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COMPUTER VISION BASED GATES APPLIED TO CONTROLLING INBOUND AND OUTBOUND FLOW OF ITEMS TO SUPPORT WAREHOUSE MANAGEMENT

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Abstract. *We are all living a time of quick changes and constant evolution, facing growing challenges which are, not rarely, boosted by external contexts like the current pandemic. Companies have always needed to improve their processes, and now they must rise to the challenge of maximum productivity and efficiency. The bigger and more complex the operations of a company, the stronger its tendency to focusing on core business-related processes, in such a way that auxiliary processes are eventually neglected to some degree. Warehouse management and, more particularly, the control of items getting in and out of the stock is a process that may suffer the consequences of an ill-adjusted operation. This paper presents the proposal of implementing instrumented gates in the main warehouse of an electric power company, aiming automated register of items through the stock, and also supplying data to support the inventory process. First, for the gates to fit the warehouse layout, some logistics aspects like the current product handling flow were evaluated and must be adjusted to the new process. The gates, one for inbound and one for outbound items, will be equipped with cameras to identify QR code tags and the general (visual) characteristics of the packages that are moved into or out of the stock by forklifts. They also have auxiliary conveyors to weigh smaller items which are either moved individually or in small packs. The images registered during the flow are treated by different techniques fitting each step of the process. Image processing methods will be combined with computer vision techniques to reach the purpose of object identification and counting. Once integrated into the company's ERP (Enterprise Resource Planning), the new system is expected to provide continuous item flow monitoring, better stock register accuracy, improved productivity and reliability, leading to labor-related cost reduction and minimizing warehouse shutdown times for traditional periodic inventory processes.*

Keywords: *Computer Vision, Warehouse Management, Instrumented Gate, Inbound Flow, Outbound Flow*

1. INTRODUCTION

Logistical processes related to the storage of products are vitally important for the healthy functioning of companies, especially in the field of manufacturing or distribution of finished products (Rouwenhorst *et al.*, 2000; Deng. *et.al.*, 2018; Davarzani and Norrman, 2015). For companies whose inventories are just the consolidation of materials or inputs for the provision of services, the impact may be different, but no less harmful. In times of full access to information technology, the speed at which flows happen greatly increases the productive potential of companies, on the other hand, there is a natural demand for greater efficiency, lower margins for errors, perfectly synchronized processes, quick deliveries (Liu and Ke, 2019; Davarzani and Norrman, 2015).

One of the options adopted by companies, in their search for greater efficiency, is to concentrate efforts on their core business, directing investments and care to processes directly related to their main product or service. Thus, not rarely, auxiliary or support processes end up being outsourced or neglected to some degree. Outsourcing is not necessarily bad for processes. In some cases, outsourcing can even bring improvements in the operations of certain areas. However, when the company decides to maintain control over a certain process but does not pay proper attention to it, its results are certainly negatively impacted.

Scenarios like that open a very promising space for testing new technologies which, in turn, if properly applied and developed, can lead to immediate and long-term gains (Liu and Ke, 2019; Smith, Smith and Hansen, 2021).

According to Deng. *et.al.* (2018), warehouse management reduces companies' costs and creates economic value for enterprises. Automated warehouses are characterized by high energy savings, security and high storage efficiency. When compared to the disadvantages of offline storage methods, automated warehouses can solve problems more efficiently and with higher quality. Consequently, in recent years, automated warehouses have become the very first choice of large companies.

In this study, the case of the central warehouse of an electricity company, responsible for consolidating and providing equipment and supplies for maintenance works in the energy distribution grid in Curitiba and some nearby municipalities, is evaluated and used as a basis for the proposed installation and integration of instrumented gates, aiming the automated flow control for products entering or leaving the stock. The combined use of computer vision and material weighing technologies is the backbone of the methodology, which, once implemented as a computer system, and integrated with the company's ERP, will enable real-time control and register of inbound and outbound flow of goods in the warehouse.

2. PROBLEM DESCRIPTION

Companhia Paranaense de Energia (Copel) is the energy concessionaire in the state of Paraná, Brazil, and it operates in the generation, transmission, and distribution of energy in the state. To meet the demand for equipment and supplies for maintenance works on the grid, Copel has distribution centers in different regions of the state. In the area of Curitiba, there is a supply pole formed by a group of warehouses. This study has been developed on the specific needs of the largest warehouse in this complex. It is a large building, 134 m long and 48 m wide approximately. The stock in this warehouse stores more than 3000 different products, distributed on shelves organized into sections. The sections are coded and properly routed within the company's warehouse management application (WMA). Figure 1 shows an overview of the warehouse.

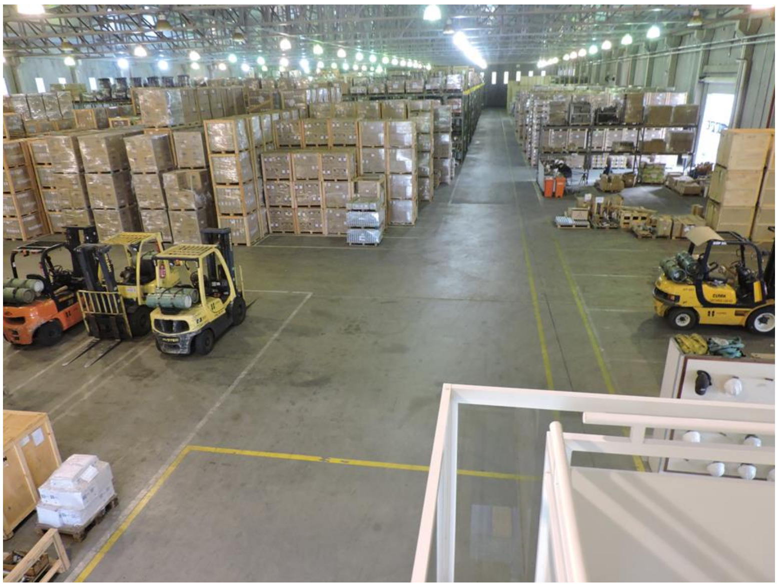

Figure 1. Warehouse overview.

Some particularities of the flow of products in the warehouse are a major challenge for the development of the system proposed here. The great variety of products and the fact that most of them enter the stock in closed packages, containing several units, and leave the stock as fractions, as shown in Figure 2, constitute the biggest challenge in terms of computer vision work. The handling of items, usually arranged on pallets, is carried out by forklifts, which collect the volumes after the receiving and inspection processes and move them into the storage, on shelves, characterizing the inflow. Likewise, when there is demand for products, they are collected from the shelves, pass through a dispatch area, and finally are transported out of the warehouse, characterizing the outflow.

Figure 2. Stock. Left: Storage in shelves. Right: items consumed separately.

This entire process is registered, through several steps, in the company's WMA/SAP. Part of this process is currently carried out manually. Periodically, the stock goes through the inventory process, which consists of closing the warehouse facility during a certain period to count all the items available in stock, making it possible to update the records. It is a complex and costly process for the company, but it allows the managing team to observe any inconsistencies in the records, divergences in the availability of materials and equipment, among other indicators. Additionally, inventory is an audited process that may result in fines for the company, depending on the inconsistencies observed.

3. A POSSIBLE SOLUTION

3.1 Methodology

The development of the work started from the analysis of the warehouse process flow, with attention focused on its efficiency gaps, or on processes performed by humans and that could be replaced by automated systems. With a focus on these gaps, many activities with the intervention of human labor were identified. Amongst them are the checking of previous operations in SAP, visual identification of products that make up a determined input volume, the input of the corresponding information in SAP, addressing the packs in stock, and many others.

The tasks related to identifying incoming or outgoing goods from stock and the data recording processes linked to these steps were taken as a problem to be solved. The implementation of a system based on computer vision that, as long as properly designed and calibrated, could replace, with advantages, human work.

A network-based computational system consisting of cameras, weighing conveyors, a central server communicating both with the sensors and with the company's WMA, was proposed. The diagram in Figure 3 illustrates the main idea of how the system works.

The basic logic behind the system is taking photos and weighing the products as they pass through the gates and conveyors. The data collected in the portals is fed into the system server that identifies the goods via computer vision algorithms and then interacts with the SAP database to update its records.

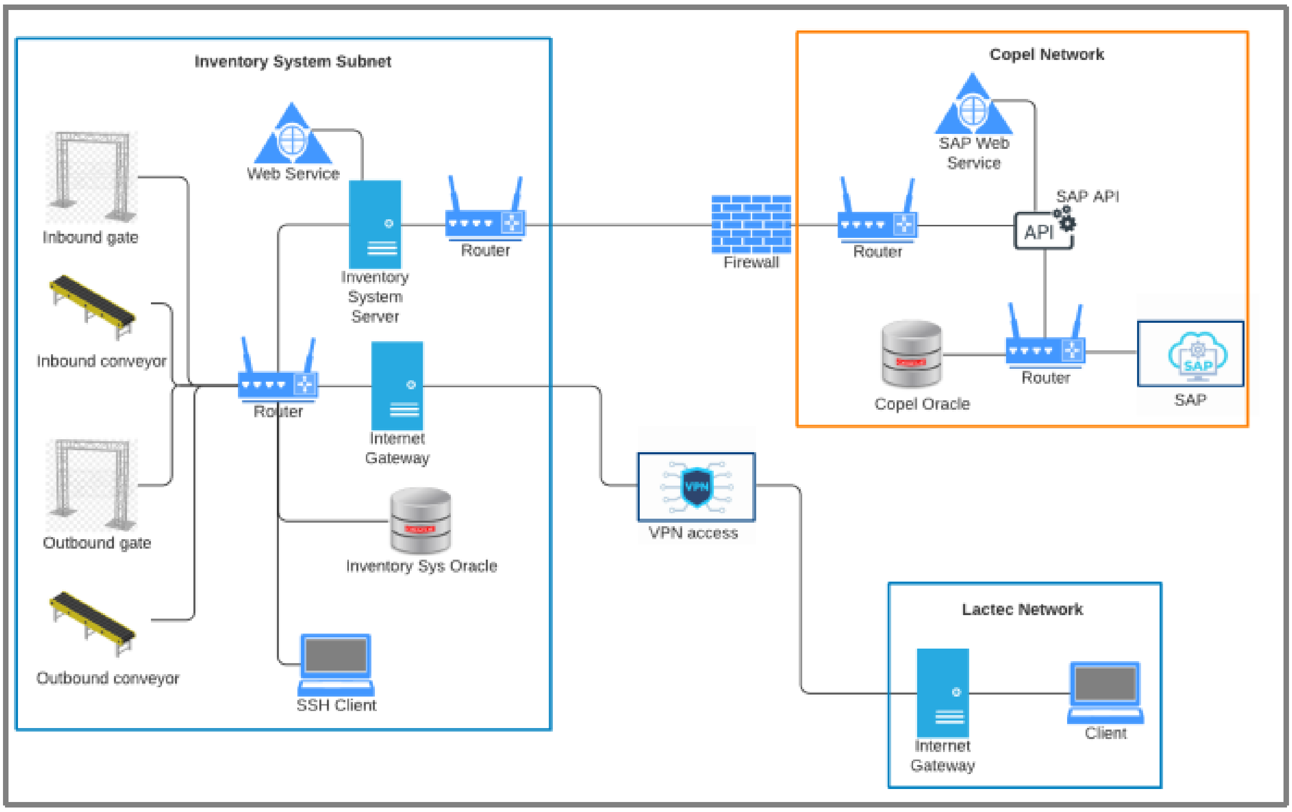

Figure 3. Basic diagram of the proposed system.

Once the system's global process was defined, the development stages started to be organized and executed, as briefly described in the next sections.

3.2 Hardware specification

The characteristics of the current warehouse process, which counts on the handling of incoming and outgoing volumes in stock performed by forklifts, led to the concept of instrumented gates. Among the first project definitions, the assembly of modular portals using a light structure was chosen to facilitate the in-loco assembly and still guarantee some flexibility in case of eventual changes and adaptations. Thus, latticed aluminum structures were selected, of the box-truss type, commonly used in stage and event structures. Figure 4 shows a box-truss module.

Figure 4. Box-truss module.

Once the construction issue was defined, the design process moved on to the location issue. Some initial possibilities were considered and illustrated for presentation and discussion with the warehouse team. At least three different options were outlined. Figure 5 shows the concepts. The first model considered mounting the portals directly on the warehouse entrance and exit doors, flush with the warehouse walls. The second brought the option of a structure suspended by cables, predominantly without contact with the floor. The argument behind the first two models was precisely the economy of space and the less "invasive" character of its installation in the warehouse layout. Finally, the third option used the traditional portal/gate shape, with bases supported on the ground and the flexibility to be mounted anywhere inside the warehouse.

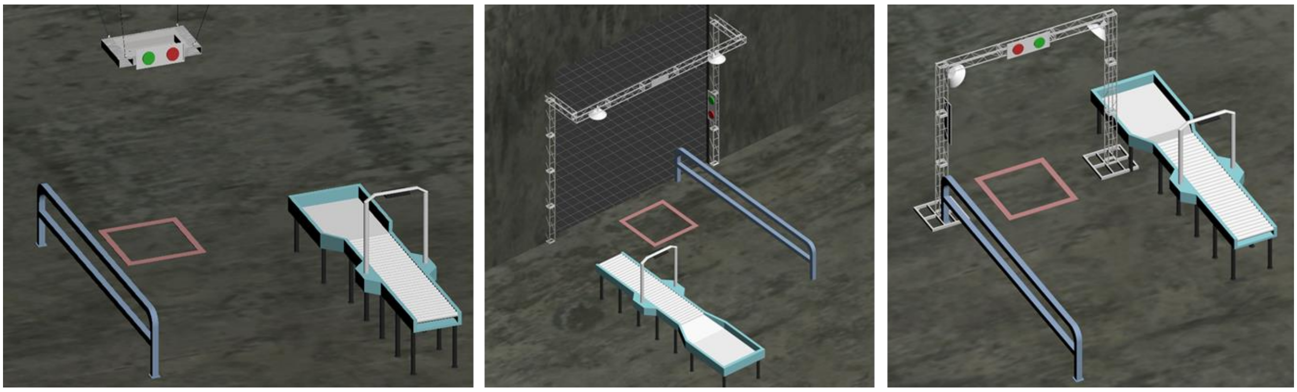

Figure 5. First design and positioning concepts.

In the end, the third option was favored by some of the following arguments: the psychological aspect of the shape and the visual presence of a new element in the warehouse space were decisive. They help the understanding of the passage through the portals as a new mandatory step in the logistics process, thus its integration into the process. The physical arrangement of the warehouse and its logistical sequence, from the arrival of new items up to the dispatch of products, demanded very specific positioning of the inbound and outbound gates. To help in a better understanding of the flow and for the team to define the best places to install the portals, the warehouse was reproduced in a CAD software environment, and it received the portal models. Figure 6 illustrates the model and shows the main areas of the warehouse.

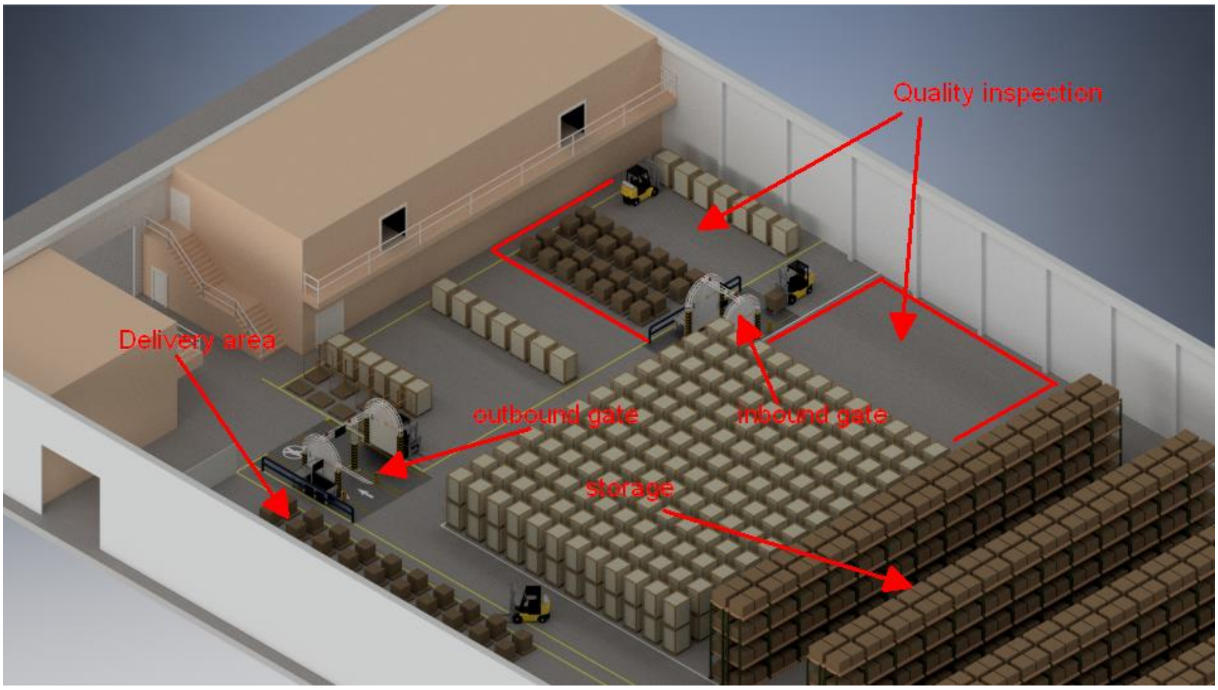

Figure 6. Warehouse layout.

On the instrumentation side, the portals are equipped with cameras for implementing computer vision technologies. The inbound gate holds a regular digital camera, with sufficient quality and resolution to detect QR Code tags. The tags will carry all the registration information (specific instructions about the product and operations in the ERP system) of the input items. The output portal holds a special camera with LiDAR technology, the Intel Realsense LiDAR L515 model, responsible for supporting the more complex computer vision operations that occur at the outbound gate. Those operations range from object identification and classification to measurements and counting, among others. Both portals are equipped with a series of sensors and auxiliary accessories: adequate lighting to better condition the scenes for image acquisition, ultrasonic proximity sensors with alarms and light signaling for operational safety when moving forklifts through the portals, LCD panels for real-time instructions for forklift operators, and barrier sensors to automatically trigger the system when the forklifts pass through. The portals are combined with conveyors for weighing smaller packages that enter the warehouse in individual volumes. The conveyors are, likewise, equipped with cameras with functions analogous to those on the portals. Details of the gates can be seen in Figure 7.

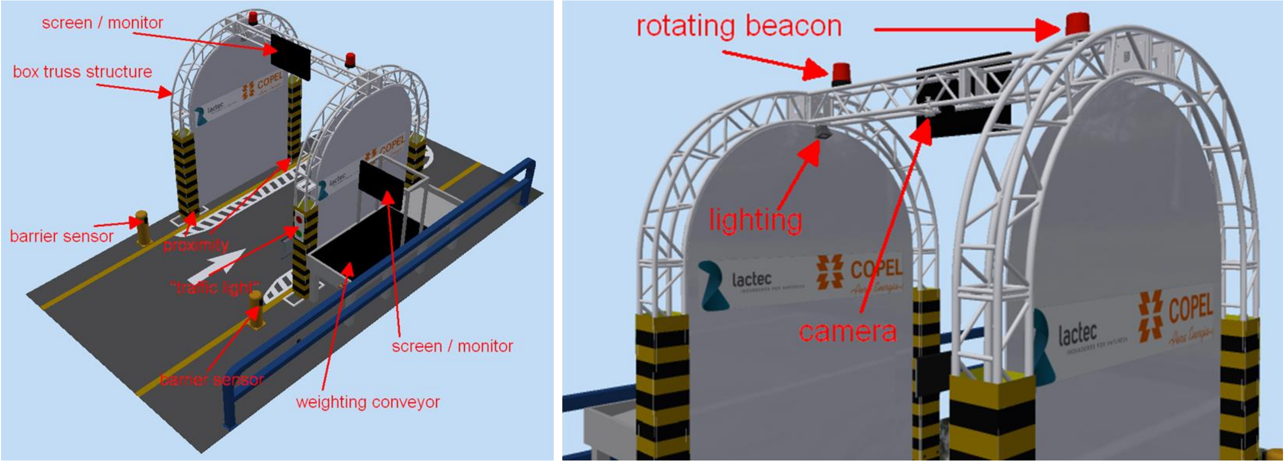

Figure 7. The gates: overview of the sensors.

In short, the gates will be responsible for collecting the "information" needed for the subsequent step, which will be based on processing the input data to update the records in the ERP system.

3.3 Computer vision and weighing technologies

The proposed control system presented in this project is based on the combination of computer vision technologies and item weighing, during the inbound and outbound stock flows, somewhat like that proposed by Liu and Ke (2019). In the inbound flow, the volumes are collected in the sorting/receiving area and transported by forklift, passing through the entry gate. The passage of the forklift through the barrier sensor activates the system, starting the image acquisition process. The weighing stage, in this case, is performed directly on the forklift. For small volumes, the same process happens on the conveyor. The input process is illustrated in Figure 8.

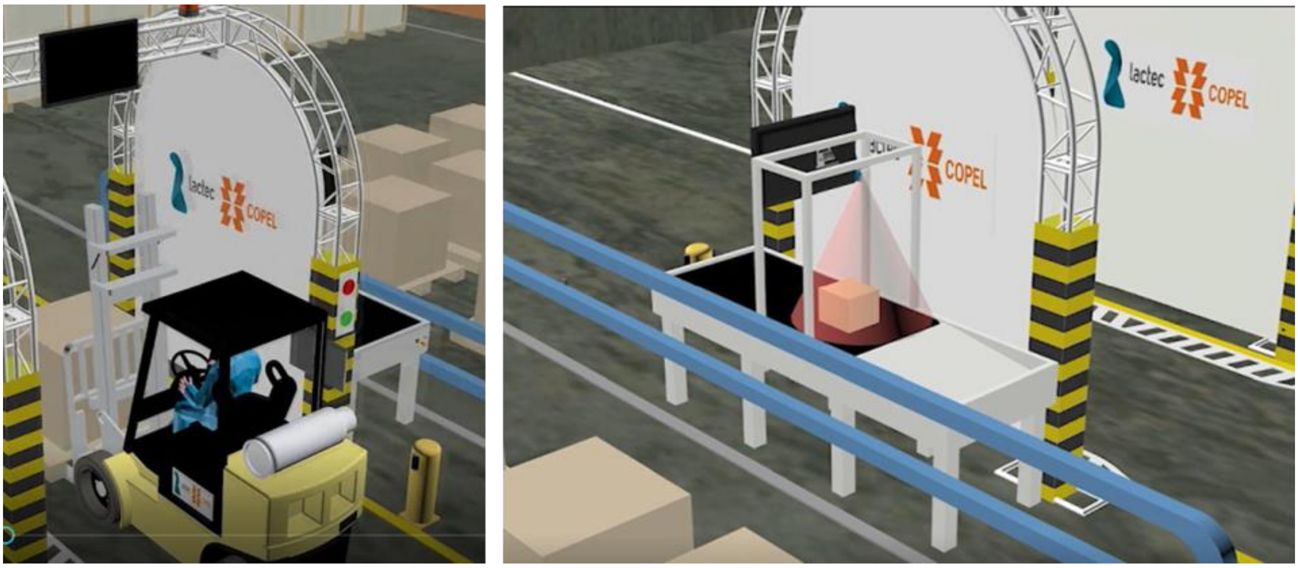
Figure 8 - Inbound flow register. Left: big packs on the forklift. Right: small packs on the conveyor.

The same data acquisition process is performed in the outbound flow. A particularization of the outbound case is the shipping of fractional items, consumed in small quantities. This case generates an important difference, in terms of images and weights, compared to the inbound process of the same products. The outbound process for a set of products is illustrated in Figure 9.

Figure 9. Outbound flow register. Left: mix of products on the forklift. Right: individual item on conveyor.

After the acquisition process, the data is evaluated by the computer system. The images registered at the entry gate provide input for the simple image recognition process based on QR Code tags. One tag will be sufficient to input all information regarding the incoming product, such as order number, product specification, quantities. In case of a prior agreement between interested parties, data such as the nominal weight of the product set, or the unitary weight of the products can be informed and initially loaded into the QR tag. The images generated in the output portal go through distinct computer vision processes, in which the filtering and pre-processing steps, segmentation, identification, eventual dimension measurements, classification, and object counting are performed. For the real-time evaluation, performed during the inbound and outbound inspections, to be feasible, an entire preliminary step of creating an image library/dataset containing thousands of images and training of the networks responsible for object recognition and classification is necessary.

Challenges in that area are widely reported in the literature, and it is known that it is necessary to use a very large amount of labeled data, which is not always available and/or affordable (Rouwenhorst *et al.*, 1999*;* Smith, Smith and Hansen, 2021). Thus, the use of an automatic annotation technique, as reported by Singh *et al*. (2018), plays a very crucial role for effective recognition of object category or instances.

The counting methodology for updating the quantities of each product in stock is based on a correlation between the input and output records of the products, that is, weight and image identification from both the inbound and outbound gates. Under expected operating conditions, the system can correctly identify products at the inbound and outbound gates and, via system integration, keep the ERP registry updated in real-time.

Kembro, Danielsson and Smaili (2017) report, in a similar fashion, that network video technology could be used to monitor events in real-time analyses by artificial intelligence (AI), facilitating the integration with other technologies, such as ERP and WMS.

3.4 Expected results

The initial proposal, outlined based on the gaps observed in the utility's process, was evaluated and approved by the client in the scope of a 36-month research and development project, and work is already underway. The results described here are based both on early advances and forecasts.

Material and equipment specification activities have been completed, and part of the purchases has been carried out. Preliminary tests related to computer vision tasks were developed in the laboratory, with the creation of experimental image datasets, network training for accuracy evaluation, and selection of the most appropriate techniques and algorithms for the warehouse context. Object identification tests, based on a reduced sample of objects, showed promising results.

The assembly of the portals in the warehouse facility, in the last quarter of 2021, and their integration with the company's ERP system will allow the acquisition of images under real operating conditions. Challenges inherent to the local environment will enable the proper adjustment of lighting conditions, focal length (camera positioning), and any instructions for an optimized physical arrangement of products on pallets as they pass through the portals.

Once the development stage is complete, a long period of operational testing, with the portals already exchanging information via communication with SAP, will identify the level of reliability and indicate any needs for refinements in the system.

At the end of the project, since the technological product installed in the warehouse operates successfully, direct and indirect operational and financial gains are expected for the warehouse and the company. The system will enable the redirection of manpower to other activities since it will automate a large part of the process, which is currently performed manually. Consequently, an improvement in the accuracy of the item flow records is expected, since errors caused by human factors will be minimized within the process.

Indirect gains will result from the improved accuracy of real-time records. The traditional inventory process, which usually happens at least once a year and requires the interruption of the warehousing services for up to 15 days, might be performed initially to verify the assertiveness of the new system, but, in the long run, could be completely extinguished.

Overall, an improvement is expected in terms of reliability in the indicators of the department, better response time for internal and external customers, and, consequently, financial savings.

Finally, the success of the project might pave the way for the implementation of computer vision and artificial intelligence technologies in other areas of the company.

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