UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

DMAIC aplicado a la industria de la construcción: Optimización de procesos para el ensamblaje de geo sintéticos.

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Ingeniería Industrial

Trabajo de fin de carrera presentado como requisito
para la obtención del título de
INGENIERO INDUSTRIAL

Quito, 20 de diciembre de 2022

UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

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HOJA DE CALIFICACIÓN
DE TRABAJO DE FIN DE CARRERA

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Quito, 20 de diciembre de 2022

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Lugar y fecha: Quito, 20 de diciembre de 2022

ACLARACIÓN PARA PUBLICACIÓN

UNPUBLISHED DOCUMENT

RESUMEN

En este estudio, con la aplicación de la metodología DMAIC a través de sus primeras fases de desarrollo, se identificaron y cuantificaron las principales problemáticas existentes que contribuían al problema central que involucraba demoras y fallos en la calidad de geo sintéticos distribuidos desde una empresa especializada en dichos productos hacia sus clientes. Una vez identificados y cuantificados dichas problemáticas, se procedió a la implementación de mejoras enfocadas en herramientas de control de producción, Lean, simulación y de diseño de plantas, atacando las problemáticas específicas y consiguiendo resultados positivos respecto a métricas clave como la efectividad de los equipos OEE y el tiempo de ciclo Takt Time, además de la mejora en la productividad diaria dentro de planta.

Palabras clave: Geosintéticos, takt time, OEE, efectividad, simulación, diseño de planta, producción, control.

ABSTRACT

In this study, with the application of the DMAIC methodology through its first phases of development, the main existing problems that contributed to the central problem involving delays and failures in the quality of geo-synthetics distributed from a company specialized in these products to its customers were identified and quantified. Once these problems were identified and quantified, we proceeded to implement improvements focused on production control, lean, simulation and plant design tools, attacking the specific problems and achieving positive results with respect to key metrics such as OEE equipment effectiveness and Takt Time cycle time, in addition to improving daily productivity within the plant.

Key words: Geo-synthetics, takt time, equipment, efectiveness, simulation, plant design, production, control.

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1. INTRODUCTION

The increase in soil contamination due to oil spills and the need to create solutions for shrimp companies have forced to generate long-term solutions that can prevent environmental impacts. One of the solutions currently used to reduce the environmental impact generated by industries such as those mentioned above is the installation of geo-synthetics as a soil protection mechanism both in industrial pools and oil wells.

Now, it is important to mention that Geo Synthetics installation companies tend to present problems throughout the processes that make up their value chain due to the high demand of such geo synthetics. This has a direct impact on the level of service and, therefore, on delivery times to the customer (Julca, 2015).

On the other hand, it is important to emphasize that the level of service at the time of producing Geo Synthetics is defined by the delivery times of installed Geo Synthetics, quality tests and the times of heat sealing of Geo Synthetics which are carried out in a planned warehouse (Mosqueira, 2014). Therefore, it was necessary to develop significant improvements for the entire value chain of the installation of the Geo Synthetics, including an organization of the warehouse with all its processes, for which Suarez (2015) suggests the application of DMAIC methodology as well as Lean Service in companies engaged in this area.

Jimenez (2017) argues that Lean principles suggest starting with the "specification of what creates value", identification of the value chain, constant flows, distribution of customer demand and customer delivery times as well as where the customer wants. It is important to note that Lean currently has more than 60 tools, among which one of the main tools is the Value Stream Map (VSM), which was developed by the automotive company Toyota. This map is presented visually and aims to show the process and possible improvements previously identified by it (Plasencia, 2013).

Because of everything previously mentioned, this study focuses on an Ecuadorian company dedicated to the assembly and installation of geo-synthetics. The group found that the services of assembly and installation of geo-synthetics have become some of the essential drivers for the care and preservation of the environment (Mosqueira, 2014) in the last 25 years. Now, it is worth mentioning that the level of service given by such companies is evidenced from the delivery times of the installed geo synthetic, heat sealing of the geo synthetic, quality tests and dispatch of the final product (López et al., 2015). That is why this study focuses on mitigating problems related to service level compliance and inadequate management of warehouse inventory which causes problems in heat seals and product dispatch. This results in losses for the company based on established fines of 1% of the contract value per day past contract time and 0.45 cents per heat seal failure.

Finally, it is important to mention that, as far this investigation has reached, there are no recorded studies or projects currently related to the implementation of lean methodologies in conjunction with inventory management meant to solve problems along the value chain of the production of geo synthetics such as Geo Membrane; therefore, this represents the unique contribution of our study and its contribution to future studies related to the production of this type of material.

2. LITERARY REVIEW

Thanks to modern views on environmental care, society has developed new materials made with components and technology which enable better overall control over contamination factors. HDPE, which stands for High Density Polyethylene Membranes, relates to this problem about environmental care. They act as a barrier between soil and hazardous liquids that could potentially pollute soil (Soto & Sacandi, 2017).

The high-density polyethylene (HDPE) Geo Synthetics respond precisely to the problem of environmental care, since they function as a waterproofing agent against external polluting agents which, if not contained by the Geo Synthetics, would present serious environmental pollution (Soto & Sacandi, 2017).

Technical, economic, and environmental advantage from geomembrane usage has helped replace common materials like clay lining or concrete; these materials are hazardous for the environment while not being cost effective (Soto, 2017).

However, the real problem does not lie in the use of the geomembrane as an innovative material in Ecuador, but in the lack of knowledge and lack of professionalism in quality control methods, production processes and inventory management that are applied at the time of marketing geosynthetics (Chavez & Andres, J. 2019). These, if they are not well defined, will represent a malfunction of civil works which triggers technical, quality and environmental problems. (Chavez & Andres, 2019).

According to (Ortiz & Tutivén, 2019), Lean service tools such as 5s greatly help to have a good warehouse management since they significantly improve the processes that take place within it, reducing downtime and eliminating bottlenecks. On the other hand, the use of the Kanban tool for the product reception and the inspection of tasks within the warehouse turns out to be most convenient since they do not require long execution time and give optimal results (Mantilla Calderon, J. M. 2021).

Similarly, to have good identification of the central problem, an Ishikawa or fishbone diagram was made. This tool helps to identify the current state of the process and in turn helps to show the improvements in each process previously identified (Plasencia, 2013). It should be noted that the analysis includes all the causes within each area, identified as problematic, that triggers the effect that represents the general problem (Cuatrecasas, 2010). It is also worth mentioning that these causes are previously determined from the use of an internal voice of the customer survey, which also includes a Pareto diagram that helps to identify 80% of the causes that involve all the problems (Gutiérrez Pulido et al., 2014).

Additionally, another fundamental point for improvement within the geomembrane production process is the adequate management and inventory control. Due to organizational constraints such as inaccurate demand forecasts, production times, and shipping security, all companies try to reduce total costs and improve supply-demand coordination through inventory. Compensation is reflected in the reduction of production and transportation costs, and in the availability of finished products. (Arango & Zapata, 2010)

Finally, it's worth mentioning that activities related to the storage of materials have the greatest impact on the total cost of logistics for a company or supply chain. One of the key steps in trying to reduce operating costs is to optimize the space required for storage (Mera & Zúñiga, 2016). Therefore, an efficient warehouse layout design is of utmost importance to have an agile and efficient production process (Arango & Zapata, 2010).

3. METHODOLOGY

The present study aims to focus on the problems that afflict the production and heat-sealing process in a company in charge of these processes for geosynthetic products, specifically, geomembranes. It is intended to address this problem with the use of Lean tools, applied throughout the DMAIC methodology. The previously mentioned production processes have a series of problems throughout their value chain, therefore, the application of the DMAIC methodology in this study is extremely useful throughout its 5 phases, which are: define, measure processes, analyze tasks, improve, and control the state of the general process. (Bustamante Mathews, A.A.T. 2019). DMAIC methodology was selected considering its approach, which is based on process improvement, reducing defects, and generating a drop in their variability rates. Additionally, it is important to mention that this methodology generally allows improving the efficiency and performance of the manufacturing companies in which it is applied, in this case a geomembrane marketing company. (De Mast & Lokkerbol, 2012). At the time of applying each stage of the DMAIC methodology, it is intended to identify and eliminate each factor that negatively affects the effective capacity of the process. Emphasis will be placed on a systematic organization of the warehouse, improvement, and standardization of production processes together with the recognition and elimination of processes that do not generate value (Ferreira et al., 2019).

To start the application of this methodology, the existing problems within the company are defined based on the documentation of information and the recognition and mapping of flows of the sub-processes that make up the general value chain. This documentation is carried out through the application of tools such as flow charts which allow identifying processes, inputs and outputs thereof, based on the characterization of key elements present throughout the value chain (Pereyra, 2018).

Next is the measurement phase, in which it is sought to collect data related to production time, delays, outputs and product inputs. From the collected data, tools are used in conjunction with key performance metrics, to recognize the current state of the process. An example of a useful tool in this case is provided in the study carried out by (Bustamante Mathews, A. A. T, 2019), in which the use of the mapping of the current state of the process (VSM) is determined as pertinent, precisely with the objective of visualizing and understanding the state of the process in a macro way. Similarly, to analyze the state of the production rate in relation to demand, the takt time metric is used as a key metric, which has the purpose of analyzing precisely this rate (Rifqi et al., 2021).

Next, the analyze phase begins. In this phase, the analysis of the results obtained for the key metrics calculated in the measure phase is carried out. The objective of the phase is to recognize the root causes that generate the problems that afflict the company. To establish these causes, the Ishikawa analysis is extremely useful (Manturano, 2017). Similarly, to recognize the elements and/or causes that generate the greatest variability within the effect generated in the production process, a Pareto diagram is used (Rifqi et al., 2021). In addition, it is used within this phase to analyze the degree of importance of each SKU based on the visual order of said characteristic. (Martinez & Sanchez, 2008)

Following the order proposed by the DMAIC methodology, the next stage is to implement. At this stage, the aim is to use several tools from the areas related to the Industrial Engineering career to achieve the objectives of the study. Initially, this stage will be supported using the 5`s, and the Poka Yokes. The general implementation plan is divided into 3 categories:

a. Order and better warehouse distribution: spaces, machinery, and inventory. This is where the 5's will be implemented, which, as María Manzaron Ramírez points out, are tools whose implementation is almost mandatory for small companies (Manzano, 2016).
b. Improvement in the rest of the standard manual processes within the production process: light equipment for basic manual use. To avoid mistakes that could lead to a lower quality level, Poka Yokes will be implemented in work systems that include light material or equipment. Poka Yoke is also known as the process that removes errors from any job with one or more operators (Tommelein, 2008).

It should be noted that all the tools used go hand in hand with correct production and inventory control practices because Lean is a methodology that works correctly when all areas of the company are brought together (Quintana, 2010). This includes not only the production and warehouse, but also inventory and forecasts.

4. RESULTS

4.1. Define

In the present phase, we sought to identify and better visualize the central problem existing within the company, for which we first quantified the problem considering economic aspects that imply losses for the company, as previously mentioned in the introductory section. In this way and through historical data, delays in production for product delivery, which also generate failures in the quality of the product, were determined as the central problem.

Based on this, we proceeded to define the existing processes within the production with a flow chart that was used as a tool which allowed a correct understanding of the different phases of the process and its operations (Manene, L., 2011), both for the assembly process of synthetic Geo Plastics and for the warehouse process that involves the storage and movement of the product, as shown in figure 1:

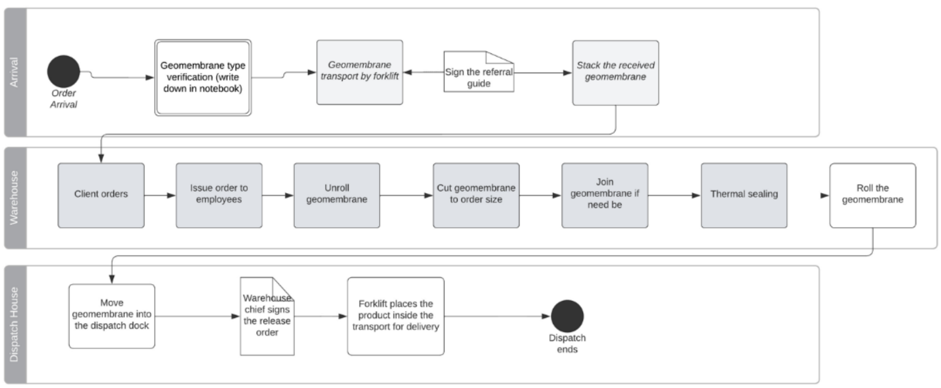

Figure 1: Production process flowchart.

Next, an added-value analysis was used to classify the activities carried out within the production process into value-adding and non-value-adding activities (Sundar et al., 2014). The focus at this point was to identify the activities that added value and that had problems related to processing time based on specific problems; these activities and problems were determined as shown in the table below:

Activity	**Observations**
Roll preparation	Non-hierarchical order
Machine calibration	Non standarized
Dispatch	Skipping of required processes
Quality control	Omission of faults

Table 1: Issues within crucial activities.

Finally, to complement everything mentioned above and to identify the problem in greater depth, a VOC survey was used, which is a very useful tool in quality aspects to know the customer's opinion (Gutiérrez Pulido et al., 2014) internally, i.e., the opinion of those who make up the company regarding the existing problems within the company. The results are shown in figure 2:

Figure 2: Results VOC.

At this point, it should be emphasized that the results presented in Figure 2 relate only to the aspects that, in percentage terms, were considered the most critical within the organization and that contribute to the central problem of production delays and quality failures.

4.2. Measure

In this phase, based on the aforementioned problems, we sought to measure the performance and capacity of the process at the time of initiating the study. For this purpose, data was collected on time. This data included finished products per shift and number of failures per product. It was collected, firstly, using historical data from the first three months of the last four years to avoid biases regarding the year 2020. Secondly, data was collected for a sample size of 367 square meters of geo-synthetics, this size was determined from the use of the sample size calculation formula with known population (Bustamante, 2019), presented in the Annex A section.

It is important to note that the known population was determined from the calculation of sales forecasts for the month of October 2022, based on historical annual sales data provided by the company. With this, the existence of a known population of 17042 square meters was determined, of which data were collected for 367 corresponding to the sample size from the use of simple random sampling in order to be statistically representative (Bustamante, 2019).

With the collected data, we proceeded to measure the capacity and performance of the process as previously mentioned, for this was of utmost importance the choice of key metrics to be applied in the study as these contributed to determine the situation in which the problem was, measuring these parameters allowed us to follow up through indicators that allowed us to later analyze the situation (Pérez, E. & García, M., 2014).

For the particular case of the established problem, the calculation of the OEE was considered, in order to measure the percentage of effectiveness (De Ron & Rooda, 2006) of the Twinny heat sealing machine. The calculation of this metric takes into account the multiplication of availability, efficiency and quality, metrics that were also computed from the use of the previously mentioned collected data. The formulas for each of the metrics are presented in the Annexes B C D E. The following results were obtained and showed in figure 3:

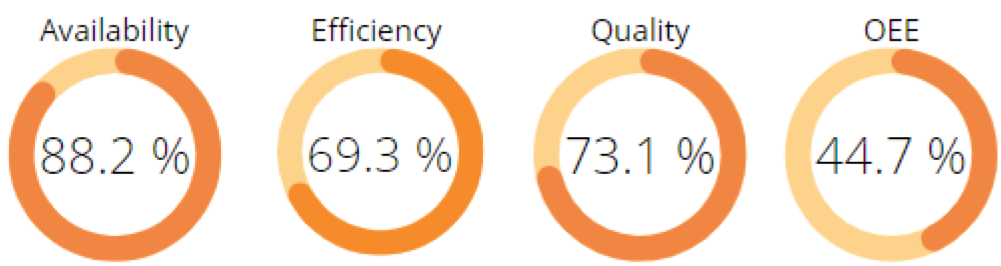

Figure 3: OEE Twinny results.

The results obtained indicated that there is an unacceptable value for equipment effectiveness that represents both delays and a high number of failures in the quality of the resulting product, which ultimately results in losses for the company, as it is less than 65% (De Ron & Rooda, 2006).

On the other hand, to understand the status of the process in relation to the expected production cycle, we proceeded to calculate the Takt Time, considering that this manages to synchronize the demand with the production rate (Monden, 2012). For this evaluation, we took into account the forecast of the monthly demand for the year 2023 calculated from historical data as previously mentioned. With this, an average monthly demand of 25 rolls of geo-synthetics was determined, equivalent to approximately 25,000 square meters of geo-synthetics. In addition, it was taken into account that the work shift is 8 hours per day and that work is done for 20 days in a month. With this, from the formula for Takt Time presented in the annexes section, a Takt Time of 6 hours and 20 minutes was obtained for the fulfillment of a given average order of 647 square meters, the result obtained is compared with the current production cycle prior to the implementations in figure 4 below:

Figure 4: Takt Time vs. Initial Production Cycle.

With this comparison, it can be determined that the process is taking almost twice as long as it should. With this in hand, and together with the obtained OEE measurement, the problem was quantified in a better way, and it allowed us to analyze the causes of the problem in greater depth in the next section.

4.3. Analyze

To better understand the problems of the company, 4 steps were followed to facilitate the visualization of the current state of the warehouse.

We began with an internal survey, which sought to better explain the reasons for some of the doubts that arose during the team's first visits to the winery. These questions were:

1. Why are there failures in heat sealing at the quality level?
2. Why is there a delay at the beginning of the heat-sealing process?
3. Why is there a delay in calibrating the machine?
4. Why is there a delay in storing the heat seal after production?
5. Why is there a problem with orders being shipped different to the customer's specifications?

These questions gave us a series of results whose information could be gathered in 7 categories. These 7 categories were plotted in a Pareto chart for better visualization and weight attribution. The Pareto is shown below in figure 5:

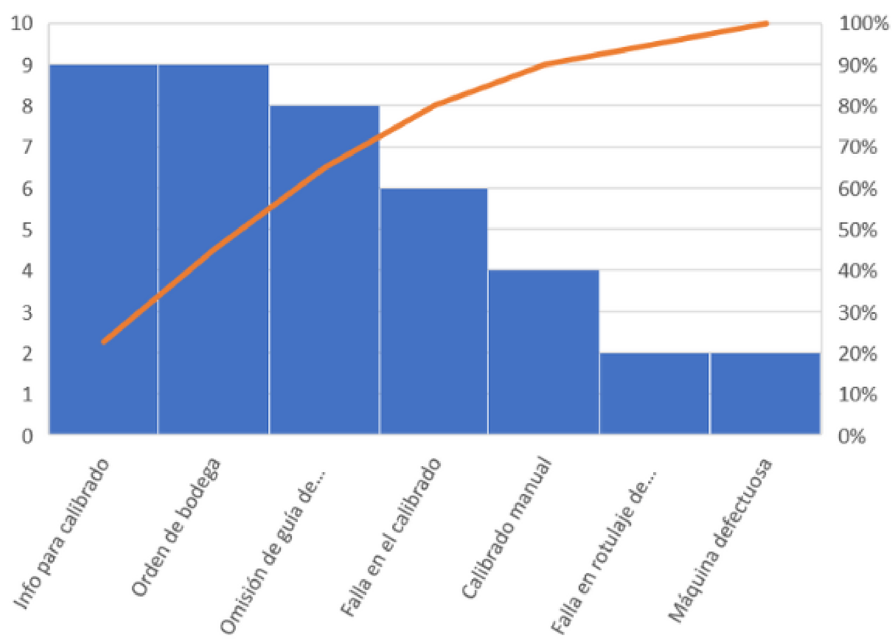

Figure 5: Pareto ABC classification.

It was found that 80% of the responses had to do with problems due to lack of information about calibrating the Twinny machine, clutter problems in the warehouse, failure to calibrate the Twinny and omission of the referral guide.

To complement the understanding of these results, an Ishikawa diagram was assembled. The Ishikawa is divided into 3 general areas which are: Calibration, Warehouse and Dispatch. The Ishikawa diagram is shown below:

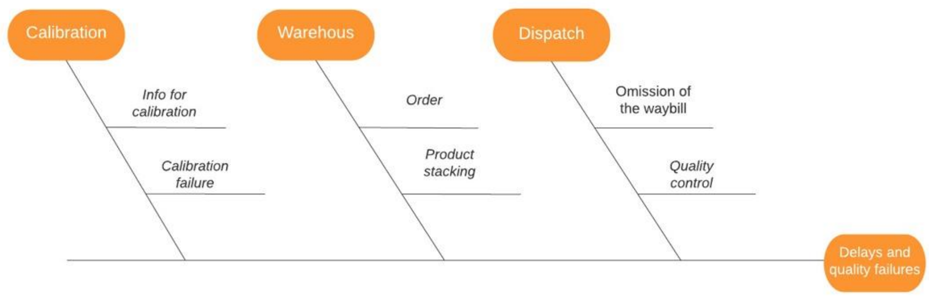

Figure 6: Ishikawa diagram.

The grouped Pareto responses are distributed in this Ishikawa and specific causes related to the general problem of the case study is better visualized: delays and failures in the quality of heat sealing within the production process of a company that works with geomembranes.

Finally, the team spent several days studying the state of the warehouse and its employees. It was determined that employees walk around the warehouse much more than they should to complete their orders. This is because the distribution of raw materials within the warehouse storage area is poorly designed, or rather, does not follow a particular layout. Because of this, employees took 30 to 45 minutes longer than they needed for each order and traveled an average of 63 meters to replenish their supplies. Below, in figure 7, a Spaghetti's diagram is presented, which shows in red lines the path an operator walks to fulfill one order:

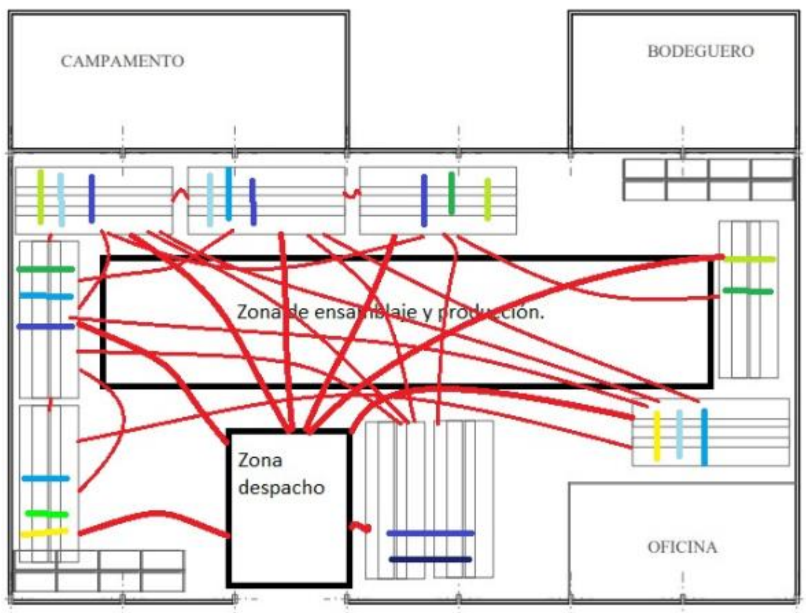

Figure 7: Spaghetti diagram of warehouse.

To explain this diagram, it must be mentioned that employees must take a quantity of geomembrane to be heat-sealed and cut from each zone. This means that for almost every order they receive, they must go through a cycle as shown in the diagram, which follows these phases:

i. Take a quantity of geomembrane
ii. Heat seal and cut
iii. Roll up
iv. Take more geomembrane

v. Adhere the new membrane to the previously heat-sealed one.
vi. Roll up
vii. Repeat until the quantity of product requested by the customer is satisfied.

As this cycle is repeated several times per order, those 63 meters traveled per replenishment add up very fast. This generates time and money costs, which hampers production and results in employees having to stay outside their designated working hours to finish time-consuming orders.

4.4. Improve

In this phase, we continued with the implementation of lean methodologies, production control and plant design in conjunction with a final simulation to meet the objective of minimizing time and quality failures for orders. The tools used are explained in detail along with the respective process implemented below.

4.4.1. ABC Classification

To start with the improvements, the first step was to know the functioning of the demand and the inventory turnover within the warehouse. The idea for this was to generate an ABC classification, which consists of organizing all the existing SKUs in a descending order according to the consumption criteria or their annual use (Alberto & Zuluaga, 2011). To accomplish this, sales forecasts were first calculated for the year 2023 for all existing SKUs, based on historical data provided by the company. With the results obtained, a Pareto diagram was generated, based on the total annual sales of each SKU, as shown in figure 8 below:

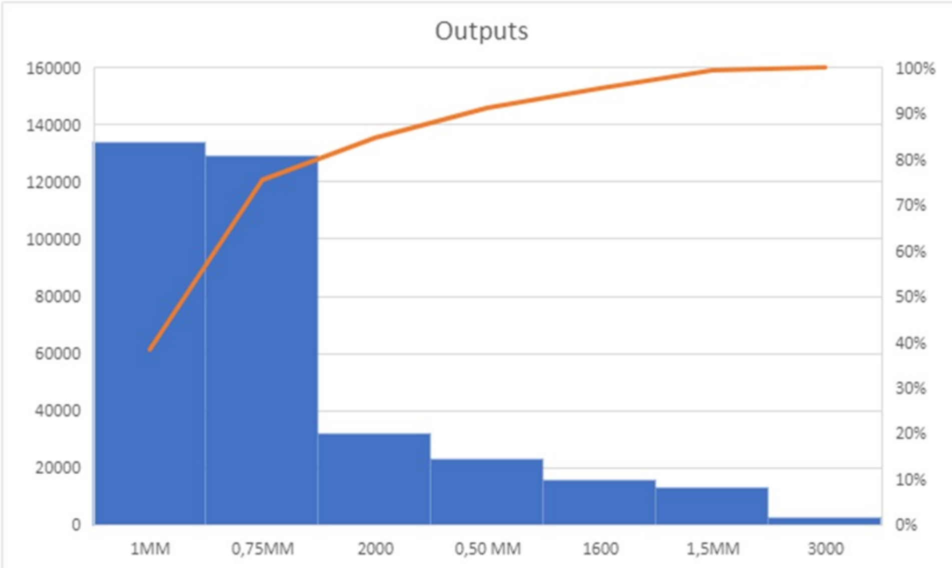

Figure 8: Pareto ABC classification.

This diagram allows us to determine that the SKUs that represent 80% of the rotation are the 1mm and 0.75 mm geomembrane and the 2000 geotextile. On the other hand, 15% of the rotation is given by the 0.5 mm geomembrane and the 1600 geogrid. Finally, 5% of the rotation is given by the 1.5 mm geomembrane and the 3000 geotextiles. Once these percentages are known, the ABC classification is presented in table 2:

Clasification	**SKU**
A	A1: Geomembrane 1 mm A2: Geomembrane 0,75mm A3: Geotextile 2000
B	B1: Geomembrane 0,50mm B2: Geogrid1600
C	C1: Geomembrane 1,5mm C2: Geotextile 3000

Table 2: ABC Classification.

This classification was extremely useful and important to rank the SKUs according to their rotation, which is equivalent to their annual use (Alberto & Zuluaga, 2011), thus contributing to their classification to reorder them within the warehouse based on the Craft methodology presented in the following section.

4.4.2. Layout redesign using the Craft algorithm

Initially, the layout of the company presented several problems mainly due to the absence of defined areas for each zone or department, where there is also disorder in these work areas. In order to substantially improve the company's situation, the results of the ABC classification previously carried out were reviewed, together with an analysis using the layout rearrangement algorithm called CRAFT. This aims to rearrange the initial layout to create a new one that is more efficient for the company in terms of costs (Leyva, et al. 2013). For this purpose, each of the layout zones was divided according to the movements of the different products offered by the company, resulting in the following distribution:

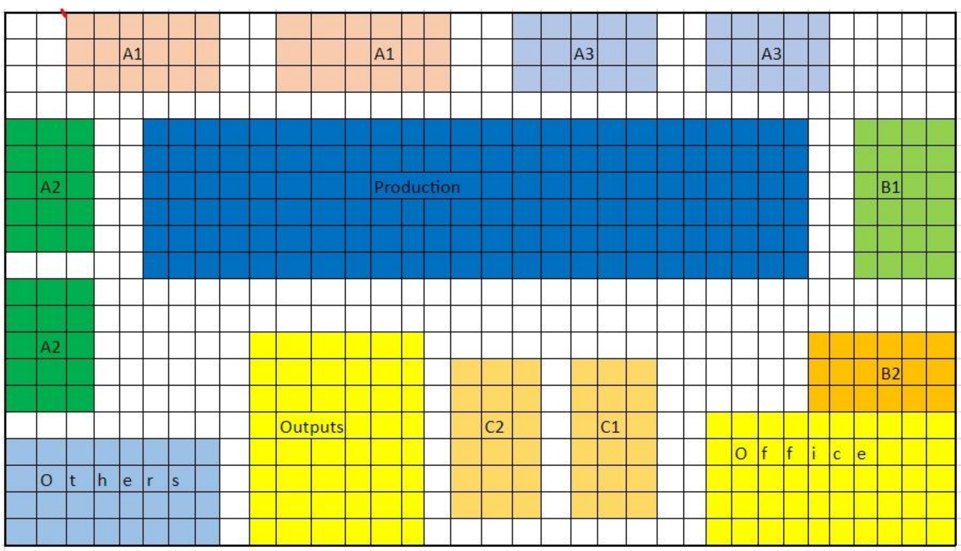

Figure 9: Recommended layout.

Taking into account the seven zones, color-coded, distributed in the layout, we proceeded to create a cost matrix, a straight-line distance matrix and a product flow matrix. By means of a product addition operation we obtained total costs of $2424.82 which is lower than the initial costs of $2545.76 as can be seen in table 3:

Layout	Total cost
Initial	$ 2.545,76

Recommended	_$ 2.424,82

Table 3: Layout cost.

It is important to mention that the total cost indicated is the result of a sum product operation involving the rectilinear distance with the flow per department. Likewise, the formula used for the calculation of the total layout cost has been attached in the annexes section.

4.4.3. Twinny standardization

The machine used by the warehouse operators to heat-seal the geomembranes is called Twinny. This product belongs to the Leister brand and has the capacity to join two membranes by means of a conduction heat sealing process. This device is set up with 3 different variables: temperature, pressure and speed.

This product comes with a user manual that specifies not only how to use the machine safely, but also specifies what values to give to each variable depending on the type of heat-sealing and the membranes to be heat-sealed. The manual mentions that the material of the membranes to be heat-sealed has different heat resistance; therefore, depending on the material and its thickness, the Twinny is prepared differently.

We found that the Twinny operators did not use this table even though they had it, because it did not always give them good results. We also came to conclude with some research that operators prefer to work with configuration values that they have memorized from previous runs. Because of this, operators incur many quality failures.

We decided to find the optimal factor levels to be used in the Twinny and supplemented with some field tests in the climatic conditions of the warehouse. Using the scientific method to find suitable calibration values according to operator and machine standards we found that the values in the manual table of the Twinny are adequate but, due to climatic conditions at the site where the operators are located, there is a margin of error in some variables.

A Poka Yoke was then created to standardize the calibration of the Twinny to reduce the number of tests that must be done to calibrate it. This Poka Yoke is intended for operators to start with the values in the table during calibration to be as close to the ideal heat seal as possible. If it turns out that the weather conditions of the day lead to a variation, it will be easy to detect the problem and adjust because operators start at the right values to heat seal; this contrasts with operators using a random calibration each time were getting to the ideal value may take longer than necessary and does not follow a standard process.

Below, in figure 10, is the Poka Yoke for Twinny calibration, in the warehouse´s native language, which is in the machine's storage box for easy access:

Figure 10: Poka Yoke calibration.

4.4.4. Kanban

For the correct standardization and ordering of the tasks that were carried out within the warehouse, it was essential to implement a Kanban board. Consisted of showing all the tasks that had to be carried out from left to right on a blackboard, with the objective that through a brief glance at the board, both operators and managers have knowledge of the task to be done, the tasks that are in progress, the task that has presented inconveniences and also the task that has already been completed (Bermejo, M. 2011).

The idea was to expose the pending tasks which could provide effective help against possible delays and general failures in the process. On the other hand, it should be mentioned that the Kanban worked as a repository of information in real time which seeks to reduce failures and bottlenecks within the system. The implemented kanban board was a simple and effective solution that in this case did not interrupt the normal operation of the company.

For the visualization of the pending tasks within Kanban, it was imperative to make a prior hierarchy for the overall process, so that the factors that are necessary for an item to move from being a request to a deliverable were understood. When it was recognized as the workflow through the system, in this case a purely productive system, it directed Kanban to the continuous improvement of the company's processes.

The initiative was the work of an X element which started in the "To Do" column and then moved to the "In Process" column and concluded when the element moved to the "Finished" column, in this way, it could easily follow the ongoing process to also identify and correct bottlenecks in time, each Kanban board is different and depends on the specific needs and processes of each organization. The proposed "Kanban Board" can be seen below in figure 11:

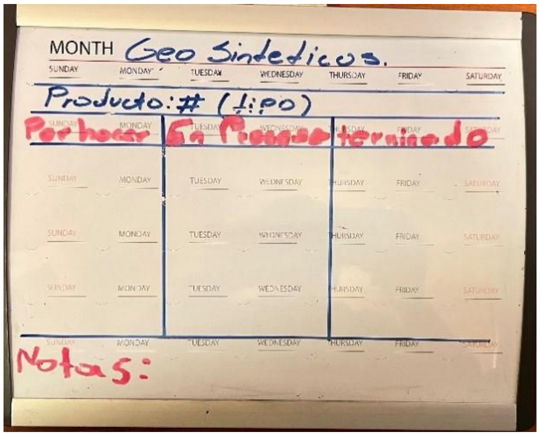

Figure 11: Kanban Board.

4.4.5. Inventories, how much to order and when to order

Another one of the fundamental aspects to be addressed to improve the processes within the warehouse is inventory management. As mentioned in the analysis phase, there are cases in which orders cannot be fulfilled on time because the company does not have the stock required to complete the work.

Based on this problem, first, the reorder point was calculated for the three SKUs with the highest turnover, i.e., those belonging to the A classification, due to the importance of these items for the company in economic terms. It is important to mention that the reorder point is related to the process of replenishment of the warehouse, creating a network between the current stock, the quantity ordered and the total stock available when the order is received, answering the question of when to place an order (Nahmias, 2014). Also, it is worth mentioning that the calculations to obtain the reorder point were made considering a safety stock of 10% for each SKU based on the monthly demand of each one of them, since orders to suppliers are placed monthly, in addition, for each SKU, the lead time was taken into account as the time that each supplier takes to deliver the product. The formula used for the case is presented in the annexes section and the results obtained are presented in table 4:

Product	**Demand (m2)**	**Safe Stock (m2)**	**Days until delivery**	**ROP (m2)**
Geotextile 2000	133	498	10	1824
Geomembrane 1mm	558	1111	15	9479
Geomembrane 0,75mm	539	1078	15	9163

Table 4: Reorder point.

To explain the results obtained, we take as an example the geotextile 2000, for which the results indicate that an order should be placed whenever there are 1824 square meters of this SKU in inventory. This is interpreted in the same way for the other SKUs presented in the table. It is important to mention that, for the calculations performed, the demand forecasts previously calculated for the ABC classification have been used.

Now once this is determined, the question that arises is: once we place an order, how much should we order? To answer this question several inventory models could be implemented, however, it is of utmost importance to first determine from the constraints presented by each one the appropriate model to be used. For this study, we proceeded to analyze the type of demand we have, considering also the forecasting method used for each of the SKUs. The method selected for the three items was the Winters method, due to the existence of seasonality in demand (Nahmias, 2014). This was evidenced from the demand and results graph obtained for each SKU in the Minitab software, such graph is presented below in figure 12 for the SKU of the example considered, i.e., geotextile 2000:

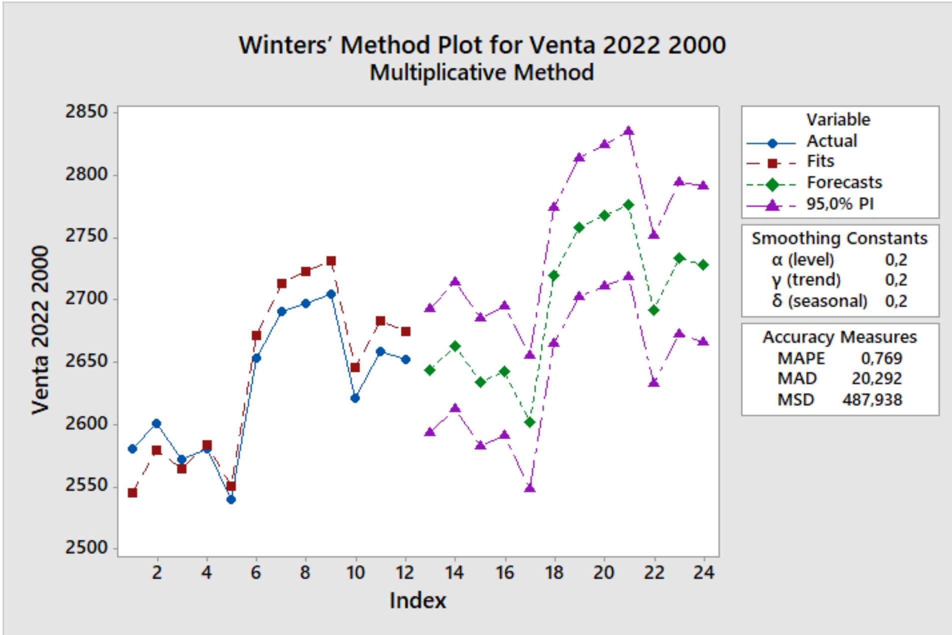

Figure 12: Geotextile 2000 demand forecast.

For example, only the calculation made for the SKU serving as an example for the reorder point is used, since the behavior of the other SKUs of classification A is extremely similar, showing seasonality in all cases, as can be seen in the annexes section where the graphs for the other two SKU's have been attached. Now, as an observation, it is important to mention that, considering the value for the mapping error in the forecasts made for all the SKUs, the EOQ model could have been used to calculate the quantity to order, since this value for the three cases is close to zero, which meets the requirement to use EOQ. However, for this study, since there is seasonality, the use of the newspaper delivery model (Nahmias, 2014) has been considered, since, having this characteristic, the use of the aforementioned inventory model is the one identified as appropriate for the case.

Now for the application of this model several aspects were taken into consideration, in the first place, it was taken into account how much the company earns for each meter of synthetic geo sold (Cu), secondly, the costs that each meter implies to the company were considered, taking into account the costs of maintaining the inventory, together with how much it costs the company each meter it orders from its suppliers (Co). From this and with the respective formulas presented in the annexes section as annex J, K and L for the calculation of F(Q), z and Q values, the following results presented in table 5 were obtained:

Tipo	Cu	Co	F(Q)	Z	Deviation	Mean	Q
Geotextile 2000	1,05	0,75	0,58	0,210428394	7906	4979	6643
Geomembrane 1mm	2,47	2	0,55	0,132163986	96	11106	11119
Geomembrane 0,75mm	1,85	1,58	0,54	0,098817972	3313	10780	11108

Table 5: Quantity to be ordered.

From the results presented, it is important to highlight that the deviation and mean values were obtained from the monthly forecasts calculated for the year 2023. Having mentioned this and taking it into account as an example, as with the 2000 geotextile order point, it is determined that the quantity to order once the reorder point is reached for this SKU is 6643 square meters. This means that for the specific example, every time you have 1824 square meters in inventory, you must order 6643 square meters more.

4.4.6. Simulation

To conclude the improvement section and to be able to demonstrate the results obtained through the implementations carried out, a simulation was performed using data collected during the following three weeks after the last implementation (Paz & Orozco, 2020). The purpose of this was to show the state in which the process would be if all the standardizations and implementations recommended in detail were followed. To accomplish this, first of all, each set of data obtained was statistically analyzed. At this point, it is important to mention that the data collected were processing times in each of the storage and preparation zones previously identified in Figure 6 presented in the section on the application of the Craft algorithm.

In addition, it is worth mentioning that the way of collecting the data followed the same steps as in the measuring phase, taking data for 367 meters randomly from each zone. Once the data was collected, as previously mentioned, a statistical analysis of the data was performed, focusing specifically on the type of continuous distribution that each zone follows, since it is processing times, thus through the use of Experfit software the following results were obtained and presented in table 6:

Zona	Distribución
1	lognormal2(0.000000, 0.000046, 58.255954, <stream>)
2	weibull(255.651313, 4.214181, 2.000000, <stream>)
3	johnsonbounded(262.299306, 266.369326, -0.446913, 0.702355, <stream>)
4	beta(243.609855, 248.317678, 2.022527, 1.864054, <stream>)
5	johnsonbounded(239.399320, 244.466912, -0.347193, 0.709224, <stream>)
6	johnsonbounded(252.579816, 256.797020, -0.039025, 1.034444, <stream>)
7	beta(243.051930, 253.785886, 13.489146, 11.692334, <stream>)
8	johnsonbounded(249.582816, 254.128388, 0.228398, 1.111276, <stream>)
9	beta(242.529066, 246.346967, 1.436724, 1.298928, <stream>)
10	weibull(0.000000, 249.670242, 183.937708, <stream>)
11	johnsonbounded(315.610824, 325.443401, 0.393930, 0.569058, <stream>)

Table 6: Statistical distributions of time with implementations.

It is worth mentioning that these distributions complied in their entirety with the goodness-of-fit tests, which indicates that all of them correctly adjust to the expected data (Romero, 2016). Once this was determined, FlexSim software was used in conjunction with the distributions for each zone in order to simulate the expected results from the implementations, the simulation model created in operation is presented in figure 13 below:

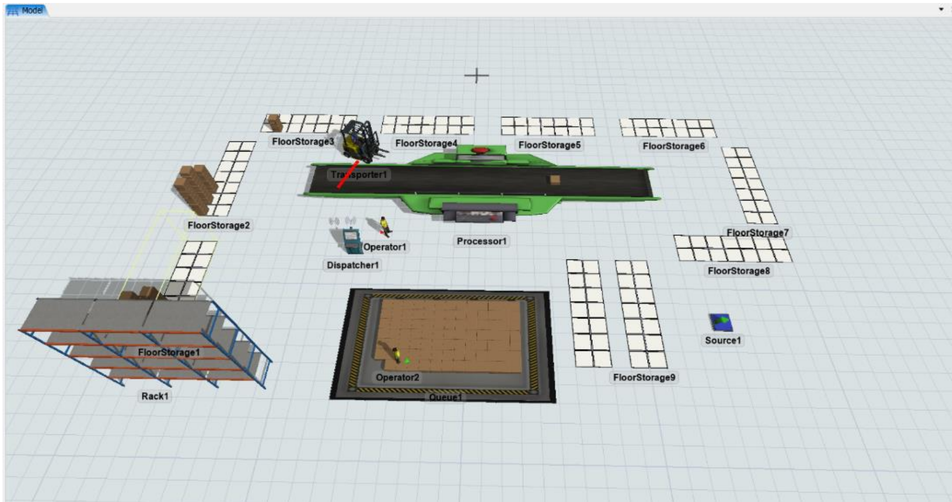

Figure 13: Simulation model.

To exemplify the movement inside the warehouse, the same number of operators and a forklift were used. The exact layout was also used to comply with the distances established in the application of the craft algorithm. Similarly, floor storage was used for each storage zone; within this storage, the distributions for the processing time of each zone were included, so that the movement from each zone to the processing zone could be simulated. Now, in the processing zone a processor was included, which was also given a processing time linked exactly to the distribution calculated for zone number 11, which is the processing zone, this time is related to how long it takes to send the processing zone to the dispatch zone, represented with a queue where the products are accumulated. With all the above mentioned, we proceeded to simulate the process, obtaining in table 7 the following result with respect to the amount of daily product dispatched.

Considerations	**Before (m2)**	**After (m2)**
Daily production (8h)	517	970

Table 7: Simulation results.

When comparing the results between the state of the process before the study and after the study, the improvement obtained within the process is clearly evidenced. In addition, these results show that, in an ideal scenario, the process complies with the established takt time of 6 hours and 20 minutes for an order of 647 square meters. For the latter, it is important to note that the result is given in an ideal scenario, since there can always be problems outside the process that generate atypical times in one or more areas. In this case, these outlier times had to be removed from the collected data because they implied a problem regarding the goodness of fit of the data (Romero, 2016).

Now taking into account the collected data, including the outliers and the simulation results, the effectiveness of the OEE equipment has been recalculated, obtaining the following results in table 8 compared to the initial ones:

Métricas	**Antes (%)**	**Después (%)**
Disponibilidad	88,2	92,6
Rendimiento	69,3	74,7
Calidad	73,1	78,6
OEE	44,7	54,3

Table 8: OEE before vs. after.

The results obtained, as in the case of the simulation, show an evident improvement in the process, which implies a reduction of time and quality failures, thus fulfilling the main objective of this study, all through the implementations carried out within the production and warehouse process.

4.5. Control

For this phase of the work, it was decided that it would be best to give the operators a guideline to follow in case they forget the stipulated way of working in some of the company's operations. This outline was communicated verbally throughout the project to the company's employees in order to help them standardize their processes and achieve a higher level of quality that achieves the lowest number of failures and waste.

Below, we show the checklist as figure 14, operators should carry it with them or keep in key places to have better access to information in an easy way:

Checklist	Dispatch	Checklist	Quality
1	Check product quality before dispatch	1	Holes
2	Check product quantity before dispatch	2	Burns
3	Check product material before dispatch	3	Malformation
4	Confirm that the product is ready for dispatch	4	Uneven cuts or seals
5	Dispatch	5	Post production damage
Checklist	**Before production**	**Checklist**	**Warehouse distribution**
1	Register customer's order	1	Verify material is classified as assigned
2	Check inventory levels	2	Verify material is stored as classified
3	Make a contract with the customer	3	Verify geomaterial stacking order
4	Ask supplier for needed amount of geomaterials	**Checklist**	**Stock**
5	Await for supplies and verify that the order can be completed	1	Verify daily amount of material for production
		2	Verify excess geomaterial destined for calibration purposes

Figure 14: Operator processes checklist.

The information is divided into 5 areas, which are highlighted in bold to the right of the word "Checklist". These areas were visualized in this way so that the operator can look for the appropriate checklist for the activity they are doing. This way of classifying tasks allows the company's personnel to validate that their process is being done in a standard way, reducing time waste and increasing or maintaining the desired level of quality.

It should be noted that some of these verification processes require information that was provided to the warehouse prior to the creation of this checklist, so that they have all the necessary tools to complete their activities in the best possible way. Some of the informative documents that are presented to the company, or that they must have, in order to complete the checklist are:

- Referral guide
- Customer contract
- Twinny calibration poka-yoke
- ABC classification of the warehouse
- Monthly/daily forecasts

5. CONCLUSIONS

The application of the DMAIC methodology has contributed to the successful development of this study since, in principle, through its phases, it allowed us to both identify the problems and quantify them. In this way, it was possible to determine the appropriate tools to be implemented in order to reduce the central problem to a minimum level, which implicitly represents the very purpose of the study.

Thus, by identifying problems that start from inventory management to time and quality control in the storage and production area, tools have been implemented for inventory management, production control, lean methodology and finally plant redesign, the latter being one of the most important in terms of reducing both time and operating costs. In this way, with all the implementations carried out, a simulation provided clear vision of the results obtained thanks to them.

With all the above mentioned and from the results obtained with this simulation, it is concluded that the implementations applied within the storage and production area are of great importance and usefulness in the mission of reducing time, costs and production failures, all this is supported by the results obtained for the current production cycle, meeting the calculated takt time, in addition to the positive economic results obtained by redesigning the plant and the efficiency of daily production, as there is a big difference between this and the initial daily production.

6. RECOMENDATIONS

As a recommendation, it is essential for the company to continue monitoring the tools implemented from the control plan established. In addition, at this point it is of utmost importance to recommend following up on the behavior of the existing demand, in order to monitor the status of both the reorder point and the quantity to be ordered, for this purpose it has been previously coordinated with the person in charge of inventories, who was instructed on the types of demand behavior.

On the other hand, regarding the studies related to the specific subject of this case, it is recommended to consider a longer time interval for data collection, in order to obtain more robust results, mainly due to the existing variation in the production process time from specific factors such as the calibration capacity of each operator. Finally, it is recommended to consider ways to mitigate external factors that influence the results obtained, considering them as part of the problem and looking for tools that contribute to minimize them, at this point it is evident that these factors will depend on the case in which we are working.

7. LIMITATIONS

With what was previously mentioned in the recommendations section, it is evident as a limitation that the time available to carry out this study, specifically the time to collect data, was a little more than one month. It is worth mentioning that the time previously mentioned was a little over a month, which for those of us who conducted this study was useful, but not completely adequate, since it was not possible to know behaviors, delays, or long-term problems. Another limitation is related to the data available to the company, although we were able to have most of it and present it in the study, many others could not be used due to confidentiality terms initially established.

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9. ANNEXES

Annex A: Sample size calculation formula.

$$n = \frac{NZ^2pq}{((N-1)e^2 + Z^2pq)}$$

Annex B: Formula used for the calculation of machine availability.

$$Availability = \frac{Hours\ worked - Hours\ stopped}{Hours\ worked}$$

Annex C: Formula used for calculating machine throughput.

$$Efficiency: \frac{Real\ number\ of\ products\ finished}{Standard\ number\ of\ products\ to\ be\ finished}$$

Annex D: Formula used for quality level calculation.

$$Quality = \frac{Finished\ products - Defective\ finished\ products}{Finished\ products}$$

Annex E: Formula used for the calculation of machine OEE.

$$OEE = Availability\ * Efficiency * Quality$$

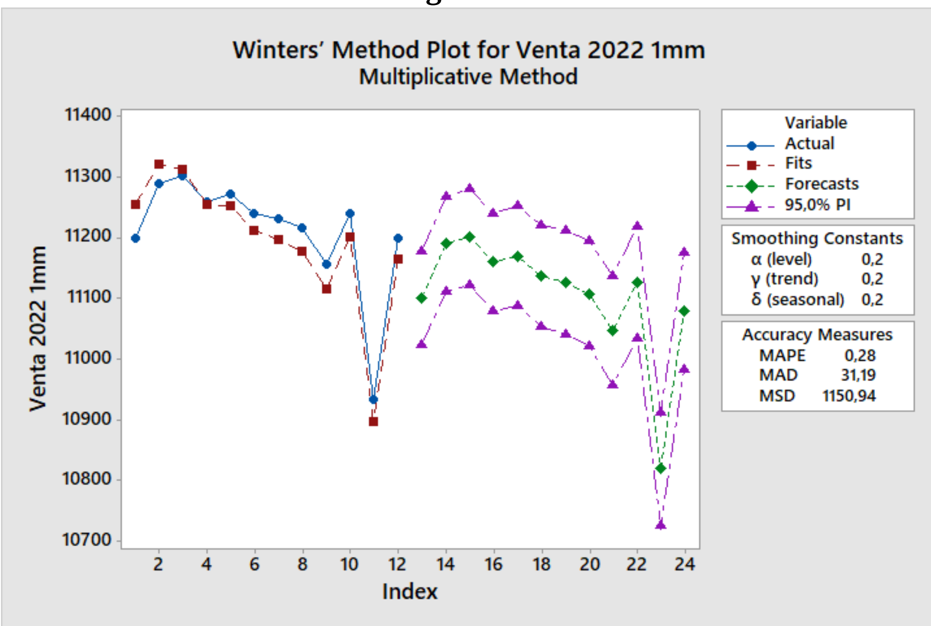
Annex F: Formula used for the calculation of total cost for the CRAFT algorithm.

$$Cost = Flux * Distance$$

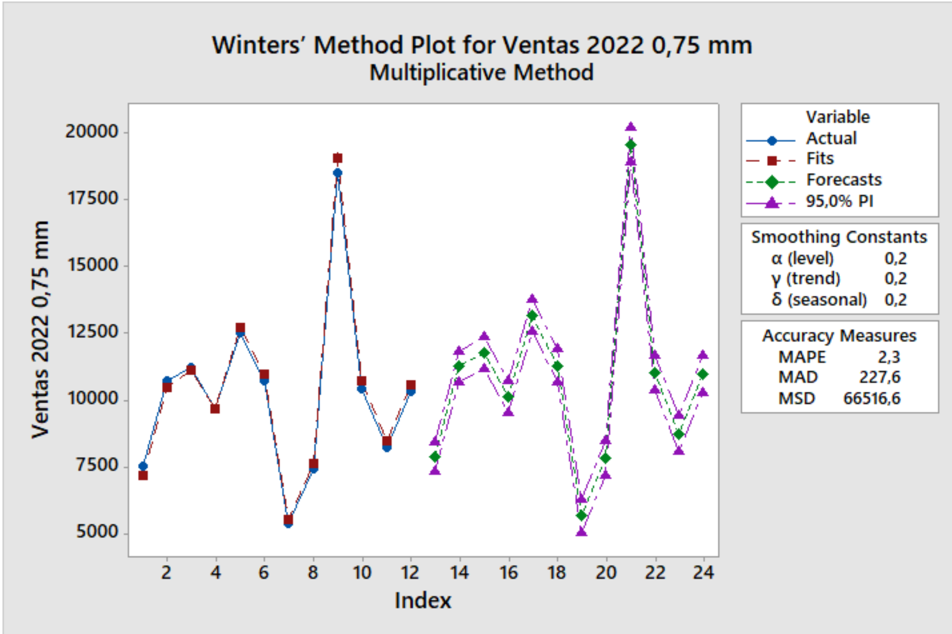
Annex G: Reorder point formula.

$$ROP = Demand * Lead\ Time + Security\ stock$$

Annex H: Demand behavior and forecasts geomembrane 1mm.



Annex I: Demand behavior and forecasts for geomembrane 0.75mm.



Annex J: Newspaper delivery model formula.

$$F(Q) = \frac{C_u}{(C_o + C_u)}$$

Annex K: Formula to see in the normal distribution table in Excel.

$$= NORM.S.INV(poner\ valor\ de\ F(Q))$$

Annex L: Model of Q of newspaper delivery person.

$$Q = \sigma z + \mu$$