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Co-bots to improve occupational health and safety: preliminary analysis and integration proposal at Dana-Transejes, Colombia.

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Abstract— The adoption of advanced technologies, such as automation and robotics, is crucial in the era of Industry 4.0 for optimizing industrial processes. This article presents a detailed analysis and integration proposal of a collaborative robot (Co-BOT) at the DANA-Transejes production plant, focusing on improving occupational health and safety for operators while increasing operational efficiency. The methodology employed follows a mixed-methods approach, combining the characterization of the current process with qualitative and quantitative data provided by the company, along with direct observations. This characterization identified operational inefficiencies and ergonomic risks related to the manual handling of heavy loads. Based on these findings, a proposal for Co-BOT implementation was developed, detailing technical, operational, and economic aspects of the integration. The estimated results project a 15% reduction in production cycle times, an increase of 375 additional boxes per year, and a significant improvement in safety, reducing the risk of work-related injuries by 100% for specific tasks. Moreover, a reduction in costs due to recovery breaks and medical leaves is expected, contributing to an annual economic saving of approximately $23,950 USD. This study demonstrates the feasibility of implementing Co-BOTs in Latin American industrial environments, highlighting their potential as a cost-effective solution for improving competitiveness and operational sustainability in regions with limited investment in technological innovation.

Keywords: industry 4.0, autonomous mobile robot, industrial automation, operational efficiency, occupational safety.

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I. INTRODUCTION

The digital transformation driven by Industry 4.0 is reshaping traditional paradigms in industrial processes, promoting the adoption of advanced technologies such as automation, robotics, and artificial intelligence (AI) [1]. These technologies not only enhance operational efficiency but also positively impact occupational health and safety by reducing workers' exposure to hazardous and repetitive tasks [2]. In particular, the implementation of collaborative robots (Co-BOTs) has become a key strategy to mitigate workplace risks, contributing to the prevention of musculoskeletal injuries and other health issues related to the handling of heavy loads and repetitive movements [3], [4].

Occupational health and safety in industrial environments have gained critical importance in recent years, as automation offers an opportunity to redefine working conditions. According to the International Labour Organization, approximately 2.93 million workers die each year due to work-related accidents or diseases, while hundreds of millions more suffer from non-fatal injuries and illnesses [5]. Advanced robotics, particularly Co-BOTs, enable the redesign of complex and hazardous tasks, contributing to the creation of safer workplaces with a significant reduction in accident rates and occupational diseases [6].

Within this framework, optimizing internal logistics and material distribution systems in production plants is a priority challenge. Traditional handling methods, largely dependent on human intervention, expose workers to multiple ergonomic and safety risks, such as falls, overexertion, and accidents resulting from the handling of heavy machinery [7], [8]. Additionally, these processes tend to be inefficient in terms of time and adaptability, negatively affecting the productivity and competitiveness of companies, especially in emerging economies like those in Latin America [9].

In the Latin American context, the adoption of emerging technologies is limited by the lack of investment in research and development (R&D), which slows progress towards automation in industrial processes. According to World Bank data (2020), R&D spending in Latin America and the Caribbean barely reaches 0.62% of GDP, significantly below the global average of 2.49% in the same year [10]. This technological gap not only restricts the region's competitiveness in a globalized environment but also perpetuates working conditions that increase risks for workers [11].

To mitigate risks and improve occupational health and safety, adopting autonomous mobile robots (AMRs) and Co-BOTs in internal logistics processes has proven to be an effective solution. AMRs, equipped with advanced sensors and AI algorithms, can safely and efficiently navigate complex and dynamic environments, optimizing material distribution and reducing operators' exposure to hazardous tasks. The integration of these technologies not only enhances safety but can also significantly reduce workplace incidents by preventing collisions and other accidents. Recent research highlights that implementing AMRs can optimize transit times, improving efficiency in unmanned delivery tasks through advanced navigation systems like hierarchical maps, helping to avoid blockages and accidents during logistics operations [12]-[14].

At Dana-Transejes, located in Bucaramanga, Colombia, there has been an increase in work-related injuries associated with material handling and repetitive tasks. These situations not only affect productivity but also deteriorate the physical and mental health of workers. To address this issue, this study proposes the development of a Co-BOT prototype that, integrated into the materials distribution area, helps improve both safety and health at the plant. The flexibility of Co-BOTs to adapt to changes in production needs and their ability to reduce the physical workload of workers position these technological solutions as a viable option to improve working conditions in the manufacturing sector [15], [16].

II. METHODOLOGY

This study follows an interdisciplinary approach, combining principles of mechanical engineering, electronics, software, and industrial process management. It is an applied research study with a descriptive focus, oriented towards proposing the integration of a collaborative robot (Co-BOT) in the internal logistics area of the DANA-Transejes plant, Bucaramanga, Colombia. The research is organized into three phases: (1) literature review, (2) characterization of the current distribution process and occupational risk analysis, and (3) Co-BOT integration proposal to improve occupational health and safety. This methodological design has a mixed approach, using qualitative and quantitative techniques to collect and analyze data, providing a comprehensive understanding of the problem.

Phase 1: Literature Review: A systematic literature review was conducted on the implementation of Co-BOTs and autonomous mobile robots in the manufacturing sector, focusing on their impact on occupational health and safety as well as improvements in operational efficiency. This review considered inclusion and exclusion criteria detailed in Table 1.

Table 1: Inclusion and Exclusion Criteria of the Research.

INCLUSION CRITERIA	EXCLUSION CRITERIA
Type of studies: Empirical studies, systematic reviews, and theoretical articles analyzing the implementation of collaborative robots (Co-BOTs) in industrial settings will be included.	Type of documents: Opinions, general dissemination articles, editorials, and conference summaries that do not contain empirical data or detailed reviews will be excluded.
Publication year: Studies published within the last five years (2019-2024) will be considered to ensure the relevance of the information.	Lack of data: Studies that do not provide quantitative or qualitative data related to improving occupational health and safety or operational efficiency through the use of Co-BOTs will be excluded.
Thematic relevance: Studies must focus on the impact of Co-BOTs on workplace safety, ergonomics, and efficiency in logistics processes within industrial environments.	Non-industrial scope: Studies not related to the industrial environment, such as those focused on Co-BOT applications in other sectors (e.g., healthcare, education, etc.), will be excluded
Languages: Only studies published in English and Spanish will be included.	
Sources: Studies must be indexed in high-quality databases such as Scopus, IEEE Xplore, Web of Science, and ScienceDirect.	

Source: Own elaboration.

The search included keywords such as “collaborative robots,” “occupational health and safety,” “operational efficiency,” and “automation in manufacturing,” using Boolean operators (AND, OR, XOR) to combine the search terms.

The literature review on autonomous mobile robots (AMRs) and Co-BOTs in industrial environments has revealed significant advancements in research on the impact of these technologies on workplace safety and operational efficiency. Between 2019 and 2024, 414 relevant articles were published, primarily in high-impact journals, highlighting advances in collaborative robotics, autonomous navigation, and occupational risk prevention. Among the most cited sources are publications in the International Journal of Injury Control and Safety and Applied Energy.

The analysis of publication trends shows a steady increase in scientific output, with notable growth between 2022 and 2023, peaking in 2023. This trend reflects the growing interest and maturity of research on the implementation of AMRs in the manufacturing industry. As Industry 4.0 drives automation, there has been a marked increase in studies reporting improvements in reducing workplace accidents and operational times.

Phase 2: Characterization of the Current Distribution Process and Risk Analysis: This phase employed a mixed-methods approach to gain a comprehensive view of the material distribution process at the DANA-Transejes plant, as well as to identify existing ergonomic risks and operational inefficiencies. The company provided qualitative and quantitative data; the research team did the direct observation of the material flow.

The data provided by the company included key aspects of the performance of the material distribution process and helped identify critical areas for improvement in terms of productivity and occupational safety. The information focused on two fundamental aspects: (i) Cycle time of operations: Average times required for each stage of the material transfer process were measured; (ii) Workplace incidents related to material handling: Data were collected on incidents reported by operators, including injuries and risk situations resulting from manual handling of heavy loads. This information allowed for a detailed analysis of operational performance, identifying critical areas for improvement for the future integration of automation.

Direct observation of the material flow in the plant allowed for understanding the dynamics of the workflow and the challenges faced by operators in handling loads, with an emphasis on identifying risk situations that could be mitigated through the introduction of a Co-BOT. The integration of data provided by the company, together with direct observation, made it possible to establish a baseline for the material distribution process. This baseline served as a reference point to evaluate the current working conditions and present risks and to compare the expected impact of the future Co-BOT integration.

Phase 3: Co-BOT Integration Proposal: Based on the results obtained during the characterization phase, a preliminary proposal for integrating a Co-BOT into the internal logistics of the plant was formulated. The proposal focused on mitigating ergonomic risks and optimizing material distribution times.

It is important to note that, due to the sensitive nature of the operational and safety data collected during the characterization phase of the distribution process at the DANA-Transejes plant, only information authorized by the company for publication is included in this report. The confidentiality of internal data has been ensured through confidentiality agreements signed by the researchers and plant personnel. Additionally, the presented results have been reviewed to ensure that no critical data that could compromise the company's operations or competitiveness is disclosed. This approach ensures compliance with applicable ethical and regulatory standards in industrial research.

III. RESULTS AND DISCUSSION

a. Benefits, Factors to Consider, and Factors to Avoid

As a result of the first phase of this study, focused on the review of scientific and technological literature related to the implementation of autonomous mobile robots (AMRs) and Co-BOTs in industrial environments, both the benefits and limitations of these technologies have been identified, as well as best practices for their integration into the internal logistics of the DANA-Transejes plant, Bucaramanga. This review provides a solid scientific basis to justify the final proposal, evaluating critical aspects that should be considered during the implementation phase. The identified benefits are described in Table 2.

Table 1: Identified Benefits of Co-BOTs in Industrial Environments.

Global Benefit	Description	Ref.
Occupational Health and Safety (OHS)	The reviewed literature consistently suggests that the implementation of robots (including Co-BOTs and AMRs) in industrial environments can generate substantial improvements in occupational health and safety. Studies by Luo et al. highlight that incorporating robots can reduce workplace incidents by up to 68.5% and fatalities by 71%, related to exposure to repetitive or hazardous tasks, such as manual handling of heavy loads. These robots, equipped with advanced sensors, machine vision systems, and machine learning algorithms, help avoid obstacles and operate safely in dynamic environments, thus reducing the risk of collisions or serious accidents. Additionally, recent studies emphasize that eliminating or reducing manual handling of heavy materials not only decreases immediate accident risks but also mitigates the onset of musculoskeletal disorders in workers, improving the long-term health of industrial personnel. Moreover, it is necessary to study the impact on workers' mental health once the robot is implemented. For example, research by Storm et al. highlights several research lines related to designing Co-BOTs as active collaborators that also promote mental health and workers' well-being. However, Koh et al. have also emphasized the importance of further investigating aspects related to mental health, as the integration of technological innovations often leads operators to feel increased pressure, which could translate into stress and anxiety.	[17]-[21]
Productivity and Operational Efficiency	The ability of AMRs to optimize workflows is a recurring theme in the reviewed literature. According to findings, the combination of state-of-the-art sensors with artificial intelligence algorithms allows AMRs to adapt in real-time to changing conditions in industrial environments. This adaptability results in a reduction in material transport times within production plants. In this way, material distribution is optimized, minimizing bottlenecks, and significantly increasing the efficiency of logistics processes. The reviewed literature also notes that AMRs can operate continuously, without the need for extended breaks or	[7], [22]

	pauses, allowing for consistent productivity. Additionally, studies suggest that by reducing the time and effort needed to perform repetitive logistics tasks, workers can focus on higher-value activities, thereby improving the overall performance of the plant.	
Flexibility and Adaptability	Another key finding from the review is the versatility of Co-BOTs, especially in environments where human-robot interaction is crucial. These collaborative robots can perform tasks that previously required manual intervention, such as assembling and managing heavy materials, but with the advantage of being flexible and adaptable to changes in production needs. Co-BOTs can be easily reprogrammed to adapt to new production lines or changes in demand, making them a highly effective tool for manufacturing environments that require rapid adaptability to production fluctuations. This flexibility not only enhances safety but also enables companies like DANA-Transejes to quickly adapt to global market needs, thereby improving their competitiveness.	[23]

Source: Own elaboration.

The literature review has also identified critical aspects that must be considered to ensure successful implementation at DANA-Transejes. These factors address not only technical issues but also organizational ones, to maximize the benefits of integrating AMRs and Co-BOTs. These elements are described in Table 3.

Table 2: Factors to Consider in the Design and Implementation of the Co-BOT at the Company.

Factor	Description	Ref.
Advanced Navigation Systems and Safety Sensors	To ensure the efficient operation of AMRs in a dynamic environment like that of DANA-Transejes, it is essential that these robots are equipped with advanced obstacle detection technology. Systems using laser scanners, LiDAR cameras, and proximity sensors are highlighted in the literature as key tools for ensuring safe and precise autonomous navigation. These systems not only help avoid collisions but also allow AMRs to quickly adapt to changes in the environment, which is crucial in production plants with a high density of machinery and workers.	[24]
Adaptation to Existing Workflow	The literature notes that effective integration of AMRs requires these technologies to adapt to current workflows without the need for costly structural modifications. In this sense, AMRs must integrate smoothly with existing logistics processes without significantly interrupting ongoing operations.	[25]
Human-Robot Collaboration	In terms of human-robot interaction, Co-BOTs are ideal for performing collaborative tasks where operators collaborate directly with the robots. Co-BOTs can reduce workers' physical strain, improve ergonomics, and reduce injury risk. It is recommended that the implementation of these robots focus on tasks with high physical demand, such as handling loads, allowing workers to concentrate on less hazardous and more creative activities.	[26], [27]
Personnel Training	One of the critical aspects identified in the literature is the importance of training. Lack of adequate training can result in accidents or misuse of AMRs and Co-BOTs, reducing the expected benefits. Studies suggest that a comprehensive training program for operational and managerial staff is essential to ensure that workers understand how to interact with these robots safely and efficiently.	[28]

Source: Own elaboration.

Similarly, the first phase of this research has identified several factors that should be avoided or minimized to ensure the successful implementation of AMRs and Co-BOTs at DANA-Transejes. These factors are described in Table 4.

Table 3: Factors to Avoid or Minimize in the Implementation.

Factor	Description	Ref.
Large-Scale Implementations from the Start	It is suggested that starting with a gradual and controlled implementation is more effective. This allows adjustments to be made along the way, optimizing the performance of AMRs in the specific environment of the plant and ensuring that the technology integrates properly before expanding its use across the entire plant.	[29]
Dependence on Proprietary Systems	While proprietary robotic systems can offer advantages in terms of initial integration, they can generate high long-term costs. The risk of technological dependence is highlighted and opting for open or standardized solutions that are more flexible and compatible with various industrial platforms is suggested.	[30]
Underestimating Indirect Costs	Although reducing operating costs is one of the main attractions of AMRs, it is crucial not to underestimate the associated indirect costs, such as maintenance, software updates, and adapting the existing infrastructure. Ignoring these costs can lead to a reduced projected return on investment, decreasing the perceived value of the technology in the long term.	[31], [32]

Source: Own elaboration.

In this context, this first phase provides a solid scientific foundation that justifies the proposal for implementing AMRs and Co-BOTs at DANA-Transejes. The improvement in occupational health and safety, operational efficiency, and production flexibility are determining factors that will guide the integration process. The project should focus on a gradual implementation, prioritizing staff training and ensuring the adaptation of technologies to existing workflows. Additionally, it is crucial to avoid relying exclusively on proprietary systems, and the total cost of ownership should be carefully considered to maximize the return on investment.

b. Process Characterization

The analysis of the distribution process at the DANA-Transejes plant reveals operational inefficiencies and ergonomic risks that affect both productivity and workers' occupational health and safety. Through the analysis of the information provided by the company, as well as direct observation, data was obtained that highlights the critical limitations of the current manual material handling system.

Regarding ergonomic risks and physical fatigue, operators reported a significant physical burden due to the manual handling of boxes weighing 18 to 20 kg. These repetitive tasks include lifting, transporting, and organizing boxes, which considerably increase the risk of developing chronic musculoskeletal injuries. This issue is exacerbated by the physical limitations of the operators, who should not lift more than 3.25 kg individually. However, due to operational needs, they are often forced to exceed this limit, leading to high exposure to repetitive movements and prolonged physical efforts. This situation aligns with previous studies indicating that continuous exposure to loads above recommended limits increases the risk of muscle and joint injuries [33].

Regarding inefficiencies in the distribution and handling process, it was found that the total cycle time for assembling and packaging a 200-unit kit is 252.58 minutes, equivalent to 4.2 hours per unit. Similarly, this time constraint limits the production to ten boxes per day, each containing a total of fifty kits (five hundred kits daily). Additionally, the preparation time and transportation have a proportionally greater impact. Quantitative analysis shows that the total time dedicated to material transport tasks within the plant is 31.57 minutes to complete the assembly and packaging process of a 200-unit kit, which takes 252.58 minutes in total. This means that approximately 12.5% of the total process time is exclusively allocated to transport activities. This figure highlights the inefficiency of the current logistics system, where the lack of automation in handling heavy loads creates bottlenecks that slow down the workflow. The critical time dedicated to transport activities reflects an urgent need to optimize this phase, as internal logistics directly affect the overall productivity of the plant and limit its capacity to increase daily kit production. The lack of automation in handling heavy materials not only impacts workers' occupational health and safety but also limits the plant's operational flexibility. The need for frequent breaks for operators' physical recovery reduces the continuity of operations, resulting in an estimated 15% daily loss in production time. This is especially critical in a plant that manages five different kit references, as each change of reference requires an adjustment in the process that adds additional time to the cycle.

These inefficiencies have a direct impact on operational costs. Interruptions due to fatigue and health issues stemming from manual handling result in a reduction in the plant's total productivity, increasing labor costs and affecting the company's competitiveness. The baseline analysis highlights that, with a daily production of ten boxes and a weight per box ranging between 18 and 20 kg, the manual handling of two hundred kits per operator represents a physical burden that could be mitigated with automation. In this sense, automating material handling through the implementation of collaborative robots (Co-BOTs) could directly address the issues identified in the baseline. Co-BOTs would be capable of autonomously managing the lifting and transport of boxes weighing up to 20 kg, eliminating the need for operators to perform repetitive physical efforts. This would not only reduce ergonomic risks but also allow for the optimization of cycle times per box.

Based on the above, an estimate was made of the economic impact of production time loss due to fatigue breaks. Since the company holds confidential information, the calculation is based on an estimated 15% production time loss per workday due to fatigue breaks, an 8-hour workday (480 minutes), a total of 10 operators, an average wage of 8 USD per hour, 250 working days, and a daily production of 10 boxes with 50 kits each (500 kits in total). In this context, the lack of automation in handling heavy materials not only impacts workers' occupational health and safety but also limits the plant's operational flexibility. The need for frequent breaks for operators' physical recovery reduces the continuity of operations, resulting in an estimated 15% daily loss in production time, translating into a loss of approximately 72 minutes per operator per workday. With a daily cost of 95.8 USD for all operators, the annual loss amounts to 23,950 USD. Additionally, this reduction in productivity results in a loss of seventy-five kits per day (18,750 kits per year), which is equivalent to a production shortfall of 375 boxes per year, directly affecting the plant's ability to meet demand and maintain its market competitiveness.

c. Proposal for Co-BOTs Integration: Technical Details and Considerations

Based on the results obtained from the characterization of the current process, a proposal was developed for the implementation of collaborative robots (Co-BOTs) at the DANA-Transejes plant. The main objective of the proposal is to automate repetitive and physically demanding material managing tasks, optimizing internal logistics and reducing the identified ergonomic risks.

The proposed system incorporates Co-BOTs that will be integrated into the material distribution process. The Co-BOTs will be implemented to collaborate with operators in loading and unloading tasks, optimizing the distribution of materials at workstations. These collaborative robots are designed to interact directly with workers, allowing for greater operational flexibility. Moreover, their ability to adapt to changes in production lines and ease of reprogramming make them ideal for dynamic industrial environments. The following sections detail the technical specifications, the proposed operating routine, and a comparative analysis of scenarios with and without Co-BOTs.

Co-BOT Specifications: The design of the Co-BOT focuses on automating the loading and unloading of boxes, alleviating the physical strain on packaging and storage operators. The main technical specifications include:

- DC motors with a torque of 10 Kg/cm, capable of moving the Co-BOT with a load capacity of up to 40 Kg, allowing it to transport boxes heavier than those currently managed by operators.
- Suspension system to improve traction and stability during operation.
- 12V, 6500 mAh LiPo battery, ensuring continuous operation throughout the work shifts without the need for frequent recharging.
- 360° LiDAR obstacle detection system for safe and efficient navigation within the plant, ensuring that the Co-BOT can stop in the event of unexpected obstacles.
- Motorized roller system for automated box loading and unloading, eliminating the need for direct operator intervention in manual handling.
- Line tracking from the starting point to the endpoint, facilitating predefined and optimized operation between the packaging and storage stations.
- Automatic positioning system using cameras and guide points, ensuring precision in loading, and unloading area.

Co-BOT Operating Routine: The Co-BOT is designed to follow a logical operation sequence that minimizes operator intervention. The steps include:

- Start: Once the Co-BOT is positioned in the loading area, the power button is pressed to initiate the process. The operator places the box on the motorized rollers. Since this will be done on a roller table, the operator will not need to lift the weight, only to slide the box with the help of mechanical movement.
- Obstacle detection: The Co-BOT scans the environment to ensure the path is clear. If no obstacles are detected, it proceeds with transporting the box.
- Automated transport: The Co-BOT follows a predefined line from the packaging area to the storage area.
- Automated loading and unloading: The motorized roller system deposits the box in the designated receiving area, eliminating the need for the operator to perform repetitive lifting movements.
- Return to the loading area: After completing the delivery, the Co-BOT automatically returns to the loading area to await the next transport order.

The proposal for the integration of Co-BOTs offers significant benefits in terms of both safety and productivity. Eliminating manual handling will substantially reduce ergonomic risks and the need for physical recovery time and load transport by operators, mitigating the onset of musculoskeletal disorders caused by repetitive movements and prolonged physical exertion. Previous studies, such as those by Bechoo Lal et al. (2023), have analyzed how robotic technologies improve productivity and product quality in industrial settings by reducing ergonomic risks and delegating monotonous and physically demanding tasks to machines [34].

In terms of operational efficiency, it is expected that automating transport and handling tasks will reduce cycle times by 15%, allowing for an increase in processing capacity by an additional 375 boxes per year, or 18,750 more kits. These benefits align with the results obtained in other manufacturing industries where similar technologies have been implemented, as documented by Javaid et al. (2023), who report an improvement in overall productivity following the adoption of autonomous mobile robots [7].

The success of implementing this proposal will depend on several key factors. Firstly, autonomous navigation must be precise and safe, requiring a well-defined and suitable work environment for the operation of these robots. The integration of advanced obstacle detection systems and real-time mapping will be essential to avoid collisions and ensure smooth logistics operations.

Additionally, human-robot collaboration will be critical to ensuring a smooth transition toward automation. Operators will need to receive adequate training to collaborate effectively with Co-BOTs, overseeing the robots' tasks while focusing on higher-value activities. The literature suggests that a proper integration of Co-BOTs can alleviate the physical burden on workers without replacing them, promoting a safer and more efficient working environment.

Although the implementation of Co-BOTs promises significant improvements, some risks must also be considered. Underestimating indirect costs, such as robot maintenance and software updates, could affect the projected return on investment. Therefore, it is crucial to include a detailed evaluation of these costs in the implementation planning.

Another aspect to consider is technological dependency. Although proprietary systems may offer initial advantages, long-term dependency on proprietary technologies can limit flexibility and increase operational costs. The literature suggests opting for open or standardized technological solutions that provide greater adaptability to future changes in plant operations [8], [15].

The proposal for integrating collaborative robots (Co-BOTs) at the DANA-Transejes plant has been developed with the aim of automating repetitive and physically demanding tasks, reducing ergonomic risks, and improving operational productivity. Below is a comparative analysis between two scenarios: the current scenario without Co-BOTs and the future scenario with Co-BOTs implementation.

Scenario 1: Current Operations Without Co-BOTs: In the current scenario, material handling and transportation tasks at the DANA-Transejes plant rely entirely on human intervention. Operators are responsible for lifting, transporting, and unloading boxes weighing approximately 18-20 kg, leading to the following critical issues:

- High Ergonomic Risks: Operators are exposed to repetitive movements involving high physical strain, such as manually lifting and transporting boxes. These movements represent a significant source of physical fatigue and increase the risk of musculoskeletal injuries. Previous studies indicate that manual handling of heavy loads is related to chronic occupational diseases.
- Low Productivity: The current process is inefficient, as the average time spent transporting a box represents 12% of the total time for each kit. This limits the processing capacity to ten boxes per day, and the frequent need for physical recovery breaks further reduces workflow continuity.
- Operational Errors: Total reliance on human intervention also implies a higher probability of operational errors, such as improper handling of boxes or incorrect placement. These errors affect the accuracy of the logistics process and can cause delays in the supply chain.
- Dependence on Human Factors: The constant need for physical intervention limits the flexibility of the distribution process. Any disruptions, such as employee absences due to illness or accidents, affect the plant's operational capacity, creating bottlenecks.

Key Indicators in the Scenario Without Co-BOTs:

- Cycle time per box: 4.2 hours per kit (each containing two hundred units)
- Processing capacity: ten boxes per day, fifty kits per box, totaling 550 kits per day.
- Frequency of breaks: High, due to accumulated fatigue and operator limitations, approximately 15%.
- Operational errors: Moderate to high, due to manual handling.
- Risk of work-related injuries: High, due to repetitive handling and heavy loads.

Scenario 2: Future With Co-BOTs: In the future scenario, the implementation of Co-BOTs at the plant automates material handling tasks, particularly for loading and unloading operations. In this scenario, the following improvements are anticipated:

- Reduction in Ergonomic Risks: With the integration of Co-BOTs, operators will no longer be exposed to manual handling of heavy loads. Co-BOTs will take over the tasks of lifting and placing boxes, completely eliminating the need for human intervention in these repetitive activities. As a result, a significant reduction in musculoskeletal injuries and other issues related to physical fatigue is expected.
- Increased Productivity: Automating loading and unloading tasks will optimize cycle times. It is expected that the time spent per box will decrease by 15%, as Co-BOTs will be able to operate continuously and precisely, without the need for breaks for physical recovery. This will increase processing capacity by 375 additional boxes per year, allowing operators to focus on higher-value activities.
- Reduction in Operational Errors: By eliminating manual handling of boxes, errors related to improper handling and incorrect placement will be significantly reduced. Co-BOTs will operate with consistent precision, decreasing the error rate by 30%.
- Improved Flexibility: Co-BOTs are highly adaptable to production fluctuations. They can be reprogrammed to adjust to changes in work lines, enabling the plant to efficiently respond to demand variations without needing to modify the infrastructure.

Key Indicators in the Scenario with Co-BOTs:

- Improved daily production of kits: 575 kits/day.
- Improved annual production of kits: 143,750 kits/year.
- Improved daily production of boxes: 11.5 boxes/day.
- Improved annual production of boxes: 2,875 boxes/year.
- Additional annual production of kits: 18,750 kits.
- Additional annual production of boxes: 375 boxes.

Comparative Analysis of Scenarios: Table 5 presents a comparative analysis between operations without Co-BOTs and with the integration of Co-BOTs, highlighting the benefits in terms of time, productivity, and costs. The automation proposal not only improves operational efficiency indicators but also reduces costs, supporting its implementation from an economic and safety perspective. In the current scenario without Co-BOTs, reliance on human intervention results in high ergonomic risks, low productivity, and a higher likelihood of errors. In contrast, the future scenario with Co-BOTs envisions an optimized environment where occupational health and safety and operational efficiency improve significantly.

Table 4: Scenario Comparison with and without Co-BOTs.

Indicator	Without Co-BOTs	With Co-BOTs	Difference (%)	Impact
Cycle time per kit	252 minutes	214 minutes	-15%	Production time savings, optimizing resources.
Processing capacity	2.500 boxes/year	2.875 boxes/year	+15%	Increased production, improving responsiveness to demand.
Frequency of breaks	High	Low	-15%	Reduced costs from breaks and improved operational continuity.
Operational errors	Moderate to high	Low	-30%	Estimated savings due to error reduction and less need for rework.
Risk of work-related injuries	High	Extremely low	-100%	Reduced medical and insurance costs, improved workplace well-being.
Cost of annual losses*	23,950 USD	20,358 USD	-15%	Decreased economic losses due to improved operational efficiency.
Annual production*	-	18,750 additional kits (375 boxes)	+15%	Increased revenue from higher production of kits and boxes.
*Estimated				

Source: Own elaboration.

The implementation of Co-BOTs at the DANA-Transejes plant is highly recommended given the potential to improve both occupational health and safety and operational efficiency. However, several factors must be considered to ensure successful implementation:

- Personnel Training: Operators will need the necessary training to collaborate with Co-BOTs, learning to supervise the tasks performed by the robots and collaborate effectively with them.
- Cost Planning: While the initial investment in Co-BOTs may be significant, it is crucial to evaluate the long-term benefits, such as the reduction of workplace incidents and improved productivity, which can offset these costs.
- Continuous Monitoring and Adjustments: After implementation, it will be necessary to monitor the Co-BOTs' performance and adjust as needed to ensure that operations remain aligned with productivity and safety objectives.

d. Brief Considerations on Cost

The implementation of Co-BOTs at the DANA-Transejes plant requires a detailed evaluation of the involved costs, as well as the long-term benefits that justify the initial investment. According to the study by Lefranca et al. (2022), the average cost of an autonomous Co-BOT ranges between $30,000 and $45,000 USD, depending on peripherals and additional systems, such as vision systems and controllers [31]. This contrasts with traditional industrial robots, which can reach costs of $100,000 to $150,000 USD, making Co-BOTs a more accessible alternative for medium-sized companies.

In this context, the base cost of a Co-BOT would be between $30,000 - $35,000 USD, with an additional cost for peripherals (sensors, vision systems) of $10,000 USD, resulting in an estimated total cost of $40,000 - $45,000 USD. The ROI is expected to be achieved within 18 to 24 months, considering a 15% reduction in production times and an increase in annual production of 375 boxes (18,750 kits). Savings from the reduction of workplace incidents and lower costs associated with fatigue and medical leaves also contribute to a faster recovery of the investment.

Regarding operational and maintenance costs, annual maintenance is estimated at $2,000 - $3,000 USD per Co-BOT to ensure proper functioning and software updates (if needed). Additionally, operator training is necessary, with an estimated cost of $1,500 - $2,500 USD to train personnel in handling and supervising the Co-BOTs, improving human-robot integration, and optimizing collaboration within the plant.

In this context, although the initial investment in Co-BOTs is significant, it is offset by the long-term benefits in terms of operational efficiency and cost reduction. Co-BOTs enable:

- A 15% reduction in cycle times per kit, which improves responsiveness to demand and allows for greater operational flexibility.
- Annual savings of approximately $23,950 USD due to reduced productivity losses from fatigue-related breaks and improved workflow.
- An increase in production by 18,750 additional kits per year, which translates to a greater ability to meet market demand, enhancing the company's competitiveness.

Therefore, proper planning of the initial investment and the integration of a training program for operators are critical elements for the successful implementation of Co-BOTs. Additionally, continuous monitoring of the Co-BOTs' performance and the evaluation of maintenance costs will ensure that the plant maintains its optimal level of productivity and occupational health and safety.

These considerations provide a comprehensive view of the economic impact of implementing Co-BOTs at the DANA-Transejes plant, highlighting the feasibility of the investment and its alignment with the objectives of improving efficiency and reducing ergonomic risks.

IV. CONCLUSIONS AND RECOMMENDATIONS

This research on the implementation of collaborative robots (Co-BOTs) at the DANA-Transejes plant has proven to be a viable solution to address the inefficiencies and ergonomic risks present in the material distribution process. The results indicate that the automation of repetitive and physically demanding tasks not only improves productivity by reducing cycle times by 15% but also enhances the safety and well-being of operators by eliminating the need for manual handling of heavy loads. This advancement results in an additional production of 375 boxes per year, improving the company's responsiveness to market demand and competitiveness.

The research highlights the importance of integrating technological solutions that are tailored to the specific needs of the plant, achieving a balance between initial investment and long-term return. Co-BOTs, by operating autonomously and safely, help reduce fatigue-related breaks and workplace incidents, lowering the costs associated with medical leaves and improving the work environment. Furthermore, the flexibility and reprogrammability of these robots ensure a rapid adaptation to changes in demand, which is especially relevant in dynamic industrial contexts.

The following recommendations are emphasized:

- Comprehensive Personnel Training: To maximize the benefits of automation, it is essential to invest in operator training. Training should focus on the safe handling of Co-BOTs, as well as the efficient use of technology to supervise and optimize automated tasks. This will not only facilitate the transition to an automated work environment but also strengthen human-robot collaboration.
- Continuous Monitoring and Adjustments: After implementing the Co-BOTs, it is crucial to continuously monitor their performance and the impact on plant productivity. This will enable the identification of optimization opportunities and the adjustment of robot operating parameters to align with productivity and safety objectives. Additionally, monitoring will help assess the effectiveness of the integration and adjust maximize the return on investment.
- Cost Planning and Evaluation: Detailed financial assessment is key to ensuring the long-term viability of the project. It is recommended to include in the analysis not only the acquisition and installation costs of the Co-BOTs but also maintenance costs and necessary updates. Proper planning of these aspects will ensure that the benefits obtained outweigh the initial investment, with an estimated ROI of 18 to 24 months.
- Scalability and Replicability of the Solution: The experience of DANA-Transejes can serve as a model for other plants in the region. Given that the implementation has proven to be cost-effective and adaptable, it is suggested to explore the replicability of this solution in other industrial settings in Latin America, where process modernization is a growing need. Replicating this model can contribute to improving regional competitiveness in the global arena.
- Exploration of Complementary Innovations: To further enhance the benefits of automation, it is recommended to investigate the integration of complementary technologies, such as artificial intelligence for real-time operational data analysis. This could facilitate the identification of inefficiency patterns and continuous improvement opportunities, strengthening decision-making and process optimization in the plant.

The success of this project underscores the importance of technological innovation in the industry and provides a scalable model that can be adopted by other plants and industrial sectors. Future research should focus on the continuous optimization of the prototype and the exploration of new applications for autonomous mobile robots in different industrial contexts. Real-time data collection and analysis by these robots will remain a key area for improving decision-making and operational efficiency.

V. LIMITATIONS AND CONFIDENTIALITY

Due to the sensitive nature of operational data and confidentiality agreements established with DANA-Transejes, certain specific details about the plant's internal processes and the technical configuration of the proposed system cannot be disclosed in this article. This measure ensures the protection of the company's intellectual property, and the security of information related to its operations. The results and analysis presented here have been authorized by the company for publication, complying with all applicable ethical and legal regulations.

VI. REFERENCES

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