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RESEARCH ARTICLE OPEN ACCESS

SYSTEM FOR ANALYSIS, SIMULATION AND IMPLEMENTATION OF IMPROVEMENTS IN THE AIR CONDITIONING MANUFACTURING PROCESS

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ABSTRACT

This work contains proposals for improvements in an assembly line of air conditioners in a factory located in the Industrial Pole of Manaus, in which the entire production process is described, as well as the presentation of its current plant. Factors that hinder the production process of the line were evaluated in order to promote improvements in the production capacity added to quality, efficiency and reduction of waste. To achieve the improvements, documentary records of the line made available by the company were used. In addition, simulation tools (Plant Simulation) were used to search for possible bottlenecks in order to correct them, as well as plan for future improvement points. In this, problems of quality, ergonomics, low quality, among other obstacles were identified. The project enabled solutions to improve processes that, consequently, will increase quality, efficiency and productivity. The advantage of the new layout is to obtain a new sustainable competitive advantage for the company. The model enables better training of employees in the use of automated tools. This is beneficial as employees will have access to product and process technologies that were previously restricted.

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INTRODUCTION

Since its birth in the 1950s in Japan, Lean Manufacturing (LM) has been defined in various ways by researchers and professionals. Many of these definitions refer to the LM as a complex socio-technical system composed of a combination of synergistic and mutually reinforcing practices where the technical and human aspects must be carefully integrated. Historically, mechanization – such as the use of timing mechanisms to trigger the pawl of a ratchet lever – has helped humans accomplish physically demanding tasks. Automation, however, goes beyond mechanization, as it reduces the need for human sensory and mental requirements, in addition to optimizing productivity (LAMB, 2015). The search for and implementation of more flexible, agile and lean production processes has currently encouraged the adoption of new corporate management practices (FERRO, 2006). Companies working with large-scale production have undergone major transformations in their economic and technological aspects. This whole process of adaptation takes place quickly and dynamically, requiring organizations to commit themselves to maintaining their production processes and quality systems. With this, companies seek more and more improvements in their processes, reducing costs, increasing productivity and improving product quality.

REVIEW OF LITERATURE

Industrial Automation: Automation and Robots have been present in the industrial environment for many years. The high demand for industrialized products has been growing every year, hence the need to invest in optimized processes in order to increase production at a lower cost. The advancement of new technologies (automation, robotics, artificial intelligence, big data, internet of things, cloud computing) has generated academic interest in the impact of automation in industry and its effect on productivity and the generation of new jobs (CAMINA). Regarding jobs, new studies show that, in the long term, we are not moving towards a general replacement of jobs, but towards a polarization of jobs, as the interaction between automation and employment not only generates a reallocation of tasks and displacement of occupations (particularly low-skilled workers in routine jobs), but also increasing human labor (especially skilled workers or new specializations within occupations), the creation of new professions is necessary to meet the demand for skilled professionals (FREY, 2017). In the last decadeinnovations of Industry 4.0 have attracted considerable interest from researchers in many fields of study, from engineering to management (PICCAROZZI, 2022). The advantages of Industry 4.0 include enhanced competitiveness and performance, improved versatility and resilience, and increased profitability. Industry 4.0

would also boost consumer service. Smart Factory technology is fascinating and thrilling; the advantages of Industry 4.0 should still be key to every conversation. This encompasses technology that enhances robotics, machine-to-machine connectivity, over-the-counter manufacturing and decision-making. The technologies of Industry 4.0 enable the manufacturer to achieve better, efficient products. In other terms, this can generate more and quicker while making the capital more cost-effective and reliable (MÜLLER, 2018). Industry 4.0 vision will render the devices interconnected and create a connection beyond the manufacturing plant walls. Data has become a modern asset for several businesses. Huge volumes of data from sensors and equipment have enormous importance. Investment in capacity building the most significant action (VRCHOTA, 2020). Industry 4.0 is the fourth industry revolution where technologies and automation are asserting themselves as major changes. Robotic process automation has numerous advantages in terms of automating organizational and business processes (RIBEIRO, 2021).

Industrial Processes: Manufacturing industry is the main pillar of national development, reflecting the level of science and technology of a country (JENNY, 2019). After World War II, the main issue for manufacturing industries was how to compete globally in terms of product quality and cost (LEVY, 2007). Production flow problems, decreased productivity and quality problems are not new; they have theirorigin of the industrial revolution and the mass production boom, where bottlenecks, downtime, line imbalances, standardization and training levels were constant in the companies (JIMENEZ, 2019). Soon industries had to implement automated techniques in their manufacturing processes, as well as improvements in control and planning (MARTIN, 1991). Industrial automation has become the main area of attention for professionals, managers and researchers due to its significant contribution to business performance, cost, customer satisfaction and profitability. All manufacturing industries seek to adopt and implement a set of automated manufacturing techniques to proactively identify and respond to necessary changes that can lead to continuous improvement in their manufacturing cycle (RACHWAL, 2011).

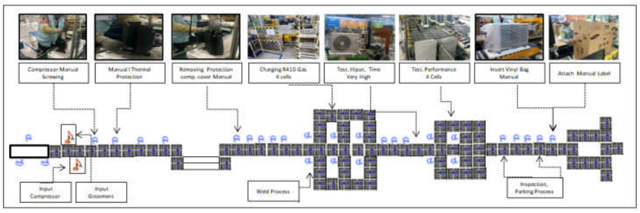
Manufacturing and Systems: In this article, an optimized manufacturing system based on a simulated system will be proposed, which is a new method for evaluating and optimization of the traditional production line. Using the basic Idea Layout change along with industrial automation, combined with Lean manufacturing mode, seeks to improve the traditional production line, this article tries to solve the main problems, such as irrational layout of air conditioner production line, unbalanced process capacity, inaccurate logistics and distribution, testing of unintelligent equipment. The proposed method is proven in the real model of Plant Simulation to improve the reliability of the improvement scheme, aiming to improve the efficiency of the production line in an integral way. The application of discrete-event simulation methodology in the analysis of high-level manufacturing systems has been limited due to the complexity of the model and the lack of aggregation techniques for manufacturing lines. Recent research has introducednew aggregation methods preparing for new approaches in the analysis of high-level manufacturing systems or networks (LAW, 1991). The process of simulating and modeling complete manufacturing plants containing different production systems and logistical processes is not an easy task, but when it becomes present, it has enormous potential to increase the efficiency of a company.

To maintain this efficiency, companies need to react faster to changes and make the best decisions with knowledge about the state of the current system, but also with knowledge about the future, considering new products and volumes. Simulation is a means of bridging the gap between what is currently known and the state to be achieved in order to fulfill future promises and goals (LAW, 1991). In manufacturing process simulation models, they are often the best way to represent manufacturing lines and answer detailed questions about line or process changes. However, executing complex and time-consuming detailed simulation models requires a large amount of data (PERSSON, 2002). It is worth noting that the simulation must contain the possibility of future changes, due to the constant advancement of new technologies.

Air Conditioning Prospects for the Future: Summer days are quite difficult to live in a house without ventilation, so most people opt for air conditioners at home, which consumes electricity, money and other resources (PRABHA, 2021). As global temperatures rise and incomes rise, air conditioner sales are set to increase dramatically (DAVIS, 2021). Sales of residential air conditioners have tripled since 1990 to nearly 100 million units a year. This means that every hour, more than 10,000 new conditioners from somewhere are sold somewhere else on the planet (INTERNATIONAL ENERGY AGENCY, 2018). Recent studies show the economic and environmental impacts of increased use of air conditioning. The benefits of using air conditioning are related to well-being, such as decreasing sweating and heat-related fatigue, increasing productivity and improving learning outcomes. But air conditioning also consumes a lot of electricity, so widespread adoption requires significant investments in electricity generation and transmission infrastructure and implies large increases in carbon dioxide emissions (WENZ *et al*., 2017). There are already solutions to minimize environmental impacts with INVERTER models, which reduce energy consumption and use non-polluting gas, research in the development of energy solutions is expected in the coming years. It is estimated that by 2050, air conditioning consumption in developing countries such as India, Argentina, Paraguay, Uruguay will reach up to 50% and in countries such as Italy and China this index will reach 75% of the population with air conditioning at home (DAVIS, 2021). The consumption of air conditioning and the increase in production planning, stimulate sales of development of ecological solutions and improvements in the manufacturing process, seeking to optimize the manufacturing process of increasingly ecological products.

MATERIALS AND METHODS

A documentary survey of the plant was carried out that allowed us to know the operational structures of the line as shown in Figure 1.



Source: Authors, (2021).

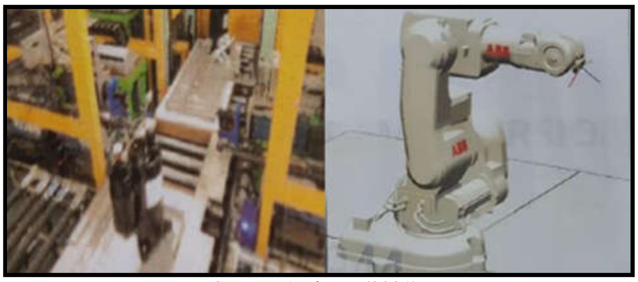
Figure 1. Estructure of operations

Line Presentation: Lean Manufacturing comprises the applicability of practices that aim to identify and eliminate waste in the production system, such as the incessant search for improvements in quality, cost reduction and greater flexibility (JUSTA, 2021). The production line where the project was developed is called the assembly line of the condenser unit – where the components produced in the subprocess sectors are assembled.

Data from the line: Line size: 74.6 m; Labour force: 31 operators; Production Time (tact time) sec: 20.4; Maximum production capacity: 1490; Quantity of automatic equipment: 01.

Problem Identification: Competition in the world market has made companies from various segments seek to increase their competitiveness using strategies that value attributes such as costs and quality (SHIMIZU, 2006). The current line layout and production process have a large amount of manual operations. This can make the production line susceptible to simple errors, generating risks for manufacturing operations, such as indefinite production time and labelling errors.Of the eight main catalogued processes, only one is made by automatic equipment, which is the HIPOT, but it is an equipment that over time had its performance reduced, causing quality problem, besides the many problems with the braking system.The layout also presents problematic ergometric points that limit the flexibility between the arrangement of different objects, installations and equipment (sensors, mats, hipot).

Choice Of Equipment For Improvements



Source: Authors, (2021).

Figure 2. Abb automated equipment and robots

The arrangement of this equipment proposes a flexibility between the installations, the operators and objects. Production capacity is 2.41 times greater than a human operator. The use of Automation Industrial by machines tocomplete complex tasks, reduce costs and improve the quality of goods and services is the core principle of smartfactories and industry 4.0 (BAHRIN, 2016). The use of Automation Industrial makes the manufacturing industry smartand capable of addressing modern challenges like customizable requirements, reduced time to reach the market andincreasing number of sensors used in equipment (ZHENG, 2018). The use of flexible robots combined with AI allows for easiermanufacturing of different products. AI methods are capable of analyzing large volumes of realtime data gathered from various sensors (USTUNDAG, 2017).

Modelling And Simulation Of Improvements: Facing an increasing demand for flexible and reconfigurable production lines, the development and implementation of extensive simulation tools for faster planning of robot cells or entire production lines continue to gain importance. Simulation tools offer the opportunity to test robotic applications before the physical existence of the system, to ensure reachability and feasibility of the actual cell implementation and examine compliance with the desired cycle time during process execution. During simulation analysis, extracting data from the given layout and building the corresponding simulation model takes a considerable amount of time (LAEMMLE, 2019).

We use the computational tool called Plant Simulation – used to model the new layout with the times of each workstation. In this, one looks for possible bottlenecks points in order to correct them, as well as to plan points for future improvements.In the models and simulations carried out through the Plant Simulation it was possible to calculate the production time (tact time) and the total efficiency of the workstations.The balancing tries to categorize the work equally for all workstations in order to have minimal number of resources in an assembly line without affecting its productivity nature (TSENG, 2008).

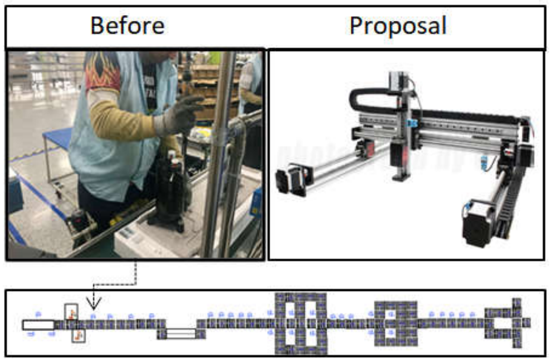
Calculation Of Production Capacity: The following formulae were used to calculate production capacity:

$$\text{Production per operator/day} = \frac{\text{Maximum production capacity of the line/day}}{\text{Workforce}} \qquad (1)$$

PROJECT AND DEVELOPMENT

Structural And Productive Description Of The Line – Condensing Unit: Structurally, the condenser unit's production line is 74.6 meters. The machines are connected to the mats, positioned side by side on a large scale and with a low variety of products. The line is dedicated to the assembly of the condenser unit of air conditioners and currently has 31 qualified operators who perform the work at fixed points. The maximum production capacity of the plant is around 1490 units per day.The production process of the line is structured in twenty operations, and these operations are composed in eight main work stations. Of which: 1) Fixed (manual compressor fastener); 2) Felt Comp (manual thermal blanket insertion); 3) Comp Cap (manual compressor cover removal); 4) Hipot (Automatic); 5) Layout charging Gás (R410 gas load control); 6) Performace Test (manual performance test); 7) Auto Insert Bag (insert of bag or protective plastic); and,8) Label (labeling).Each process, with the exception of Hipot (High Potential), is done manually by the operator. The line has a tact time or production time of 20.4 seconds.The improvement proposal encompasses changes in the manual operations points to automated. Thus, a new safety test design is presented that would replace manual processes with automated operations (Lcia) and the use of robots, as well as other structural changes.Labour substitution from automation and robotics is increasing in a wide range of modern mining processes. Such labour replacement is likely to intensify in the coming years due to advances and cost reductions in technology. Additionally, the COVID-19 pandemic also adds to the impetus of relying less on human interaction for critical operational processes (PAREDES, 2021).

Compressor Fixer – Comp Fixed

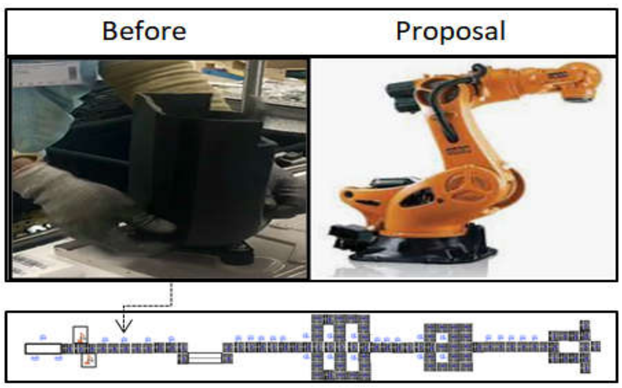


Source: Authors, (2021).

Figure 3. Manual and automatic compressor attachment

The compressor attachment to the chassis is done manually by the operator, using a vertical pneumatic wheel. The operator positions the compressor on the chassis by fixing it with three screws with torque 150-300 kgf/cm^3.The improvement proposal for the procedure described above is to optimize the process, that is, to carry out the fixing automatically by means of automatic test equipment (Lcia). In this, the compressor fixation will be made by two Companionworker coupled to cylinders that work together with the touch control simultaneously.

Thermal Blanket Insertion – Felt Camp

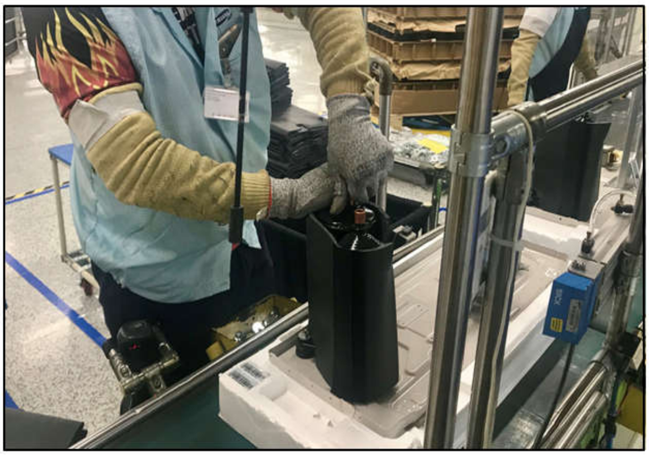


Source: Authors, (2021).

Figure 4. Manual and automatic insertion of the thermal blanket

The objective of the thermal blanket is to dissipate the heat. It has the flame retardant function in an eventual overheating. The current thermal blanket insertion procedure is done manually by the operator. The improvement proposal is to automate this process, in which the blanket will be inserted automatically through a robot. Once the process is automated, the insertion time of the blanket will be reduced.

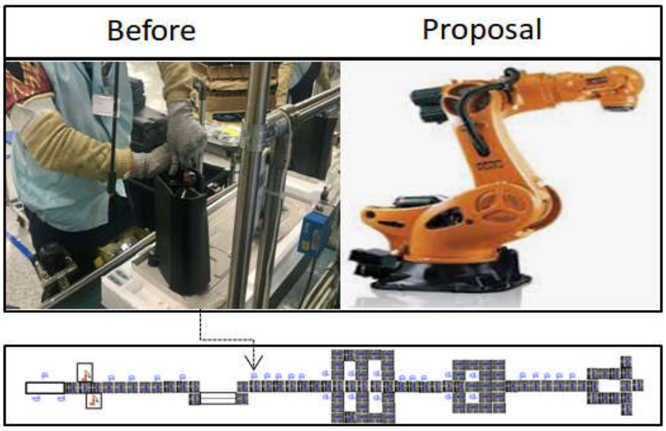
Removal of the Compressor Protective Cover – Comp Cap



Source: Authors, (2021).

Figure 5. Manual and automatic removal of the protective cover

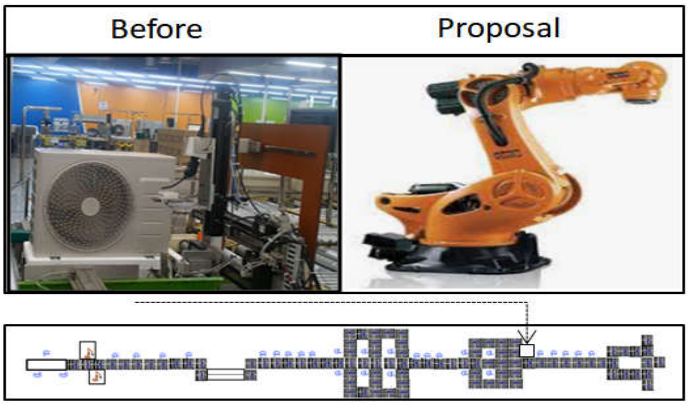
Removal of compressor protection is done manually by the operator. This protection prevents the compressor from contaminating itself with impurities before being used in the final process. Each compressor contains two covers, which are pressurized under vacuum. For this workplace, constant monitoring is necessary, as it is a post with a considerable incidence of removal due to repetitive movements performed by the operator. So the proposal for improvement is to automate this process. It is proposed to perform the removal of the compressor protection through a KUKA robot. This change will bring agility to the process, as well as cost reduction and reduction of sick leave due to occupational diseases from repetitive actions. For better flexibility between equipment, objects and operators, it becomes necessary to add another 1.3 m belt between the removal of the compressor protection and the welding area, thus completing eight belts as shown in the ilustration below.



Source: Authors, (2021).

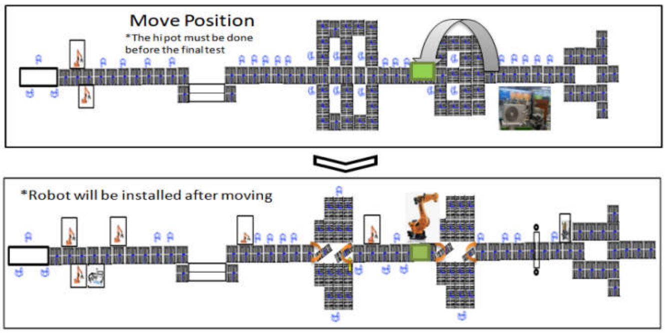
Figure 6. Withdrawal area compressor protection and welding área

Hipot: The HIPOT – which allows the test of dielectric stiffness or withstandable voltage is operated by an electropneumatic equipment (Lcia), but the equipment is old and over time had its performance reduced, besides having a high rate of stops for maintenance. Today its 19-second cycle time would not meet an increase in production demand. Therefore, it is proposed to change the operation of the test using a robot. This change will speed up the process as it will increase the precision of the movements, make the test more reliable and reduce the amount of false defects and braking problems. In the area between Hipot and mats that take air conditioners to the performance testing sector, it is proposed to reduce the sizes of the mats from 1.5 m to 1.3 m, in addition to adding three more conveyor belts in the area. This will bring better fluidity in transport and processes between equipment and operators. See the illustration below.



Source: Authors, (2021).

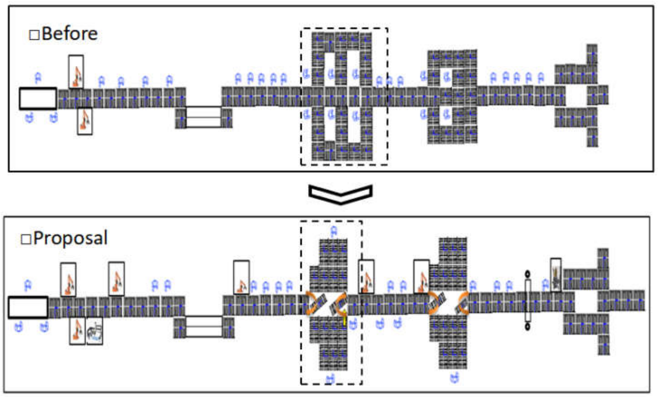
Figure 7. Hipot operated by automatic and robot equipment



Source: Authors, (2021).

Figure 8. Area between hipot and performance test.

R410 Gas Control – Control Box

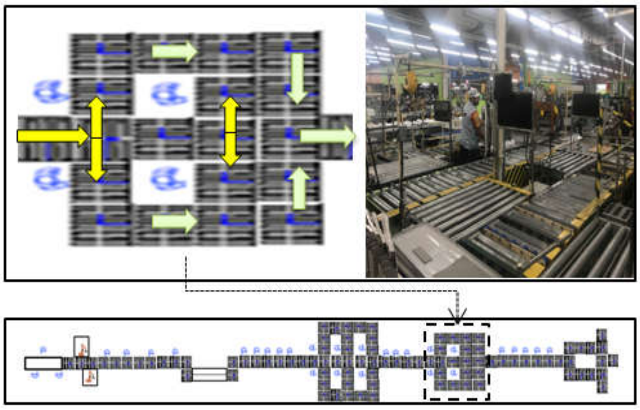


Source: Authors, (2021).

Figure 9. Gas control with 4 operators and 2 operators

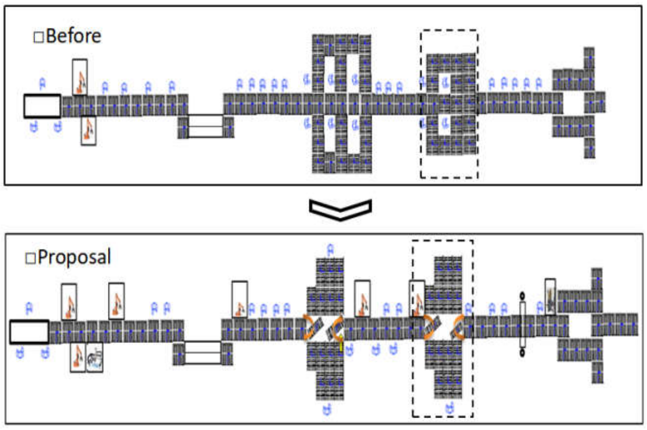
Currently the process is done with four operators inside the working cells making the injection of refrigerant gas R410. Operators use a pneumatic gun where they control the flow of gas.For this workstation it is proposed a reformulation of the refrigerant gas R410 injection cells to give fluidity to the process, as well as reduction of the number of operators and addition of another conveyor belt in the assembly area. Thus, the process will be done with only two operators that will be outside the cells (1 operator makes the assembly and the other makes the control).

Performance Test – Performace Test: The functional or performance testing sector of the apparatuses is operated by 4 operators inside the cells, as shown in Figure 10. The proposal is to reformulate the cells in the sector and reduce the number of operators. The idea is to bring more fluidity to the process with the reduction of bottlenecks as shown in Figure 11.



Source: Authors, (2021).

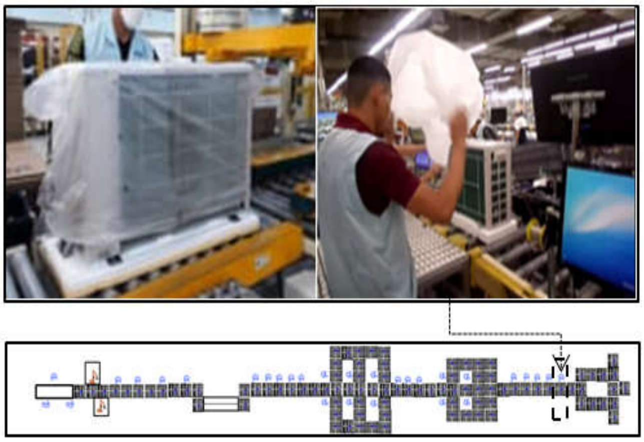
Figure 10. Performance test with 4 operators



Source: Authors, (2021).

Figure 11. Performance test with 2 operators

As in the area between Hipot and mats that take air conditioners to the performance testing sector, the belt size is reduced from 1.5 m to 1.3 m. Thus, we have a reduction in this area from 6 m to 5.2 m.

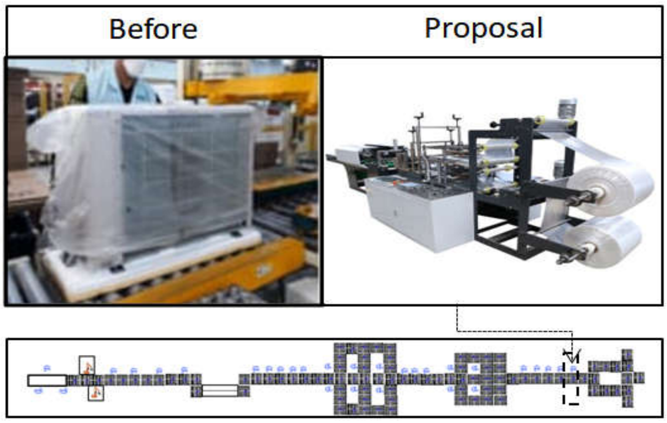


Source: Authors, (2021).

Figure 12. Manual insertion of the protective bag

Protective Bag Insertion – Auto Inser Bag: The insertion of the bag or protective plastic is done manually by the operator. The proposal is to replace this operator with an automatic equipment (Lcia) that will bring more speed to the process, as well as lower costs.

The area in which the automatic protective bag insertion equipment is located has also suffered a decrease in the size of the belts, before 1.5 m, now being 1.3 m. It is also necessary to add two more belts for better process fluidity.



Source: Authors, (2021).

Figure 13. Insertion area of the protection bag

Labelling – Label

Source: Authors, (2021).

Figure 14. Manual and automatic labelling

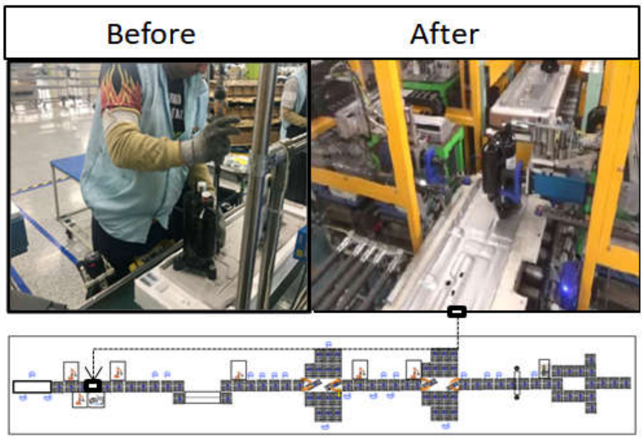
The operator labels manually. However, in order to reduce labelling errors, it is proposed to replace the operator with automatic equipment (Lcia). This change will reduce costs for the company.

RESULTS AND DISCUSSION

Workstations

Compressor fastener becomes automatic: compressor fastening by means of automatic equipment (Lcia). The compressor attachment is made by two roller couplings on cylinders that work together to the touch control simultaneously.

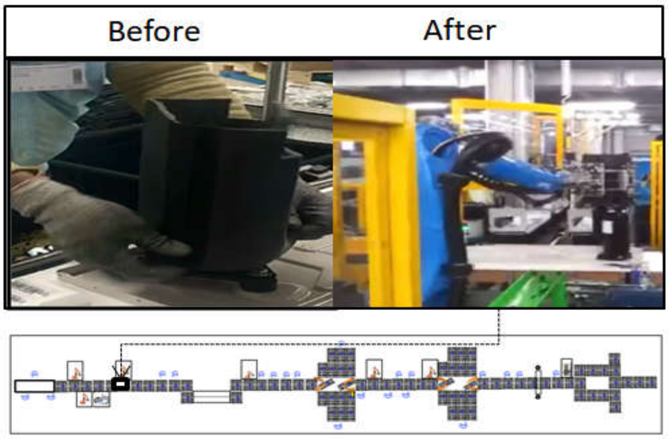
- Reallocation of the operator.



Source: Authors, (2021).

Figure 15. Compressor fastener

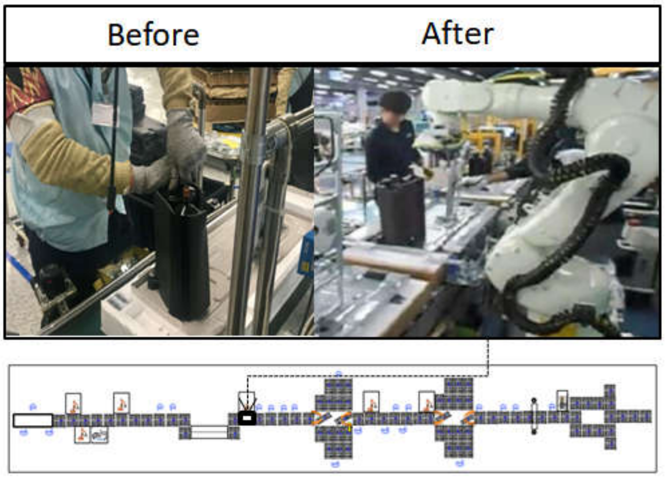
Insertion of the thermal blanket becomes automatic: the blanket is inserted automatically by means of a robot. The insertion time of the blanket is reduced. Reduction of 1 operator.



Source: Authors, (2021).

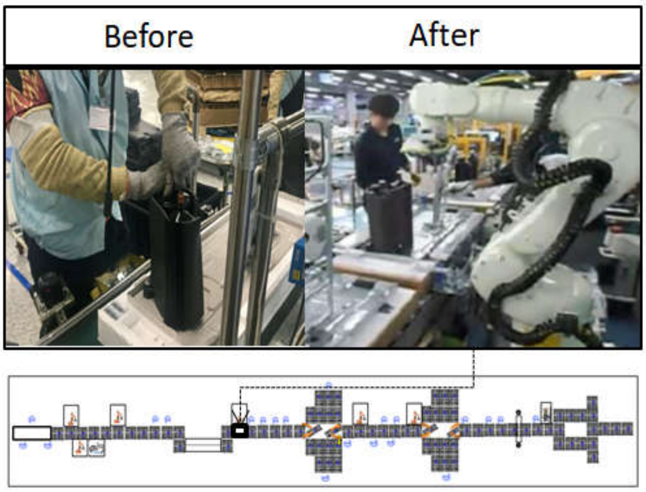
Figure 16. Insertion of the thermal blanket

Removal of the compressor protection becomes automatic: the removal of the compressor protection made by a ABB-branded robot brings agility to the process, as well as reduction of removal due to occupational diseases arising from repetitive actions.
Reduction of 1 operator.



Source: Authors, (2021).

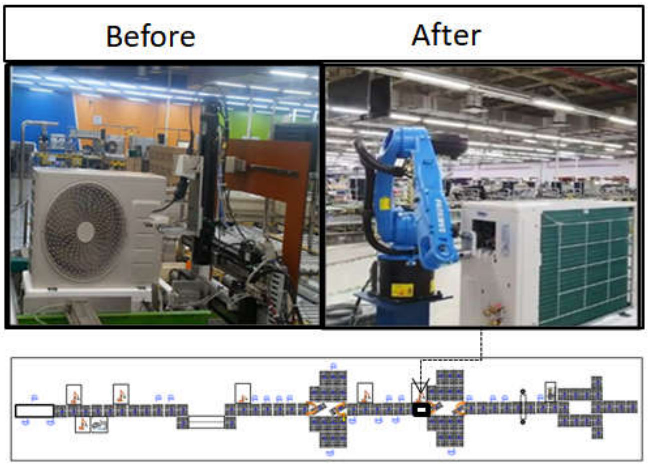
Figure 16. Insertion of the thermal blanket



Source: Authors, (2021).

Figure 17. Compressor protection removal

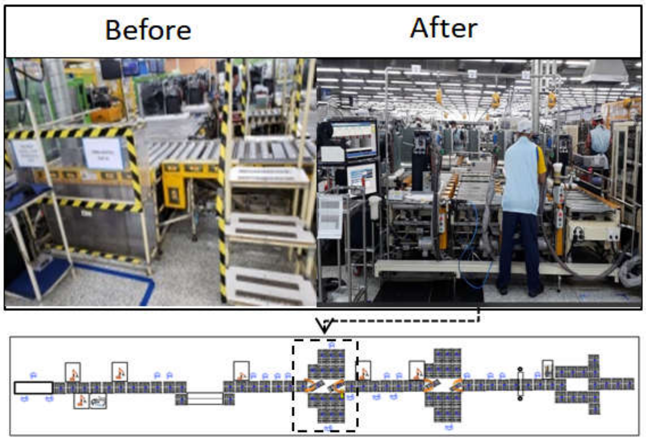
HIPOT is now operated by a robot: resulting in fast process and increased precision of movements, more reliable testing and reduction of false defects.



Source: Authors, (2021).

Figure 18. Hipot – Image of the author

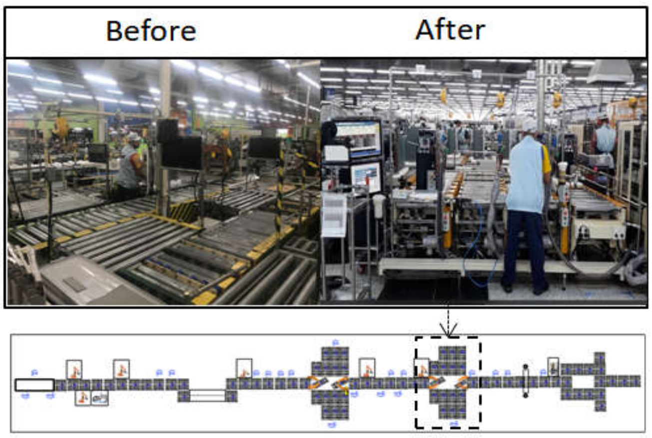
Gas control is now done with only 2 operators: the number of operators has been reduced. Now the process is only with two operators that stay out of the cells (one operator makes the assembly and the other makes the control). Another conveyor belt has also been added to the assembly area. Reduction of 2 operators.



Source: Authors, (2021).

Figure 19. Control of r410 gas

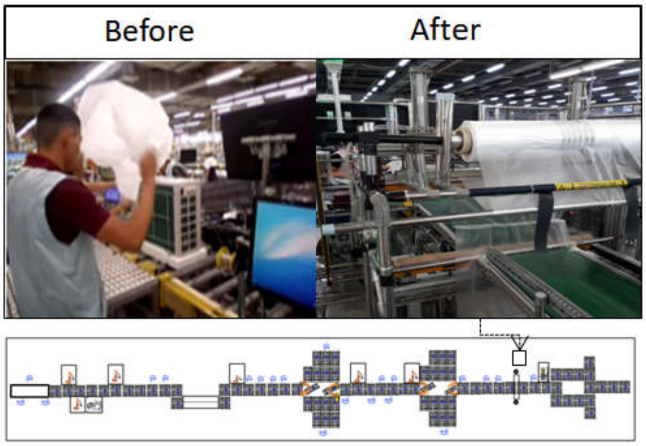
Performance testing is now done with 2 operators: the air conditioner performance testing industry now has only 2 operators outside the cells. Reduction of 2 operators.



Source: Authors, (2021).

Figure 20. Performance test

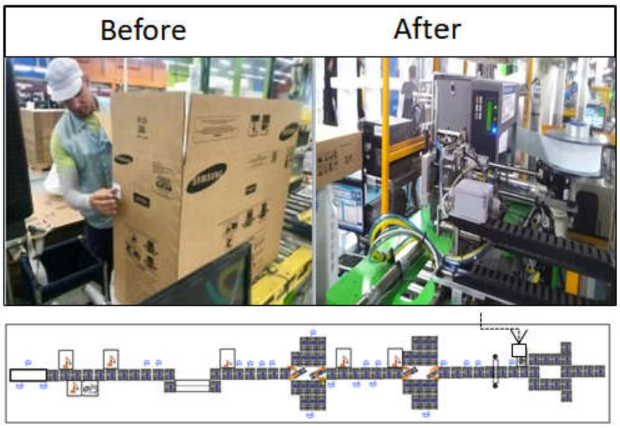
Insertion of the protective bag becomes automatic: the insertion of the protective bag or plastic is done by means of automatic equipment (Lcia). Reduction of 1 operator.



Source: Authors, (2021).

Figure 21. Insertion of the protective bag

Device labelling becomes automatic: product labelling passes and is made by an automatic equipment (Lcia). Reduction of 1 operator.



Source: Authors, (2021).

Figure 22. Labelling of the device

Total operators removed: 08.
Total automatic equipment inserted: 03
Total number of robots inserted: 03.

Line Size: The easing of installation arrangements between equipment, objects and operators (as in the case of reduction or relocation of operators in the area of gas control and performance testing)as well as the standardization and increase of conveyor belts and buffer implementation resulted in increased line size from 74.6 meters to 79.6 meters.

Production Capacity: Currently, the line produces about 1490 units of air conditioners per day, being operated by 31 operators. With the new layout, the line can produce 1800 units of air conditioners per day.

This daily production is made with 23 operators. To find this new production number we have the following calculations.

Data:

Previous line workforce: 31 operators
New line workforce: 23 operators
Maximum production capacity of the previous line: 1490
Number of machines and robots in the new line: 06

$$Production\ per\ operator = \frac{1490}{31} \quad (2)$$

$$Production\ per\ operator = 48\ unities$$

There was a reduction of 08 operators.

08 operators x 48 units = 384 units.

So, 1490 - 384 = 1,106 units

1,106 units is the daily production of 23 remaining operators.

Now, calculating the productivity of the machines we have:

Data:
A robot or equipment produces on average 2.41 times more than a human operator
Production per operator: 48 units

Thus,

$$Production\ per\ machine/day = 2{,}41X\ Production\ per\ operator$$

$$Production\ per\ machine/day = 2{,}41X\ 48\ units\ per\ operator$$

$$Production\ per \frac{machine}{day} = 115{,}7$$

Now, 1 robot produces 115.7 units per day. That is, 115 x 6 = 694.08.

Finally, we have the following result:

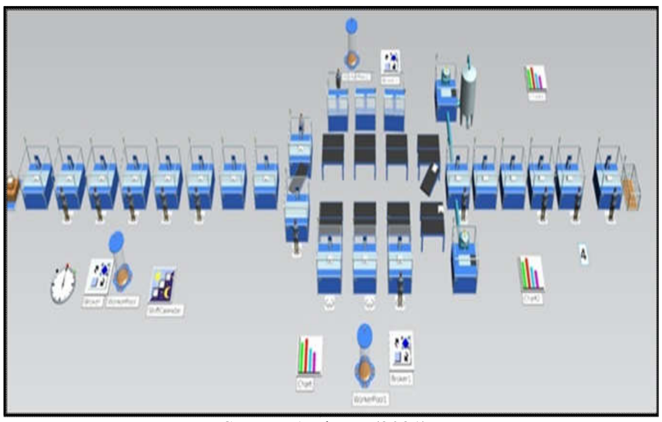
Total production of the new layout = *Production Mach + Production Op*
Total production of the new layout = *694,08 + 1.106*

Total production of the new layout = *1800*

06 robots producing 694.08 units per day + 1,106 units produced by the 23 operators. The new layout will produce approximately 1,800 units per day.

Production Time: The simulation is based on the balancing of process activities, aiming to achieve a tact time of 16.9 seconds, reduction of 3.5 seconds.

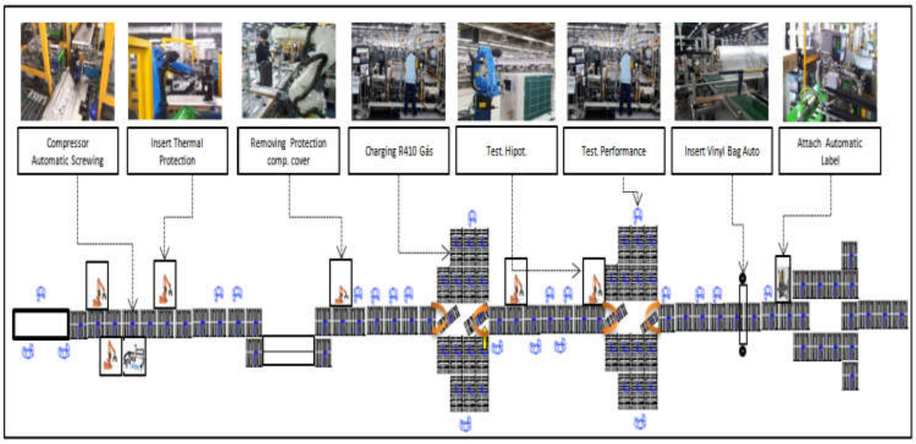
To achieve this time, there was a need to increase the amount of R410 gas injection cells, test performance and automation of the main gas stations, as well as create additional gas stations and conveyors to give fluidity to the process.



Source: Authors, (2021).

Figure 23. Simulation of the removal of the protective compressor cover until the assembly – Plant Simulation, 2021

The replacement of human labor by automation, at certain points of the production line, is seen as advantages for the company, as it



Source: Authors, (2021).

Figure 24. Updated plan

Line size: 79.6 m
Labour force: 23 operators
Production Time (tact time) Mon: 16.9
Maximum production capacity: 1800

Table 1. Data obtained in the simulation – Plant Simulation

Analyze productivity			Number of Operators			
Berofe	After	Diff	Before	After	Reduce	Total Cost.
1490 pcs	1800 pcs	310 pcs				
Tact time	T/T	Diff	31 op.	23 op.	8 op.	912k
20.4 sec	16,9 sec	21%				

Source: Authors, (2021).

Table 2. Data obtained in the simulation – Plant Simulation

Time Required for Full Process	Balance Loss Process	Process Efficiency	Neck Time
277,7 sec	8%	78,4	16,9 sec

Source: Authors, (2021).

reduces the production time from 20.4 seconds to 16.9 seconds (tact time); reduces labor costs and reduces errors in production processes, and proposes higher production volume and quality of processes and products.

Process Efficiency: With the refurbishment of the layout, an increase in daily production of 1490 units is expected to 1800 units of air conditioners, that is, 21% increase in productivity conforms to Table 1. There is also a completion time for each workstation in approximately 4.6 minutes with a total efficiency of 78.4% according to Table 2.

CONCLUSION

The legitimization of the proposals for improvement and application allows the generation of a diagnosis. Therefore, based on the results, the conclusive points of this work are the following:

- The realization of the project contributed to the learning of the author. This learning built with theoretical and practical bases, enable the effectiveness in the implementation of the new layout;
- The perceptions of before and after the application of the study become indispensable, since change is a prerequisite for organizational transformations to occur;
- The advantage of the new layout is to obtain a new sustainable competitive advantage for the company;
- The model enables better training of employees in the use of automated tools. This is beneficial as employees will have access to product and process technologies that were previously restricted;
- It will enable employee growth through participation, motivation, integration, initiative, creativity, discipline of new habits and better quality of life in the workplace.

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