	Lumber (supply tools for schools and offices).
Warehouse characteristics	Non-specific	Non-specific	Vertical structure warehouse with 36 columns and 9 levels per column. Workers can move in all directions.

4.4 Characteristics of the initial scenario of the simulation of the automated picking system

The initial scenario of the first and second simulation cases converge with respect to their initial problem, since they focus on the elimination or reduction of the makespan in the development of picking activities, however, the hypothesis that each case proposes to address the problem posed is different. The first of these seeks to analyze different system configurations, to determine which of these is the most efficient and thus save makespan time and, therefore, man hours. The second case hypothesis dwells on the application of three algorithms to search for process optimization, with the aim of reducing the number of trips made by the worker in charge of picking. The third case, unlike the first two, focuses on automating the process of preparing a route, since the initial problem demonstrates the great inefficiency that results from the self-determination of the route prepared by the worker. The hypothesis that arises for the resolution of this problem is the implementation of a Routing or Travel sequence system in the warehouse, in order to standardize and optimize the time per journey. Table 6 summarizes the initial problem, hypothesis for resolution and the objective of that three simulation cases focus on compare and differentiate cases from each other.

Table 6. Characteristics of the initial scenario

Simulation study	Initial problem of the simulation study.	Hypothesis for the resolution of the problem.	Simulation objective.
See the light: Optimization of put-to-light order picking systems	During the layout design of the put to light system, it must be evaluated whether the worker must necessarily walk through the entire lane or if he could return earlier (makespan), in case the remaining orders do not request the current SKU. This leads to making decisions about storage allocation problems, because if the order bins located at the end of the lane are the ones that require the most different SKUs, it would influence the walking distance of the worker and the picking, because if the bins with full orders immediately leave the storage area for the shipping area for the subsequent order bin to enter and replace its place, the travel length is reduced.	By analyzing three layout configurations related to how order bins are stored along the lane and/or sequence in which each SKU bin is processed, their impact on picking performance can be determined.	Determine how much labor can be saved by changing the sequence of SKUs and the way order bins are placed along the lane.
A multi-objective model for minimizing makespan and total travel time in put wall-based	The travel time of the codes of the put to wall system is not optimized, so there is a high makespan due to the inefficient times of unnecessary or poorly calculated transfers within the warehouse. Furthermore, the worker does not know the optimal order for picking up the products to speed up the exit of the bin bins with fewer SKUs pending to be prepared.	With the application of the three algorithms GA, COGA and AMOSA, it will be possible to define a model that results in less order preparation time used in the	Create a new mathematical model to minimize the makespan and total travel time for a given order, route, and

picking systems		transfer of the worker between locations.	sequence of proposed orders.
Optimizing the order picking of a scholar and office supplies warehouse	The worker is the one who defines the picking order of the products in the warehouse, which is considered inefficient and irregular. Likewise, it also defines in which order to place the bins as a priority, so it does not carry out the correct consolidation of SKUs, having to collect the same product more times and making the preparation of each order less efficient.	With the application of a programmed and modeled mathematical model to solve a warehouse routing problem, travel times within the warehouse can be drastically reduced.	Present an optimization and its programmed and modeled mathematical model to solve a warehouse routing problem.

4.5 Methodology used in the simulation

In the three evaluated simulation cases put to light, put to wall and routing of picking, the Gurobi Optimizer solver was used to test its hypotheses based on fiction. However, each one used its own algorithms to perform the simulation (Figure 1 and Figure 2).

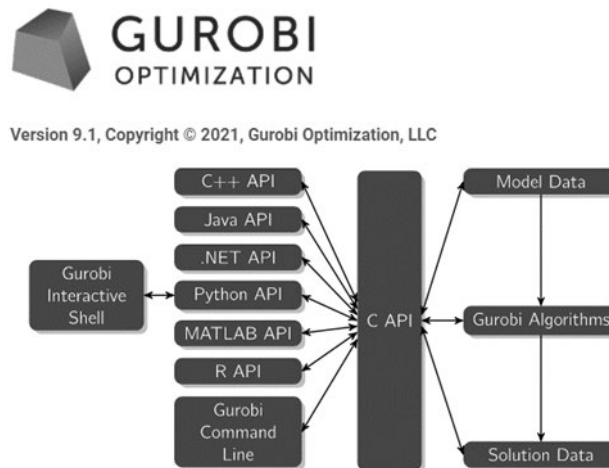


Figure 1. Gurobi Optimizer

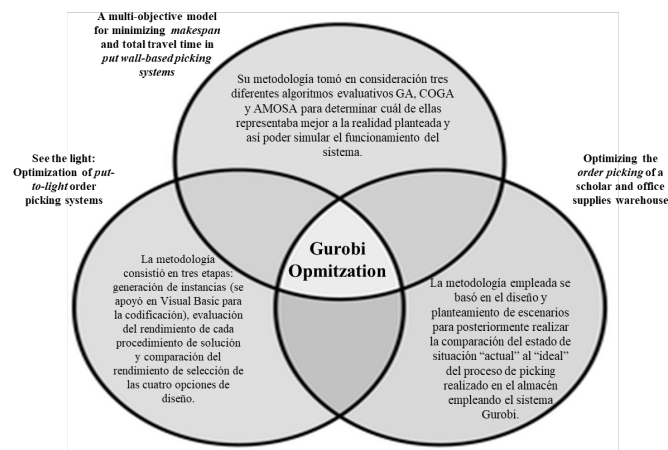


Figure 2. Venn diagram: characteristics of the applied methodology

5. Discussion

The three simulation cases of automated picking systems compared in the previous section reflect a series of convergences and divergences according to each category, which will be elaborated in the following lines.

Starting with the country of origin, three nations of different languages and cultures are presented. On the one hand, Germany is located in the center of Europe (language: German); on the other hand, the United States (language: English) and Brazil (language: Portuguese), both belonging to North and South America, respectively. This is in line with the ranking presented in the World Robotics 2021 report by the International Federation of Robotics IFR, where the United States and Germany are among the 15 largest markets with industrial robot facilities in 2020, which shows the technological progress being experienced in each country. (International Federation Robotics, 2021).

Regarding the applied technologies, they were put-to-light, put-to-wall y Travel Sequence / Routing of Picking. Their effectiveness was tested in each simulation study and found to be directly related to one of the picking stages. According to Vargas & Moncayo (2019), each of the four stages presented by the authors occupy a percentage of the total time of order preparation, which are explained in Table 7 below.

Table 7. Percentage of time required per picking phase

Stages of the picking process	Percentage of picking time required
Preparation	5% - 25%
Routes	25% - 35%
Extraction	10% - 35%
Packaging	15% - 25%

Then, according to Table 7, the analyzed simulation cases that apply the Put to Light and Put to Wall technologies focus their study on the travel phase, which is a fundamental part of the picking process, as the time required to perform this phase can represent 35% of the total time of order preparation. This is because this activity consists of the operator's journey between multiple SKU locations and the order to be completed. This route is called by the analyzed simulation cases as makespan.

On the other hand, the third simulation case that applies the Routing technology (travel sequence) maintains an approach in the phase of the picking process called Preparative, which occupies between 5 and 25% of the total time of the order preparation. In this phase the data collection activities of the elements held in the warehouse, classification and analysis of orders are carried out.

Finally, the category that refers to the characteristics of each of the warehouses in the simulation cases presented provides information on the hauling system used, the dimensions of the warehouse, the type of merchandise to be transported within the distribution center, among others. Two of the simulation cases use picking systems that require a specific handling of the goods. That is why, the cases related to put to wall and put to light systems use bins as a transport base in the warehouse; however, the first case of these two confirms the use of conveyor belts to increase the movement dynamism of the system. Regarding the characteristics of the warehouse, the only case that shows them explicitly is the one that applies the travel sequence system, this being a vertical type warehouse with 36 nine-level aisles. According to Pinto and Nagano (2019), the travel time of a picking worker can take up to 50% of said activity, so tackle the problem of travel time means using half the time wasted in carrying out the process, mainly reducing the distance to be traveled by the worker.

6. Conclusions

After having performed a comparative analysis of the cases of simulation of automated picking in warehouses, we first conclude the importance of the process and each of the stages that includes the preparation of orders within a warehouse, which also leads to the imminent need to optimize the procedure in order to reduce dispatch times and man-hours, thereby generating greater productivity and savings for companies that venture to refine or modernize the picking process within their distribution center.

In addition, it was observed that the testing of the picking technologies of the three simulation cases required different scenarios according to the basic characteristics of the warehouse in question such as the type of goods, the type of transport

within the distribution center, the size of the establishment, among others. These scenarios also reflect possible future situations that could occur after applying the new automated system in the picking process in order to test its effectiveness and efficiency during its simulation stage on the chosen platform.

Finally, for those companies considering the application of an automated picking system it is recommended to perform an analysis that considers the exact situation and characteristics of their distribution center, as well as the objectives to be achieved by such implementation. Any modification in a warehouse must be feasible in the long term, since these mean possible service shutdowns that not every company could be allowed in a recurring or unexpected way.

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