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Inventory Record Accuracy Improvement Based on Multicriteria ABC Analysis, RFID Technology and Sustainability: An Agricultural Company Case Study

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Abstract*– This recent investigation has the objective of improving the inventory management of the agricultural company Andrea SAC via the implementation of RFID technology, Cycle Counting based on Multicriteria ABC Analysis and Systematic Layout Planning. At the end, the goal is increasing the Inventory Record Accuracy (ERA). On other things, the investigation is going to be based on the application of every single tool mentioned with the goal of solving the root causes that are generating the low Inventory Record Accuracy problem. To achieve this, we need first to determine the background of the agricultural sector and grape exports, while highlighting the reasons why this topic was chosen, and the research related to this problem. Also, we´re going to detail the ways RFID technology helps us to improve the accuracy in inventory counting, the recommended counting frequency to do for every inventory group (A, B or C) with the objective of increasing the ERA indicator and maximizing the visibility of every SKU using Systematic Layout Planning.

Keywords—Industrial simulation, Inventory Record Accuracy, Multicriteria ABC Analysis, RFID Technology, Systematic Layout Planning.

I. Introduction

In the realm of the retail sector, inventory register accuracy (IRA) emerges as a critical challenge. A low IRA index can lead to stockouts and lost sales, significantly impacting on business operations. This issue extends to specific sectors such as the agricultural industry, where precise inventory management is equally vital. Previous research efforts, exemplified by studies [1], [2], [3], [4], [5], have explored various strategies to enhance inventory accuracy, ranging from adjustments in counting frequency to advanced technologies like R-FID and Systematic Layout Planning (SLP).

This study is situated within this context, focusing on the problem of low inventory accuracy. Despite significant advancements, a gap in existing research is apparent. While some solutions have integrated techniques such as ABC analysis and SLP, none have fully incorporated the technological component in the agricultural context. Additionally, a multicriteria ABC method adaptable to fluctuations in both demand and supply, especially in the volatile agricultural sector, has not been considered. This knowledge gap presents an opportunity to develop a comprehensive methodology that addresses these deficiencies and allows us to create new future-proof solutions.

In response to this gap, this research proposes an innovative and complete solution to enhance inventory accuracy in agricultural enterprises. This study will focus on integrating R-FID technology, multicriteria ABC analysis, and SLP. The incorporation of R-FID will enable precise and automated inventory tracking, while multicriteria ABC analysis will ensure appropriate product prioritization in a dynamic agricultural environment. Additionally, SLP will be applied to optimize the physical distribution of products in the warehouse, further enhancing efficiency.

This research will be structured in three parts: firstly, a critical analysis of previous research will be conducted, identifying limitations and unexplored areas. Secondly, the proposed methodology will be presented, detailing the integration of R-FID technology, multicriteria ABC analysis, and SLP. Finally, the results obtained through the application of this methodology will be presented, demonstrating its effectiveness in improving inventory accuracy in the agricultural context. This endeavor aims not only to fill an existing knowledge gap but also to provide agricultural enterprises with a practical and effective tool to manage their inventories more accurately and efficiently.

II. STATE OF THE ART

We analyzed a total of 40 scientific articles about several solutions to our problems, always focused on getting relevant (the data must be younger than three years since publication) and expert-approved information (the articles must be ranked Q1 or Q2 on Web of Science and Scimago). These previous cases and studies will form the bases of our project, focusing on the importance of applying the correct tools on inventory cases. At the end of the day, the investigation led us to three main typologies centered on Systematic Layout Planning, multicriteria ABC analysis and R-FID technology. The findings have enough evidence to support the use of these three methods as one singular project and detailing how to implement them and what to do on specific cases.

To begin with, we start detailing info about SLP application aimed to improve inventory distribution and maximize SKU visibility. The article [5] shows us a model composed of SLP, 5S, demand forecasts and cycle count, which together are applied to a major store and manage to reduce the picking time by 36.7% and increase ERI by 5.42%. This tool also reduces 40% of movement on a perishable food enterprise as told by [6], improved the total visibility of every present SKU according to [7], and by the words of [8] it manages to reduce 50 travelling hours and 48 working hours by combining it with AHP.

The second main pillar of our model is the use of multicriteria ABC analysis to classify articles and pave the way to efficient inventory management. The data brought by [9] tells us that by forming part of the current MMGS model of the company, the prioritization accuracy is 12% to 26% better than any other models like SVM. There are several examples about its advantages on industries: According to [10] it helped the personal to define that 82.05% of all costs is concentrated in only 15 articles, the studies [11] says that it was applied to perishable supply chains and it reduced 39% of all faulty products and decreased the total cost by 1.7%, [12] mentions that by combining it with PBIC it reduces the total costs by a notorious margin compared to other models like ADV.ABC, and last but not less important the project made by [13] managed to improve by 47% the efficiency on the item classification. An additional point to take int account is the necessity of well-defined analysis criteria. As mentioned by [14], we need to focus on criteria terms thar analyze and classify various article types and sizes.

The third main theme consists of the application of R-FID to improve item registration accuracy of agrarian inventory companies. According to [2], the implementation of this technology on automated robots managed to improve the ERI value to 99%, and by the words of [15], applying it to the inventory of an air command complex decreased the picking times and erased trajectory clashes. Its superiority over similar tracking systems is also observed, since according to what [16] said, RFID is more profitable and flexible than a Wireless Sensor System (WSN). Other cases include the investigation [17] highlighting the small companies choosing it (every single one improved their inventory accuracy to at least 97%), and the studies spearheaded by [18], which mentions that its application on an e-commerce enterprise achieved a 25% decrease on employee use and increased the number of completed orders by period.

III. CONTRIBUTIONS

To develop the proposed solution model, we drew inspiration from [6] approach, which combines ABC multicriteria classification with inventory management, aiming to enhance indicators such as inventory record accuracy (IRI). Another important approach for the formation of models is the study [19], in which the SASC methodology is used to search for information about models and tools to delimit the information according to the goals and topics important to the company. Similarly, the sequence of implementing SLP and cyclic counting, based on ABC multicriteria analysis, was grounded in the model proposed by [5]. This model encompasses the initial phase of implementing 5S and SLP, followed by demand forecasting and concluding with cyclic counting.

Subsequently, to determine the order of implementing RFID technology, we relied on the research by [20]. In this study, the warehouse layout was first designed, even specifying the type of shelves to be used, and then the necessary quantity of RFID antennas was calculated to maximize RFID reader coverage and minimize implementation costs. This article was crucial as it not only provided the implementation sequence but also detailed the essential steps for incorporating RFID technology, from choosing the RFID technology type to optimizing reader coverage. Fig. 1 shows the conceptual model we described before.

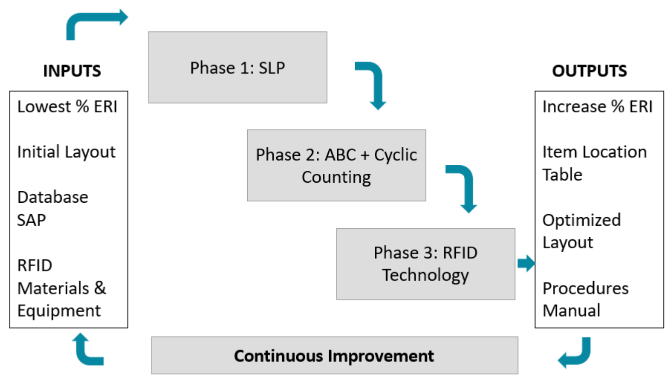

Fig. 1 Conceptual Model of Solution

The conceptual model also shows that Inventory record accuracy (IRA) is the main indicator of our project, so all the tools we show in the conceptual model must work in the same goal too. Now we're going to describe each phase and components necessary to reach complete the conceptual model.

A. *Applying systematic layout planning (SLP) to improve the materials visibility*

In this first phase, the goal is to create a layout of the warehouse area in the California plant of Agrícola Andrea SAC, following the Systematic Layout Planning method. The aim is to achieve a layout that considers materials visibility, relevant regulations and the occupational health and safety law (law 29783).

To address this problem, understanding the current situation is crucial. Therefore, before applying the SLP method, it is important to have the current dimensions and distribution of the warehouse areas. After that, it's necessary to define areas or storage zones where activities support the production process of the California packaging plant. The following areas are considered for the research administrative office, reception, box assembly, internal packaging, external packaging material, supplies, restrooms, waste disposal area, cold tunnels, harvest zone, maintenance zone, production zone, discard zone, and raw material (grape) reception.

Something additional to justify this section involves the creation of a relational diagram of activities, considering the aforementioned areas and additional areas such as toilets, waste disposal, cold tunnels, harvest, maintenance, production, disposal and reception of raw materials (grapes). It is important to make this diagram when applying the PSL, since what was investigated by [21] it is possible to apply the Graph Based Theory (GBT). This methodology consists of the actual definition of each activity or area present so that everyone knows the current state of the process and decisions can be made based on this, which a relational diagram helps to synthesize this important information. The proximity or distance between areas can be influenced by factors such as process sequence, material contamination, noise pollution, traffic restrictions, sun exposure, necessity, strong odors, and cold exposure. An example of this is seen in Fig. 2, where the definition of the relationships between different tasks and areas will be planned.

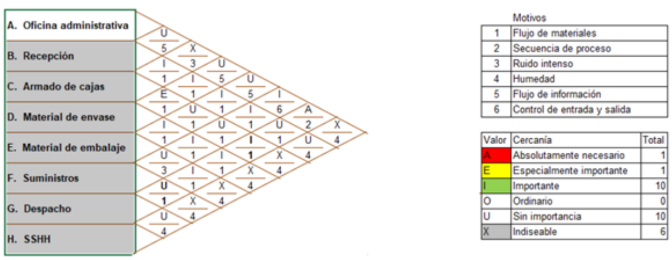

Fig. 2 Activity Relational Diagram Format

Next, the existing flows between areas will be determined through circles and lines, where each circle represents an activity or area, and lines indicate movement between activities or areas.

Afterwards, layout proposals will be developed, considering technical aisle standards, risk prevention, and ensuring material safety. The proposal will respect the flow of activities, prioritizing the placement of areas or activities with higher flow intensity. Additionally, the proposal will include a top and front view of the suggested layout.

Following this step, a distance matrix will be created to determine a proposal that minimizes distance for inventory and dispatch processes. Distances will be measured considering the zone center as its center of gravity from which travel distance is calculated.

In the last stage of the phase, layout proposals will be evaluated using a Benchmarking matrix to choose a design that meets technical standards, security, ease of access and minimizes activity distances. The selected layout must effectively address the root cause of the problem (difficult access to materials) and comply with safety regulations. It is advisable to detail each main attribute of the determined layouts through tables and key points, as indicated [22]. Once the layout that minimizes the travel time and thus the picking time has been selected, the CO2 emission saved by each of the forklifts used in the warehouse can be calculated monthly. To do this, knowledge of data such as the generation of CO2 in kg per hour of fuel consumed, the travel time made for each order and the total orders per month will be key. For this, the formula proposed [23], is that used.

$$CO2\ emissions\ [Kg * CO2] = Carbon\ footprint\ \left[Kg * \frac{CO2}{h}\right] x\ Travel\ Time\ [h] \quad (1)$$

B. Multicriteria ABC Analysis and Cycle Counting

This research presents a robust strategy for inventory management, with a particular focus on the second phase, which revolves around the crucial task of categorizing items based on their level of importance within the inventory. The proposed model ingeniously combines the sophisticated ABC multicriteria analysis technique with cycle counting, providing a comprehensive solution for accurate and efficient inventory control over various work periods. Emphasizing the need for continuous classification, the model intelligently leverages insights obtained from the preceding Systematic Layout Planning (SLP) phase to strategically position products, ensuring optimal operational flow.

In the initial step, researchers delve into the intricate process of Analytical Hierarchy Process (AHP) analysis, which involves the meticulous definition of criteria where measurable units are identified and decimal weights are assigned based on their relevance. Next, an in-depth examination of the potential criteria is carried out, considering the importance of various aspects in the context of current operational processes. The final step of this stage revolves around selecting the most relevant criteria among the possibilities. Despite the variable context, most of the crucial criteria turn out to be common. This is demonstrated in the research carried out by [24], which highlights that in almost all cases the most important evaluation criteria will be annual demand, unit price, annual use value, product weight and physical size. Redundancies are eliminated, and the weights of the chosen criteria are adjusted proportionally (aligning them with the general objectives of the inventory management strategy).

Moving on to the second stage, the research underlines the importance of data normalization, involving the creation of tables to systematically list the elements and justify the criteria chosen for evaluation. The normalization process focuses on synthesizing and schematizing the wealth of information efficiently, setting the stage for subsequent numerical evaluations. Continuing with this point, it is important to understand that present products will need to be reclassified constantly in the future. As investigated by [25], periodic reclassification consists of changing the classification limits for types A, B and C according to the period or production rate of the company, and its constant execution allows us to implement and effectively exercise the control policies of inventories that the company has adopted. Scoring each item against the selected criteria is a crucial aspect as it provides a nuanced understanding of the importance of each item within the inventory. This step involves a variety of activities, from data monitoring and scanning to temperature observation and screening.

The final stage of this phase centers on the meticulous assignment of classes to each type of item in the inventory. It could be reached through assignment in a table a later in the layout as it shows in Fig. 3.

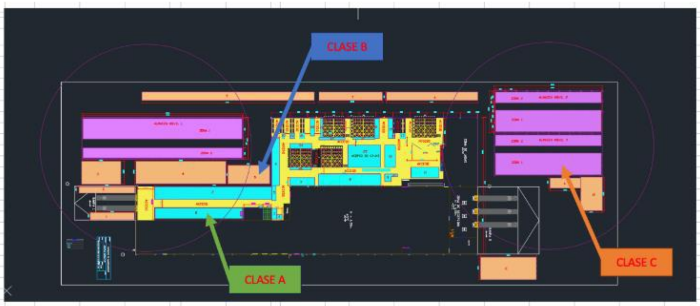

Fig. 3 Location Allocation Based on ABC Multicriteria Analysis

C. Radio-Frequency Identification (RFID) Technology

The final phase of model implementation deals with the implementation of RFID technology in Andrea SAC's grape production inventories, which consists of three stages. In the first stage, RFID selection, the reading range required for the operating environment is determined by analyzing factors such as the area of operations, types of items, working hours and economic conditions. Do not forget that, as mentioned by [26], it is crucial to see how RFID is applied in case of competing suppliers. Although in almost all cases the benefits of RFID are greater than the initial costs to be incurred, it is necessary to achieve a balance of the level of its execution according to competing events, such as whether both or only one supplier decides to apply RFID on its own. account. Additionally, the appropriate type of RFID (passive or active) is chosen based on specific needs, considering factors such as cost, size, and read range.

Moving on to the second stage, the distribution of antennas, it is planned to integrate tracking antennas for each inventory item, considering its individual dimensions. This is crucial to avoid exceeding the allocated budget, a common obstacle when convincing stakeholders to implement RFID systems. If possible, in the context, the implementation of IoT sensors is also recommended. As mentioned by [27], these sensors allow us to monitor the temperature and status of the items in their range, can be simply linked with an RFID system and can be used in areas with temperatures other than ambient. In the case of perishable or heat-sensitive products, its use is of great help. The objective is to define the locations of these antennas based on the dimensions of the SKUs in circulation, looking for common positions for the accessories and comparing their performance according to the transmission level issued for each item. In addition to being able to define the correct location by observing the current state of the warehouse, [28] mentions that there are numerical methods to define the appropriate location of the antennas and the system. Among those mentioned, the RSSI, Phase, ToA and TDoA, and Fingerprints method stand out; all of these using measurements between tags and antennas and using triangular and tangent theorems so that they can be defined quickly. An example of the antenna distribution is shown in Fig. 4.

Fig. 4 Possible Antenna Locations

In the third and final stage, which is to maximize the reading, the positions of the readers are calculated to avoid transmission problems and tests are carried out to ensure that the RFID system works correctly. The objective is to determine the best positions for each type of SKU in inventories and confirm the effective application of the RFID system. A user manual for RFID readers is then developed to document daily work performance, item locations, and solutions to past errors, serving as a valuable resource for employees involved in grape production. In the study by [29], several points are mentioned in their manual, such as: RFID and waste reduction, Temperature monitoring, emissions monitoring, monitoring of possible present humidity, product preservation, security and privacy, present costs, and future trends with their possible strategies. The objective is to apply RFID technology effectively, providing real-time information about the location and status of each product in production inventories.

IV. VALIDATION

With the planning and creation of the defined model, the next step consists of executing the solution plan in a simulation to demonstrate the importance of this solution. The simulation software chosen turned out to be the Arena program, in which the selection is supported by what was mentioned by [30]. According to the author, it was applied in the reception logistics flow of a company with the objective of balancing the workstations and a redesign of the layout, and in addition to achieving this goal it was able to reduce travel and processing times that did not add any value. This validation method will be crucial for phase 1, in which Systematic Layout Planning is used. For the second phase with ABC multicriteria analysis and cyclic counting, and the third phase with RFID technology, this software will also be used to carry out the simulations. In the Case of ABC analysis, [8] says that its use is crucial because making any change in the organization of inventories will lead to the modification of the paths in the processes, and it is better to simulate all possibilities to define the best places. In the case of RFID technology, what was mentioned by [18] tells us that the Arena simulation can find weak links in management and transportation and then optimize them (going from 556.7s of average unnecessary travel time per cycle to 192.8s).

This validation is divided into different stages: Data collection, data analysis, development of the Arena model, data entry and data execution for the simulation. To summarize these points:

1) About 30 measurements of each process and wait in the company must be collected in a database, as well as information on the average arrival times of orders
2) Use the "Input Analyzer" program to define the correct trend of the data obtained and approved. It normally alternates between Normal, Triangular and Exponential.
3) When we use the Arena software, we create the 3 models or process diagrams relevant to our 3 tools. Here the input, output, attributes, record, wait and other entities are defined.
4) Once the models have passed the basic tests, the introduction of defined data begins. The defined tests will be carried out twice to then be able to analyze the previous situation with the solution.
5) After making the final changes and considering every possible external detail, we proceed with the final simulation run. It will be done twice to analyze the initial and final scenarios.

In our context as an agricultural company, we focus on the process times of grape production. After eliminating the special cases, we managed to define 30 possible production times divided into 5 processes. After this stage, we continue with the use of the Input Analyzer to define the appropriate trend. We achieved the requirement of. "$p > 0.15$" with the UNIF or Uniform distribution.

Then we moved on to the construction of the models, in which various entities were used in their construction such as the processes that make it up and 16 "Transports" that symbolize the movements. Consequently, follow the route configuration. 11 hours of work per day were considered, minutes as a base unit, 24 days per month, the hallway design was adjusted and the ABC classification was followed for the second attempt (final), and we were guided by a schedule (as mentioned above). The validation lasted about 35 days and was carried out between March 18, 2024, and ended on April 3, 2024). At the end of everything, we carry out some functional tests and go through the final run of the initial situation.

At the end, we compare the results and see how it changes compared to the beginning. We have defined 3 crucial indicators, which took relevance in the process and define the success or failure of the process:

1) Picking time: Goes from 95.40 minutes to 66.5 minutes with the process, meeting the goal of being less than 70 minutes.
2) Materials without defined location: Goes from 21% of items with this problem to only 9.63%, meeting the goal of only being less than 10% of total SKUs.
3) Materials counted correctly: Goes from 94% of total SKUs with this status to 97.2% of the items, meeting the company's goal of going from 95% of the total.

Additionally, after the simulation, data related to the number of orders fulfilled (shipments) made per month of work were obtained. Then, by using said data in the formula mentioned in the model, the following results were obtained regarding the consumption in Kg of CO2 per month and forklift. So, the CO2 emission per month for each forklift has been reduced, going from an initial value of 386.4 Kg of CO2 to 289 Kg of CO2. Which shows the significant impact on the environment that can be achieved because of the application of SLP combined with sustainability, since a reduction in CO2 generation by 25% was achieved.

V. DISCUSSION

The initial validation was done considering that only one warehouse operator is responsible for dispensing materials; however, it is important to evaluate scenarios where the company hires another dispatcher to accelerate the material release process. Then, in the Arena software, the flow was modified, dividing the material orders so that they are attended to by 2 operators, using the "Separate" function. Thus, for the output of materials, 2 routes are drawn to take 2 different groups of the order. The result of this scenario shows that there was indeed a reduction in picking time, since it went from a value of 66.5 min to 38.71 min.

Although it seems to be a tempting solution to reduce picking time, it is important to consider the associated extra costs such as the hiring of additional personnel, rental or purchase of another forklift, training, PPE and the increase in the risk of accidents as there are more forklifts in circulation. Considering the above and also that the warehouse aisles are designed for one-way circulation, the more operators are added for the dispatch of materials, the picking time will no longer be reduced but on the contrary, it will increase because it will be generated traffic within the warehouse that will hinder the picking of materials.

Simulating the proposed solution in a second scenario, this time changing the work performed to the night shift, a reduction in picking time of 12.2 seconds is expected, that is, close to 18%, which is quite significant. This shows an opportunity for improvement that must be evaluated considering the extra costs associated with the night work that employees would do. Likewise, it should be noted that this being an agricultural company, the products must be harvested, packed and shipped in the shortest possible time to avoid deterioration, therefore the company would have to change the work schedule not only of the employees of the production plant. packaging (including warehouse) but also the cultivation area, increasing these labor costs even more. Finally, it must be considered that this reduction in picking time is due in part to the free movement that will be had in the dispatch of materials since the simulation has not considered the processes of reception, unloading, location, inspection and ordering of new materials, which generate delays when picking. Therefore, in order for this reduction in picking time to be fulfilled, work must be ensured during the day shift to carry out activities of reception, inspection, ordering and location of materials, in such a way that at night only the outflow of goods is carried out.

From this analysis, it is suggested for future research to answer the following question: to what extent is it advisable to increase the number of warehouse operators to minimize picking times? Considering industrial safety, profitability, among others. Another related idea is the exploration of technologies that automatically and in real time generate optimal routes for the movement of the forklift in such a way that there is an uninterrupted flow, also that guides them to the location of the material, relying on technologies such as RFID and IoT. Also, it will be important to investigate how other processes within the warehouse such as inventory, reception, ordering and inspection of materials affect picking time and, in turn, the accuracy of inventory registration.

V. CONCLUSIONS

At the end of the context explanation process, contribution, validation and discussion about the contributions provided by the solution model, we highlight some crucial points that can be extracted from the article.

To begin with, our problem is real, it can occur in most companies, and it causes greater negative effects if there is no detailed contingency plan in the organization. In the company we have applied our ERA improvement model; Before its application, the number of SKU types with unregistered units made up 64% of the total present in the company, and the total value of the unregistered units of the SKUs in the warehouse reached a value of $1,690,715.84 and exceeded the limit of losses in relation to profit of 3% maximum (reached 3.86%). Due to the dimensions of the situation, a single tool will not be sufficient. The creation of the model with SLP, ABC cycle counting, and RFID tools was necessary to cover the crucial root causes, in addition to the collection of crucial data on efficiency in the company and theoretical support with mostly recent scientific articles.

Then, it was defined that the first component of the model (Systematic Layout Planning) would be responsible for improving the present difficult access to materials. The tool presents the ability to define the ideal area for each product and work zone present in the factory to reduce unnecessary trips during the work period. In addition, it allows establishing the correct relationship between all activities and areas present along with the planning of a layout that correctly places the types of products according to their importance. As a final point, it was clarified that the execution of this tool does not imply major changes in the most valuable parts of the process sequence.

Continuing with the analysis, it was defined that the second component of the current model (Cycle counting and ABC multicriteria analysis) will be responsible for organizing all materials with an undefined location. Its attributes are easily adaptable to the present context: It allows defining the importance criteria of the company through the analysis of its factors and effects, it allows applying numerical values by weight in the company of each of these criteria that are then used to define the weighted importance values of each SKU unit present, allows the preparation of calculation records that explain the steps necessary to define the importance of each area present, and allows the use of the information collected in the previous component so that in the end it is defined the correct location of each item (as an example, crucial sales SKUs may be located in the A classification areas that are the most accessible).

Afterwards, it was defined that the last component of the model (RFID Technology) can improve the manual counting of items and define their movements. The main reason for the problem is the lack of a uniform tracking system in the company's warehouses and that the current number of items makes any non-intensive physical counting insufficient, for which this technology was created and formulated for these situations. To conclude the research, it is stated that a good RFID system is crucial for each tracking problem, since the antennas themselves can record each movement, state, location and accident of each unit of each item in a ratio suitable for most warehouses in companies.

Concluding with this part, we concluded that, from the evaluation of the two scenarios presented regarding the SLP and multi-criteria ABC classification, it is true that the greater the number of warehouse operators the picking time can be reduced, although it has only been tested simulated without problem up to two operators. And after what has been discussed, it can be concluded that picking time can be reduced further only if it is accompanied by an automatic route generator in real time, otherwise traffic will be generated within the warehouse that would slow down picking since it would only the warehouse has been designed for one-way circulation. In addition, it was possible to discuss the shift change, where it was concluded that it is possible to reduce the percentage of picking time; however, it will be necessary to evaluate the profitability of the proposal based on the costs associated with the extra payment to plant and cultivation collaborators. due to nighttime.

Likewise, the importance of coordination with suppliers for the smooth reception of materials during the day and night, also including the planning of the development of other processes within the warehouse such as organization to be carried out during the day shift and thus ensure a smooth flow. uninterrupted in the dispatch of materials during the night.

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