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Journal of Technologies in Industrial Processes

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Presentation of the content

In the first article we present, *Diagnosis to determine the root cause of unproductive times in the release of ascorbic acid as a raw material* by GÓMEZ-VICARIO, Miguel Ángel, HERNANDEZ-LUNA, Teresa, BAHENA-MEDINA, Lilia Araceli and PÉREZ-ESPAÑA, Nohema, with adscription in the Universidad Politécnica del Estado de Morelos, in the next article we present *Implementation of an inventory control system in the snack company* by ACOSTA-GONZÁLEZ-Yanid, DELGADO-GÓMEZ Gilberto, ESTRADA-NAVARRETE Jorge and DE LUNA-CARDONA, Emmanuel, with adscription in the Universidad Tecnológica de Aguascalientes, in the next article we present *Grounding System Design of the main Electrical Substation of stones and minerals breaker plant in Campeche State to comply with the NOM-001- SEDE-2012, IEEE-Std-80-2000, and the Código de Red* by LEZAMA-ZÁRRAGA, Francisco Román, SHIH, Meng Yen, CHAN-GONZALEZ, Jorge de Jesús and SALAZAR-UITZ, Ricardo Rubén, with adscription in the Universidad Autónoma de Campeche, in the next article we present *Design of a model for the correct reporting of unproductive times in production lines* by REYES-OLÁN, Claudia, PINILLA-RODRÍGUEZ, Juan Antonio, POZOS-TEXON, Felipe de Jesús, GASCA-CABALLERO, Carlos Javier and ROSALES-LASNIBAT, René Valdemar, with adscription in the Universidad Cristóbal Colón.

Content

Article **Journal of Technologies in Industrial Processes**
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Diagnosis to determine the root cause of unproductive times in the release of ascorbic acid as a raw material

Diagnóstico para determinar la causa raíz de tiempos improductivos en la liberación de ácido ascórbico como materia prima

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Abstract

The present work was carried out in a company dedicated to the elaboration of medicines and food supplements, in which a diagnosis was made in the raw material release process, specifically, in ascorbic acid; where the critical points of the release process that presented a difference in time (unproductive time) were detected in the analysis of the parameters of each test of the raw material with respect to the established time. The objective of this work was to determine the root causes of unproductive times that affect the release of raw material; the methodology used was a study of times and movements, process flow diagrams and route diagrams. During development, the proposal for traceability formats of the characteristics of the raw material was designed.

Study of times and movements, Process Diagram, Unproductive periods

Resumen

El presente trabajo se desarrolló en una empresa dedicada a la elaboración de medicamentos y suplementos alimenticios, en la que se realizó un diagnóstico en el proceso de liberación de materia prima, específicamente, en ácido ascórbico; donde se detectaron los puntos críticos del proceso de liberación que presentaban una diferencia en tiempo (tiempo improductivo) en el análisis de los parámetros de cada prueba de la materia prima con respecto al tiempo establecido. El objetivo de este trabajo fue determinar las causas raíz de tiempos improductivos que inciden en la liberación de la materia prima; la metodología utilizada fue un estudio de tiempos y movimientos, diagramas de flujo de proceso y diagramas de recorrido. Durante el desarrollo se diseñó la propuesta de formatos de trazabilidad de las características de la materia prima.

Estudio de Tiempos y Movimientos, Diagrama de Procesos, Tiempo improductivo

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Introduction

Our country represents the second largest pharmaceutical market in Latin America, after Brazil. The revenue generated by this industry, by way of sales, has grown at a compound annual growth rate (CAGR) of 3.3% from 2016 to 2022 [1].

In 2021, the Gross Domestic Product (GDP) of the pharmaceutical industry grew 8.4% compared to 2020. From 2003 to 2021, the establishments of the pharmaceutical industry increased from 480 to 908. The jobs in the pharmaceutical industry were 79,000 in 2020, a 3.6% higher figure compared to 2019 [2].

Given the importance of the pharmaceutical industry and its focus on health care, high quality standards have been determined both in raw materials, manufacturing processes and the transfer of its products.

Between the process of receiving the raw material and its passage to manufacturing, there is an intermediate step that is the process of releasing the raw material by the quality area, whose objective is to ensure that it complies with the pre-established standards. Precisely in this intermediate step, the present project was developed, which focused on the identification of root causes of unproductive times in the process of analysis of ascorbic acid raw material through a Study of Times and Movements, in a company dedicated to the manufacture of medications and supplements. It was observed in the first half of 2022 that the company was two days late in the release of raw material (average of 7 days), and that in the last week of February there was the highest peak of days taken to this process (eleven days), while the lowest amount during the entire period was six days (Figure 1).

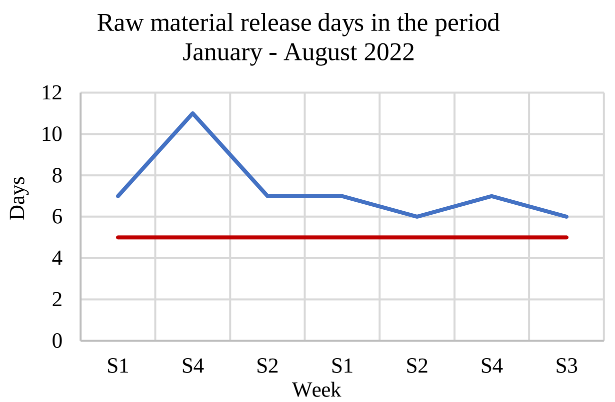

Figure 1 Days corresponding to the release in the period January-August 2022

However, for this process it is required that the release be given in at least five days, which implies that, in order to comply with these, it is necessary to identify the areas that affect it; For this, in the diagnostic phase, a Cause-Effect diagram was made to identify the causes that cause unproductive time and a Pareto diagram to identify the activity with the longest time within the raw material release process.

The study of movements is the analysis and study of the movements that constitute an operation, to improve the pattern of movement by eliminating inefficient movements and reducing efficient ones; This is accompanied by the study of times, which is the procedure for measuring the time it takes to carry out the operations to determine a standard [3].

Ovalle-Castiblanco and Cárdenas-Aguirre [4], in a review of the literature on the use of the study of times and movements of 90 articles published between 1996 and 2016, document that its application has spread to other sectors, including health. , 83 (92.2%) of these of these belong to health with favorable results; One of the most explored relationships with this methodology (46% of the articles) is that of patient-care, making it possible to determine the percentage of time invested in it by health professionals vs. in other activities. 74% of these were published in the last six years including the year of this review. They also document the geographical extent of its use, 32 of the articles are from the United States, 12 from the rest of America, 14 from Australia, 15 from Europe, 10 from Africa and 7 from Asia.

In a food technology company, Polo, Villar and Gutiérrez [5], implemented a study of times and movements to reduce those that are considered inefficient in preventive maintenance operations, specifically, greasing bearings. They carried out a sample of 53 greasing activities, for which process analysis diagrams and two-hand diagrams were developed to identify activities that do not add value and downtime. One greasing task was found to take 222 minutes and a second 107 minutes; once the study was implemented, the first was reduced to 150 minutes (32.43% less) and the second to 85 minutes (20.56% less); These allowed three bearings to be greased per day to be increased to four per day.

Body and Gatta et al [6] conducted a study of times and movements in 189 patients from oncology units (DOUs) over 10 days in Italy, Germany, and Belgium in order to measure the duration of administration of two medications for the prevention of events in patients with bone metastases. One of the drugs (Denosumab) is applied intramuscularly and the second. (Zoledronic acid) intravenously. 82 (104 observations) of the patients received zoledronic acid and 107 Denosumab (134 observations), recording a total of 238 observations. Process time included task time and HCP time; in addition to the time that includes the entry and exit of the patient from the treatment room and the examination.

The authors document that means total task time was decreased by 81% when Denosumab was used compared to zoledronic acid (8.4 vs. 44.2 minutes) in all countries. The HCP time was 12.2 m. for zoledronic acid and 6.9 min. for Denosumab (44% less). These results show that the use of Denosumab reduces the total task time and the activity time of the HCP, which would allow that time to be devoted to other patients or related activities; It can also contribute to reducing waiting lists by improving the hospital service.

A study carried out by Bruland et al [7] whose objective was to measure the impact of integrating a system that facilitates the workflow when carrying out documentation as part of routine patient care, involved modifications to the process, data quality and the execution times. For this, the integrity, correctness and concordance of the data was measured, the cost-benefit analysis was carried out and to evaluate the modifications to the process, a study of times and movements was carried out before and after the implementation. The authors document that 50% of redundant processes were eliminated and the average documentation time per patient visit was reduced by 70.1% (from 1116 to 334 seconds) after implementation.

During the blister packing process of a pharmaceutical company, Escobar-Vera [8] carried out a study of times and movements whose objective was to define standard times for each of the activities in the packing process in order to improve their productivity.

The first thing he did was an analysis of the work methods and times used in the process, later, the activities that generated value were identified and achievable standards and goals were established through specification sheets, which allowed the work method to be improved and increased productivity from 90% to 95%, likewise, increased production capacity from 78% to 90%.

Methodology

The methodology for the development of this project was based on the Study of Times and Movements, in addition, the application of other tools such as Process Flow Diagram and Route diagrams, the steps that were applied are presented below:

1. Elaboration of the diagnosis of the current situation in the Physicochemical Laboratory.

2. Identification of critical factors in the ascorbic acid analysis process through a Time and Movement Study.

3. Design of the program proposal to reduce unproductive time in the analysis process.

1. Diagnostic phase

As the first part of the development of the project, the initial diagnosis of the current situation was carried out, in which it was found that the company was two days late in the release of raw material, and that, in the last week of February, it presented the highest peak of days taken for this process (11 days), while the shortest time was six days Through a visual inspection and consultations with the personnel in charge of the quality control laboratory, a Cause-Effect diagram was prepared to identify the causes that cause the late release of ascorbic acid (figure 2).

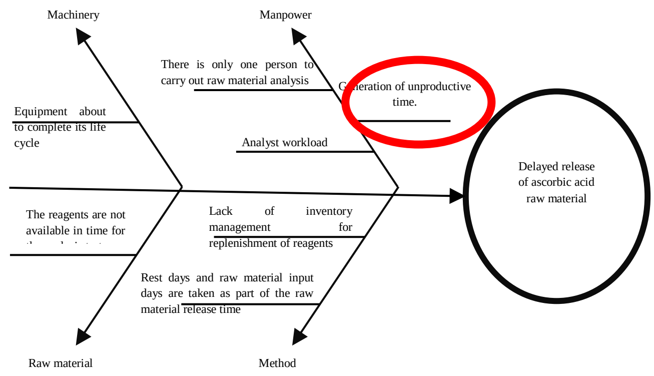

Figure 2 First level Cause-Effect Diagram

Once the causes have been identified, the only one that could be addressed at the time by the resources that the company had is the generation of unproductive time, for which a second Ishikawa diagram was made.

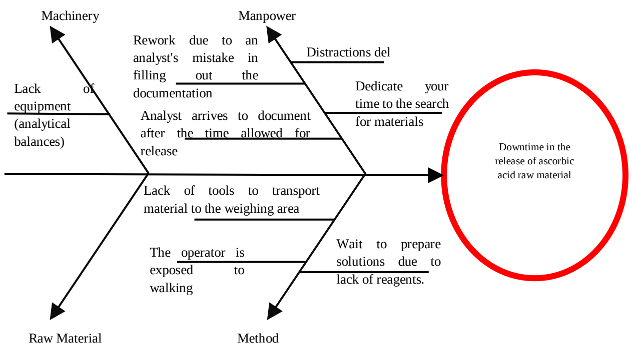

Figure 3 Second level Cause-Effect Diagram

In the second level Ishikawa diagram (figure 3) the main causes of the generation of unproductive time can be found, it can be seen that a greater number are attributable to labor, such as: allocating part of the time to carry out rework for mistakes in filling in the codes for equipment, reagents and solutions; distractions by the analyst; document after the time allowed for release has elapsed and spend part of the time searching for materials.

Once the main causes were identified, it was decided to carry out a study of Times and Movements to identify those that consumed the most time and where idle time occurred.

2. Identification of critical factors in the ascorbic acid analysis process

According to the information collected and the Study of Times and Movements, it was possible to identify that there were activities within the analysis process that caused the delay in the release of raw material, as well as.

That there was unproductive time, it is important to mention that, the analysis process has nine tests to be released, solubility (Sol), pH, particle size distribution (DTP), IR, color and appearance of the solution (CAS), optical rotation and heavy metals (ROMP), valuation (Val), ignition residue (IR), UV. It was considered to time four cycles for each one, since taking the time of each test lasted around two weeks and the entry of this is not constant (Table 1).

Parameter	Analysis	materials search	Walked	Wait	Documentation	Total (min)
Sol.	35.35	20.01	4	0	62.32	121.68
Ph	13.2	3.07	0.81	0	27.64	44.73
DTP	20.46	0.12	0.77	6.14	32.65	60.13
IR	9.76	0	0	7.91	0	17.67
CAS	18.08	0.33	0.78	16.31	14.54	50.04
ROMP	6.54	2.36	2.35	0	19.37	30.6
Val.	61,093	2.96	1.0925	0	14,745	79.89
IR	564.36	2.6125	0.8125	147.21	9.28	724.27
UV	12,783	0.42	0.665	2:25 p.m.	11,883	40
Totals(min)	741.62	31.88	11.28	191.82	192.42	

Table 1 Times per test for the release of ascorbic acid

For a better analysis of the unproductive time in the release of ascorbic acid, the process flow diagrams (see annex 1) and route diagrams (figure 4) were developed for each of the test cycles, which allowed obtaining the mentioned times and the distances traveled (table 2) by the analyst.

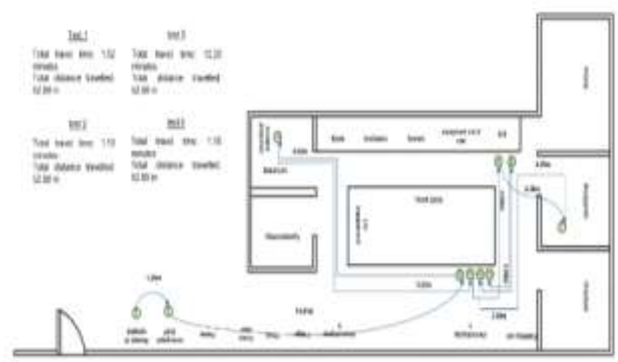

Figure 4 Path diagram for the solubility test

Distances traveled	
Proof	Before
	Distance (meters)
Sol.	52.88
pH	76.84
DTP	54.88
IR	0.00
UV	33.29
CAS	50.22
ROMP	62.87
Val	78.26
IR	44.25
Total	453.49

Table 2 Distances covered in each test

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According to the study carried out, it was identified that the analyst has experience to carry out his activities, but there are circumstances that make his release process take longer than established, since it influences the company, the planning and logistics area is the one in charge of managing the purchase and entry of raw materials, when they arrive, the quality inspector is in charge of taking the sample to be inspected to the physicochemical laboratory, however, the laboratory is not aware of said entry until the inspector is in the area. As there is no prior notice for their receipt, it is unknown if the reagents or solutions for the tests are available, this influences the delay in the release of ascorbic acid.

Once the process for the release of ascorbic acid was analyzed (figure 5), it was detected that another factor that influences the delay is the time of entry of raw material, since it is allowed until 8:00 pm, and this day is counted. as one less to carry out the analysis and the release, taking four days in total to carry it out and not the five established.

Rework due to documentation errors is another factor that causes release delays; When filling out the established formats to record the parameters, each record is done manually and according to its Standard Operating Procedure (SOP) of good documentation practices, they are filled out and canceled, if necessary, the latter is done in most tests.

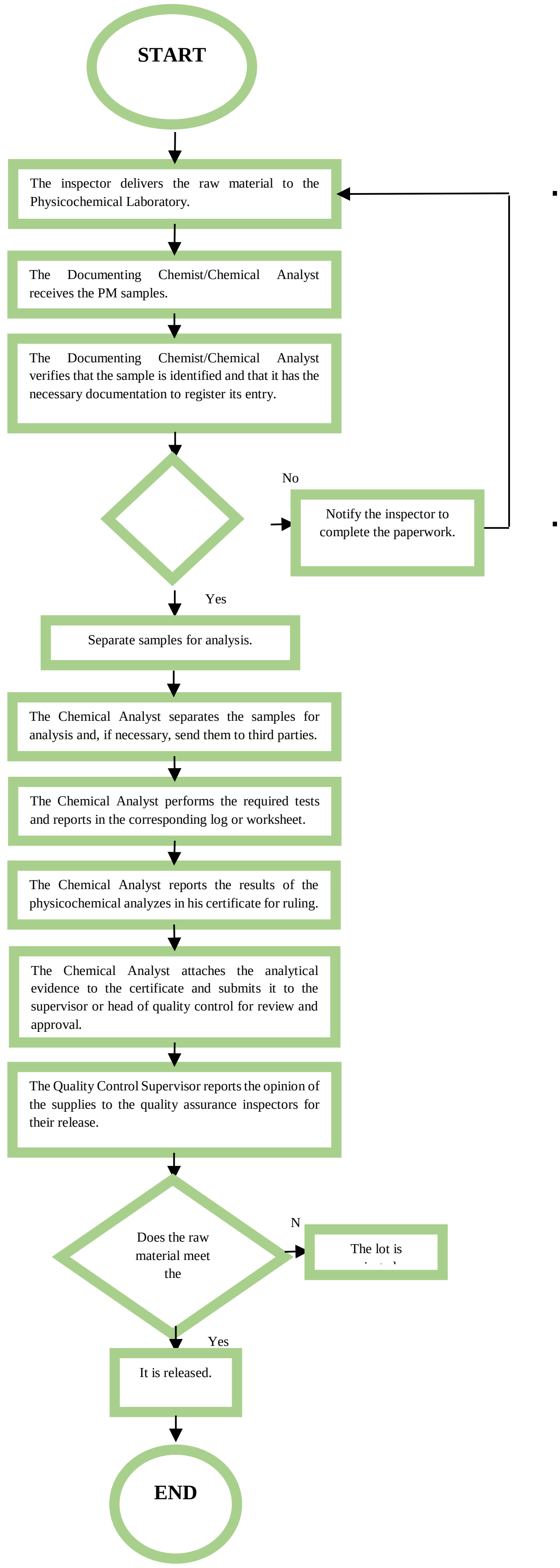

Figure 5 Process for the release of ascorbic acid

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3. Design of the program proposal to reduce unproductive time in the analysis process.

The improvement proposals for the reduction of unproductive time in the Laboratory were the redesign of traceability formats (figure 6 and 7) and the preparation of solutions at least one day before.

Are the samples identified?

Test:	Identify		Other:		
Product name					
Batch					
Method reference					

Figure 6 Identity traceability format

Uv traceability format

Test:	UV analysis
Product name	
Batch	
Method reference	

Figure 7 UV traceability format

A database was prepared that contains the necessary information to prepare each of the materials, solutions, copies for documentation at least one day before, which is shared with the storage area (see figure 8); The format includes input data for raw materials and supplies from both production plants and from the finished product warehouse. The entry date section is considered essential, because in this way, it is known when the solutions have to be prepared, saving that time when documenting and the days that are available for analysis.

Figure 8 Database

In addition to the formats, a scheduling is proposed (table 3) to propose an improvement to the reception, analysis and opinion procedure for raw materials, bulk product and finished product of medicines.

In order to establish the reception schedules, in which, the delivery is not allowed to be until the time of the last shift and non-working days and rest days are taken into account as part of the days that are available to be released.

Arrival Day	Release Day
Monday	Wednesday
Tuesday	Thursday
Wednesday	Friday

Table 3 Days of receipt and release of raw material

Results

During the diagnostic phase and through the study of times and the realization of the process and route diagrams, it was identified that it is not possible to reduce times in operations since, according to what was specified by the analyst, there is no way to make a different use of procedures and/or equipment.

The realization of Process Flow Diagrams and Route Diagrams of each one of the tests allowed to identify the fundamental activities of the same, and those that did not add value to the process flow, such as transport, documentation and the preparation of solutions. It was also detected that there is a lack of communication between the area of quality control and the warehouse.

Once the areas of opportunity were identified, the proposal was developed, which includes the following measures: a) the design of the database that allows the information to flow between the quality control area and the warehouse, b) the documentation that allows the traceability of the materials, it should be noted that the formats were not implemented because they must be approved by the Quality Management System and the next review and control is scheduled for the second half of 2023, c) a schedule was suggested for the days of entry of raw material to the laboratory.

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Annexes

Annex 1 Process flow diagrams of the first test cycle

PROCESS FLOW DIAGRAM

Location: Quality Control Area	Summary			
Activity: Solubility analysis	Event	Present	Proposed	Savings
Date:	Operation	12		
Chemical analyst: / Observer:	Transport	9		
Circle the method and type	delays	0		
Method: Present / Proposed	Inspection	0		
Type: Worker / Material / Machine	Combined	1		
Comments:	Storage	1		
	Time (min)	237.95		
	Distance (m)	52.88		

Description of events	Symbol: ●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
Raw material sample receiving rack						●	0.00	0.00	
Take raw material from sample reception area	●						1.00		
Go to certificate monograph shelf		●					0.03	1.34	
Search for certificates and check information					●		15.00		
Go to work tables		●					1.15	15.41	
Filling of documents according to certificates	●						10.00		
Walk to weighing area		●					0.06	9.03	
Weigh 4 samples on an analytical balance	●						5.00		
Go to work tables		●					0.06	9.03	
Place samples on the work table	●						0.08		
Search Containers for Test Solutions	●						0.33		
Go to the hood to turn on		●					0.05	3.58	
Turn on hood and leave material with sample	●						0.02		
Go to warehouse R of reagents		●					0.04	2.34	
Search for reagents	●						5.00		
Go to work tables		●					0.06	4.99	
Prepare test solutions	●						120.00		
head to the hood		●					0.04	3.58	
Transfer reagents to containers	●						5.00		
Add solvents to reagents	●						5.00		
Prepare samples for testing and perform analysis	●						10.00		
Go to work tables		●					0.03	3.58	
Register in the documentation (certificate)	●						60.00		

PROCESS FLOW DIAGRAM

Location: Quality Control Area	Summary			
Activity: pH analysis	Event	Present	Proposed	Savings
Date:	Operation	14		
Chemical analyst: / Observer:	Transport	10		
Circle the method and type	Delays	0		
Method: Present / Proposed	Inspection	0		
Type: Worker / Material / Machine	Combined	0		
Comments:	Storage	0		
	Time (min)	41.98		
	Distance (m)	76.84		

Description of events	Symbol: ●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
Go to weigh to take weighing filters		●					0.09	9.03	
Search weighing filters	●						1.38		
Go to work table		●					0.04	9.03	
Raw material intake	●						0.50		
Go to weighing area		●					0.10	9.03	
Weighing of raw material for samples	●						2.10		
Go to work table		●					0.06	9.03	
Placing samples of raw material on the table	●						0.02		
Go to warehouse R of reagents		●					0.06	4.99	
Search for reagents	●						0.78		
Go to the washing area		●					0.05	5.13	
Drink water	●						0.82		
Go to granulometry area		●					0.12	13.11	
Calibrate potentiometer while recording its use in the log	●						5.10		
Prepare samples	●						2.00		
Place samples in a sonicator and wait for their dissolution.	●						0.90		
Perform test with potentiometer	●						1.40		
Equipment cleaning	●						0.55		
Go to work table		●					0.09	7.51	
Leave the proof on the table	●						0.03		
Go to warehouse R to leave reagents		●					0.05	4.99	
Leave reagents	●						0.65		
Walked to work table		●					0.09	4.99	
Result record	●						25.00		

PROCESS FLOW DIAGRAM

Location: Quality Control Area	Summary			
Activity: Particle Size Distribution Analysis	Event	Present	Proposed	Savings
Date:	Operation	23		
Chemical analyst: / Observer:	Transport	18		
Circle the method and type	Delays	2		
Method: Present / Proposed	Inspection	1		
Type: Worker / Material / Machine	Combined	0		
Comments:	Storage	0		
	Time (min)	85.88		
	Distance (m)	54.88		

Description of events	Symbol: ●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
Waiting for equipment use			●				24.56		
Take raw material in weighing area	●						0.97		
Go to granulometry area		●					0.10	2.96	
Verification/Inspection of the mesh agitator equipment				●			0.83		
Place the sample in the equipment and start work	●						0.50		
Wait waiting for the end of the equipment			●				5.00		
Take the mesh	●						0.05		
Go to the work table and take a sheet		●					0.04	2.96	
From the 1st mesh clean raw material	●						0.53		
Go to weighing area		●					0.03	3.06	
Weigh 1st mesh sheet	●						0.37		
Go to work table		●					0.03	3.06	
From the 2nd mesh clean raw material	●						0.50		
Go to weighing area		●					0.03	3.06	
Weigh 2nd mesh sheet	●						0.27		
Go to work table		●					0.03	3.06	
Clean PM of 3rd mesh	●						0.63		
Go to weighing area		●					0.03	3.06	
Weigh 3rd mesh sheet	●						0.47		
Go to work table		●					0.03	3.06	
4th mesh cleaning	●						0.97		
Go to weighing area		●					0.03	3.06	
Weigh 4th mesh sheet	●						0.33		
Go to work table		●					0.03	3.06	
5th mesh cleaning	●						0.60		
Go to weighing area		●					0.03	3.06	
Weigh 5th mesh	●						0.27		
Go to work table		●					0.03	3.06	
6th mesh cleaning	●						0.67		
Go to weighing area		●					0.03	3.06	
Weigh 6 mesh	●						0.33		
Go to work table		●					0.03	3.06	
7th mesh cleaning	●						0.50		
Go to weighing area		●					0.03	3.06	
Weigh 7th mesh	●						0.35		
Go to work table		●					0.03	3.06	
Cleaning 8th mesh	●						1.20		
Go to weighing area		●					0.03	3.06	
Weigh 8 mesh	●						1.00		
Go to work table		●					0.03	3.06	
Equipment cleaning	●						3.00		
Search and log taking	●						0.13		
Record of equipment used in log	●						9.23		
Record in the corresponding documentation	●						32.00		

PROCESS FLOW DIAGRAM

Location: Quality Control Area	Summary			
Activity: IR analysis	Event	Present	Proposed	Savings
Date:	Operation	6		
Chemical analyst: / Observer:	Transport	0		
Circle the method and type	Delays	1		
Method: Present / Proposed	Inspection	0		
Type: Worker / Material / Machine	Combined	0		
	Storage	0		
Comments:	Time (min)	27.58		
	Distance (m)	0.00		

Description of events	Symbol: ●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
Turn on equipment	●						0.01		
Equipment power on wait			●				13.27		
IR Test Equipment Cleaning	●						2.40		
Put sample in pan (no need to weigh)	●						0.50		
Analyze and print the generated document	●						5.57		
Final cleaning of the equipment and registration in the log	●						5.53		
Turn off the equipment	●						0.30		

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PROCESS FLOW DIAGRAM+B2:N2B2:N29

Location: Quality Control Area
Activity: UV analysis
Date:
Chemical analyst: | Observer:
Circle the method and type
Method: Present Proposed
Type: Worker Material Machine
Comments:

Event	Present	Proposed	Savings
Operation	8		
Transport	6		
Delays	1		
Inspection	0		
Combined	0		
Storage	0		
Time (min)	43.72		
Distance (m)	33.29		

Description of events	●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
From the work table, go to the reagent warehouse R		●					0.17	4.99	
Search for reagents in warehouse R	●						0.36		
Go to the work table to place reagents		●					0.10	4.99	
Place reagents	●						0.05		
Go for the equipment for proof of identity essay		●					0.10	5.61	
Turn on equipment	●						0.38		
Go to work table		●					0.08	5.61	
Wait for the equipment warm up			●				15.00		
Go to the weighing area with reagent and raw material		●					0.10	9.03	
Weigh raw material for sample	●						1.45		
Take sample and reagent to walk to the equipment		●					0.04	3.06	
Preparation of the test with the sample	●						2.35		
Analysis by the equipment	●						5.55		
Log record of the equipment used	●						3.00		
Documentation in certificate	●						15.00		

PROCESS FLOW DIAGRAM

Location: Quality Control Area
Activity: Analysis of Color and appearance of the solution
Date:
Chemical analyst: | Observer:
Circle the method and type
Method: Present Proposed
Type: Worker Material Machine
Comments:

Event	Present	Proposed	Savings
Operation	14		
Transport	8		
Delays	2		
Inspection	0		
Combined	0		
Storage	0		
Time (min)	100.55		
Distance (m)	50.22		

Description of events	●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
From the work table, go to the reagent warehouse R		●					0.17	4.99	
Search for reagents in warehouse R	●						0.20		
Walked to work table		●					0.05	4.99	
Leave reagents	●						0.50		
Waiting for equipment use			●				65.23		
Take raw material	●						0.01		
Walked to weighing area		●					0.10	9.03	
Weigh raw material for samples	●						1.32		
Analytical balance cleaning	●						0.05		
Walked to work table		●					0.33	9.03	
Prepare solutions for tests	●						1.04		
Take tests to granulometry		●					0.03	7.51	
Put the tests in a dissolving apparatus	●						0.03		
Waiting for evidence			●				1.65		
Take tests from the dissolving apparatus	●						0.03		
Walked to work table		●					0.10	7.51	
Reference preparation and samples	●						2.52		
Walked to the chamber where the equipment for the analysis is located		●					0.13	3.58	
Take the equipment	●						0.10		
Walked to work table		●					0.07	3.58	
Test analysis	●						0.87		
Record of material used	●						5.00		
Equipment cleaning	●						5.52		
Registration in the corresponding documentation	●						15.50		

PROCESS FLOW DIAGRAM

Location: Quality Control Area
Activity: Analysis of optical rotation and heavy metals
Date:
Chemical analyst: | Observer:
Circle the method and type
Method: Present Proposed
Type: Worker Material Machine
Comments:

Event	Present	Proposed	Savings
Operation	11		
Transport	7		
Delays	1		
Inspection	0		
Combined	0		
Storage	0		
Time (min)	33.00		
Distance (m)	62.87		

Description of events	●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
Turn on equipment for optical rotation test	●						0.50		
Go to warehouse R for reagents and water		●					0.50	13.58	
Material Search for Heavy Metals	●						2.00		
Go to weighing area		●					0.10	14.74	
Sample weighing for heavy metals	●						1.00		
Walked to the hood		●					0.03	7.43	
Reagent is added to the flask	●						0.93		
Reagent is mixed with raw material to obtain the solution	●						0.43		
Go to flask lids area		●					1.00	4.83	
Lids search and placement	●						1.00		
Continue with the test	●						0.33		
Waiting for results			●				0.50		
Reading of results	●						1.00		
Walked to work table		●					2.00	8.41	
Record log is taken and record	●						0.50		
Go to the weighing area to leave RO test material		●					0.04	9.03	
Raw material weighing	●						0.67		
Go to granulometry area		●					0.05	4.85	
Optical rotation analysis and result annotation of both tests	●						20.42		

PROCESS FLOW DIAGRAM+B2:N17B38B2:N29

Location: Quality Control Area
Activity: Valuation Analysis
Date:
Chemical analyst: | Observer:
Circle the method and type
Method: Present Proposed
Type: Worker Material Machine
Comments:

Event	Present	Proposed	Savings
Operation	13		
Transport	10		
Delays	1		
Inspection	0		
Combined	0		
Storage	0		
Time (min)	78.27		
Distance (m)	78.26		

Description of events	●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
Go from the workbench to the reagent warehouse R		●					0.04	4.99	
Search for reagents	●						2.00		
Walked to weighing area		●					0.12	10.05	
Reagent weighing	●						3.15		
Walked to work table		●					0.10	9.03	
Walked to wash area for flask and water		●					0.06	3.97	
Filling the flask with water	●						1.07		
Walked to electric stove		●					0.32	8.04	
Placing flask with water on electric stove	●						0.04		
Walked to work table		●					0.12	8.04	
Search for materials (flasks, flask lid, etc.) and place on the table	●						0.62		
Walked to weighing area		●					0.10	9.03	
Perform weighing of raw material for tests	●						5.46		
Walked to work table		●					0.10	9.03	
Place the heavy raw materials on the table	●						0.50		
Walked to electric stove		●					0.12	8.04	
Remove water from electric stove	●						1.00		
Walked to work table		●					0.12	8.04	
Wait for water cooling			●				15.00		
Preparation of solutions	●						1.50		
Run tests	●						18.00		
Make calculation corresponding to the tests	●						1.00		
Cleaning	●						12.31		
Equipment registration in log and certificate	●						15.42		

PROCESS FLOW DIAGRAM

Location: Quality Control Area
Activity: Ignition Residue Analysis
Date:
Chemical analyst: | Observer:
Circle the method and type
Method: Present Proposed
Type: Worker Material Machine
Comments:

Event	Present	Proposed	Savings
Operation	12		
Transport	5		
Delays	6		
Inspection	0		
Combined	0		
Storage	0		
Time (min)	724.24		
Distance (m)	44.25		

Description of events	●	➡	D.	■	◉	▼	Time (min)	Distance (m)	Comments
In the weighing area weigh a sample of ascorbic acid	●						5.00		
Go to the grill		●					0.15	7.37	
Connect the grill	●						0.05		
Waiting for grill heating			●				60.00		
Place sample on grid	●						0.02		
Leave until the organic of the sample disappears			●				300.00		
Take out sample from grill	●						0.33		
Let sample cool while going to reagents for sulfuric acid search		●					0.20	14.07	
Search for sulfuric acid	●						2.23		
Waiting for sample cooling			●				27.57		
Add sulfuric acid to sample and place on grid again	●						4.00		
Wait for it to release odors			●				180.00		
Go to muffle		●					0.15	14.07	
Place sample in muffle	●						0.12		
Wait			●				60.00		
Remove samples from muffle	●						0.33		
Let samples cool			●				60.00		
Go to desiccator		●					0.08	0.70	
Place sample in desiccator	●						0.03		
Go to weighting		●					0.14	8.04	
Weight resultant	●						5.33		
Log record of the equipment used	●						10.00		
Documentation	●						8.51		

Acknowledgments

To the Polytechnic University of the State of Morelos and to the auto parts company for the facilities granted for the realization of this project.

Conclusion

The study of times and movements, despite being a tool that emerged at the end of the 19th century, is still widely applicable and useful to identify operations in production processes that do not add value, offering the opportunity to optimize the resources used.

In the present work, it was possible to detect the operations with waste of time in the analysis of ascorbic acid as a raw material and to develop proposals for improvement that allow reducing this time.

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Implementation of an inventory control system in the snack company

Implementación de un sistema de control de inventarios en la empresa de botanas

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Abstract

This engineering research consists of improving the control of inputs and outputs from the warehouse; Optimize the operations that are carried out to streamline the flow of the process towards production, using equipment (Racks, pallets, among others) and content that provides added value to generate a continuous flow within the company. These improvements will make it possible to devise a control system in the warehouse area that allows the user to carry out a verification of what enters and leaves the warehouse. In such a way, that it constantly reflects the fluctuating needs of the consumer. This will allow the company to better position itself in the market, translating this into an increase in sales and optimization of its resources (raw material and finished product).

Inventory system, Continuous improvement, Work measurement, ABC inventory

Resumen

Esta investigación de ingeniería consiste en mejorar control de entradas y salidas del almacén; optimizar las operaciones que se llevan a cabo para agilizar el flujo del proceso hacia la producción, utilizando equipos (Racks, tarimas, entre otros) y contenido que aporte valor agregado para generar un flujo continuo interno dentro de la empresa. Ésta mejora permitirá idear un sistema de control en el área de almacén que permita así al usuario llevar una verificación de lo que entra y sale del almacén, de tal forma, que éste refleje constantemente las necesidades fluctuantes del consumidor. Lo anterior le permitirá a la empresa posicionarse mejor en el mercado, traduciéndose esto en un aumento en las ventas y una optimización de sus recursos (Materia prima y producto terminado).

Sistema de inventario, Mejora continua, Medición del trabajo, Inventario ABC

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† Researcher contributing as first author.

Introduction

The project was developed in a company dedicated to the sale of snacks, located in the municipality of Jesús María, Ags.; it has 20 workers, including two managerial positions.

This project arises from the need to improve the delivery times of the orders and the conservation of the good condition of the product, for it was defined the control of inputs and outputs as well as specific measures related to waste and product shortages. The activity is carried out in the warehouse area where there is a product packaging area (see Figure 1).

Figure 1 Botanas Macías Warehouse
Source: Own elaboration with information from the company Botanas Macías

It is feasible to develop an inventory control system because it has a time of 15 weeks since it is intended to improve delivery times and the conservation of the good condition of the product. It will allow the worker to have a better control of the inputs and outputs in the warehouse. In such a way that it reflects the fluctuating needs of the consumer.

Description of the Problem

The company has been operating for five years without methodologies for the management and improvement of its results.

Given that the company intends to position itself in the market, improving compliance and the quality of its services to its customers, this project was proposed.

The first approach consisted of a Genba tour in its facilities, in which observations were made and workers were consulted.

Genba: "the real place" and refers to the act of directly seeing what happens (Melo, 2020).

Through this activity, we learned about the general problems in the warehouse area and basically the slowness to deliver the product to the shipment, as well as the waste of the product because there is no sequence of supply, packaging and delivery.

With the purpose of identifying the areas of opportunity in the mentioned areas in conjunction with the operators, from the 5W2H tool helped within what fits to identify what should be done, and question the objective raised, so that the action can be carried out, determine those responsible, to execute it and verify the location, duration, form and action in which it should be carried out, to be able to make an analysis of the cost of this with the PDCA cycle being able to act to planning and reality (Mercês Oliveira, 2021).

- What: What are the inputs and outputs of the process?

- Who: Who are the people involved in the processes? Who provides input to the processes? Who are the "customers" of the process?

- Where: Where does the work take place? Are all the necessary materials and equipment on site?

- When: Are all process inputs and information available when needed? Are lead times high or low?

- Why: What value does this process bring to the customer?

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A record of the answers of each operator and the observations seen during the tour was taken, reaching the conclusion that currently there is not adequate equipment to organize the warehouse (racks, shelves, among others), this causes that once the raw material is received from suppliers, This causes delays (see Figure 2) at the moment of delivering the product to the clients and there is no control of the inputs and outputs of both raw material and finished product; Considering that these are perishable products, this makes it difficult to comply with delivery times and leads to waste (MECALUX, 2021).

Name of the process: Compliance with the material requested by production.
Area: Warehouse of the company Botanas Macías.
Starts: Warehouse receiving rack
Ends: Warehouse receiving rack
Done by: Emmanuel De Luna Cardona.
Date: *02/21/2022*

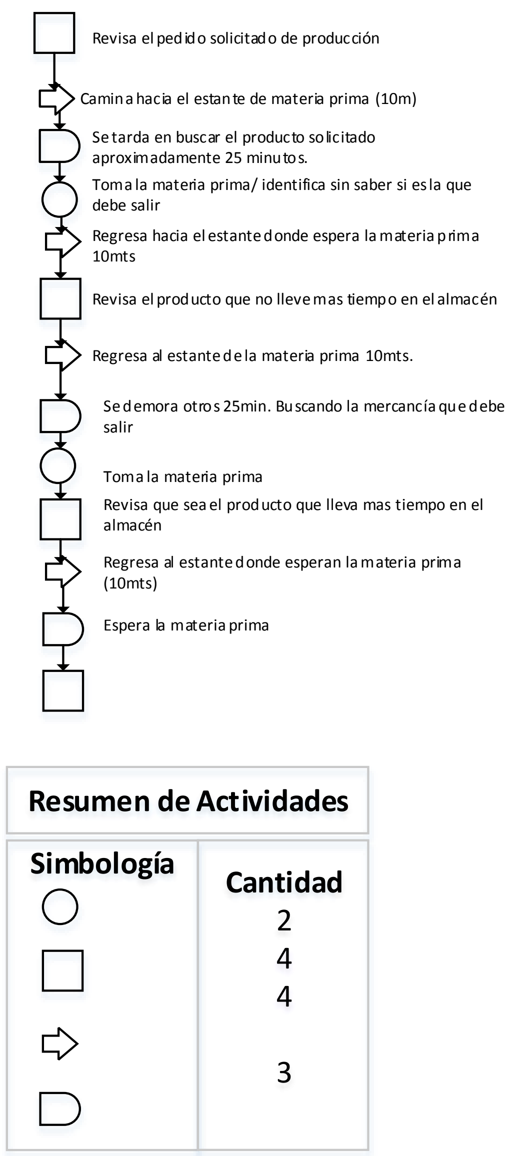

Figure 2 Process Flow Diagram
Source: Prepared by the company with information from Botanas Macías

A spaghetti diagram was made as a visual aid of all the routes that are made when raw material and finished product are requested to the warehouse manager. It was represented as it is in the actulity without making the established improvements where you can see the delays and all the dead times that are inside the warehouse (See Figure 3).

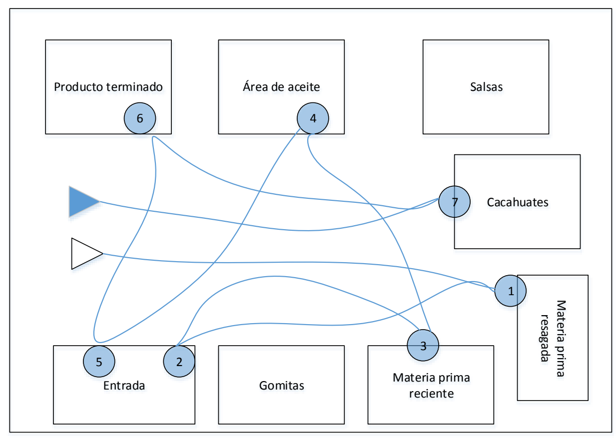

Figure 3 Spaghetti Diagram
Source: Own elaboration with information from the company Botanas Macías

General objective

To reduce by 50% the preparation time of a standard batch of product for shipment.

Methodology

The methodology to be applied is QC-STORY based on the Deming Circle to carry out the implementation of the project. The Deming Cycle (PDCA) is composed of four stages, so that, at the end of the last one, the first one begins again. This allows the activity to be evaluated again and again periodically incorporating new improvements. The four stages are as follows: Plan, Do, Check and Act (Eurofins Enviroment Testing Spain, 2023).

The stages on which the project will be based are as follows:

1. **Plan.** Identify the situation of the company with the help of a scatter diagram to see how far out of range the data obtained after having performed a process timeline (See Figure 4.).

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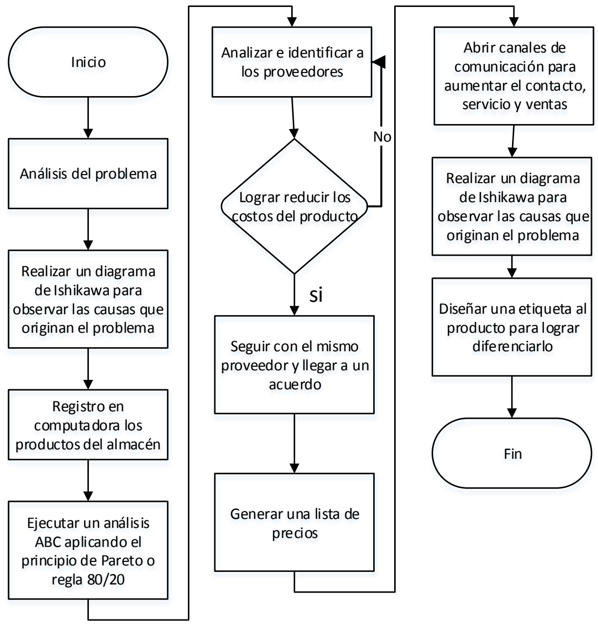


Figure 4 Flowchart for the application of the Kaizen methodology

To do**.** Perform a Cause-Effect diagram (Ishikawa) in order to observe and analyze the different causes that originate the problem and arrive at the root cause and be able to establish the necessary measures and actions to control the warehouse.

1. Verify. Classify the products in the warehouse with the help of an ABC analysis in order to identify all the most important items we have in the warehouse.

2. Act. Check sheets will be used to have a control and evidence of the improvements in the warehouse control system and once approved by the manager, they will be implemented.

Development

1. Plan

The identification of the problem and the objective are exposed at the beginning of this document, so we go directly to the next steps of the methodology.

Analysis of the current situation

We started with the stage of a time study with a stopwatch in the process of orders (30 pieces) to the customer that are made during an average day, in order to have a control of the situation in which the company is.

"The study of methods is the technique par excellence to minimize the amount of work, eliminate unnecessary movements and substitute methods. The measurement of work in turn, serves to investigate, minimize and eliminate unproductive time, that is, the time during which no added value is generated (Salazar Lopez, 2019).

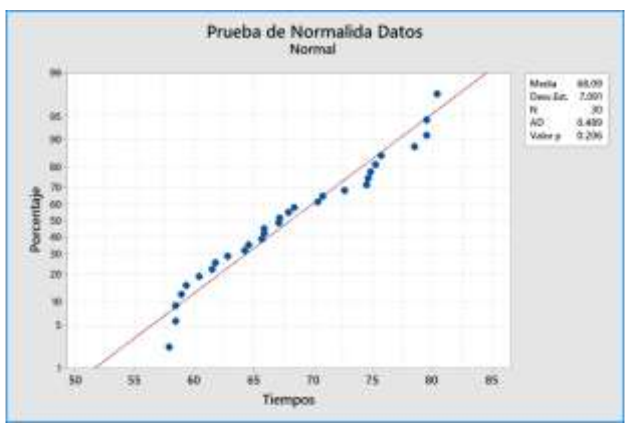
The customer cyclically places orders on a specific day of the week, and this information serves the operator to prepare the order one day prior to the scheduled delivery date and avoid waiting times.

The average time for order preparation is 68.09 minutes; this time is considered as the cycle time of the order preparation activity; it should be noted that the objective is to reduce 50% of the time (see Table 1).

Media	68.09
Medium	67.15
Mode	65.9
Standard Deviation	7.09

Table 1 Order preparation times.
Source: Own elaboration with information from the company Botanas Macías.

The average time to place it is 68.09 minutes. Taking into account that the problem is to reduce 50% of the time generated by the delays, it can be established that the objective is outside the specification limits as can be seen in the image (See Graph 1).



Graph 1 Normality test
Source: Own elaboration with information from the company Botanas Macías: Own elaboration with information from the company Botanas Macías

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The purpose of the Ishikawa Diagram is to make a graphical representation that allows to visualize the causes that explain the problem identified with the Gemba path and the process flow diagram because it brings better results and to ask the why of each cause. At this point the five whys technique will be used to discover the root cause of the problem.

As can be seen in the cause-effect diagram, all the causes that generate the lack of organization in the warehouse are found within the machinery, labor and method, all are focused on the absence of equipment in that area, therefore the operators do not perform their activities efficiently, causing these delays in the warehouse (See Figure 6).

Figure 6 Ishikawa diagram of the lack of organization in the Warehouse area
Source: Own elaboration with information from the company Botanas Macías

ABC analysis for inventory classification

The ABC analysis helps to prioritize performance and resources in the items that are important for the company.

A items: These refer to the most important items (the most sold or most urgent). The ones that provide the most revenue and have the highest profit margin (See Table 2).

ID100	Cueritos	105020	25	$ 263,000.00	$ 793,000	39.0%	A
F0205	Hard White	9402	22	$ 206,844.00	$ 999,844	49.0%	A
ID101	Fried	476	315	$ 149,940.00	$ 1,149,784	56.0%	A
K0300	Pistache	390	260	$ 101,400.00	$ 1,251,184	61.0%	A
2.07E+13	Confió chok	590	90	$ 53,100.00	$ 1,304,284	63.0%	A
3.07E+13	Gummy Fruit	1040	50	$ 52,000.00	$ 1,356,284	66.0%	A
3.07E+13	Gummy Bear	832	56	$ 46,592.00	$ 1,402,876	68.0%	A
k0302	Striped Carrot	1872	24	$ 44,928.00	$ 1,447,804	70.0%	A
7.50E+12	Dove	104	360	$ 37,440.00	$ 1,485,244	72.0%	A
3.07E+13	Gummy Worm	624	56	$ 34,944.00	$ 1,520,188	74.0%	A
IA101	Pork trunk	416	70	$ 29,120.00	$ 1,549,308	75.0%	A
F0101	Choco Strawberry	396	70	$ 27,720.00	$ 1,577,028	77.0%	A
C0003	Pork rinds	260	100	$ 26,000.00	$ 1,603,028	78.0%	A
C0001	Pork ear	364	70	$ 25,480.00	$ 1,628,508	79.0%	A
				$ 1,628,508.00			

Table 2 Products A
Source: Prepared by the company with information from Botanas Macías

Type B products: These are those of lesser importance or secondary use, i.e., all products that are for resale (see Table 3).

[illegible]

Table 3 Products B
Source: Own elaboration with information from the company Botanas Macías

Type C items: These are unimportant items. Therefore, having them in the warehouse often costs more money than the benefit they provide because they are perishable products (see Table 4).

[illegible]

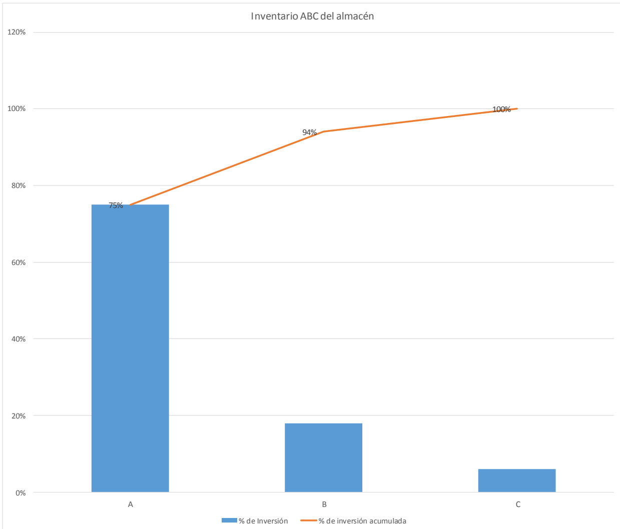
Table 4 Products C.
Source: Prepared by the company with information from Botanas Macías

Once the ABC analysis had been carried out, in which all the products in the warehouse were identified, the necessary calculations were made to have a record in numbers of what is in the warehouse (see Table 5).

	ZONA	Nº ELEMENTOS	% ARTICULOS	% ACUMULADOS	% INVERCION	% INV.ACUMULADO
0-80%	A	15	34%	34%	75%	75%
80% - 95%	B	17	39%	73%	18%	94%
95% - 100%	C	12	27%	100%	6%	100%
	Total	44	100%		100%	

Table 5 Item warehouse calculations
Source: Prepared by the company with information from Botanas Macías

The following Pareto Chart 2 shows the percentages of investment invested in the warehouse, which helps to see which products will be standardized first and, once this is done, the performance of the products and the reduction of the delays that currently exist can be seen.



Graph 2 Pareto Diagram
Source: Prepared by the company with information from Botanas Macías.

This diagram shows that starting with type A products, which are the most frequently ordered and sold products per day, we can achieve our proposed objectives.

In Zone "A" there are 15 items which represent 34% and are responsible for 75% of the investment.

In Zone "B" there are 17 items which represent 39% of the total number of items and are responsible for 18% of the investment.

In Zone "C" there are 12 items which represent 27% and are responsible for 6% of the company's investment.

Results and conclusions

We began to organize all the products (raw materials, peanuts, sauces, fried foods, gummies, among others) that are in the warehouse, giving priority to the products that were classified in section "A" according to the ABC analysis and consequently to products "B and C".

Next, we can see a before and after view of the routes that are made, visually we can see an order and better organization of the warehouse in which a better distribution of the area is observed, as well as a visual organization and with fewer routes within the same, reducing delays and search times, thus reducing the time of placing orders by almost 50% (See Table 6).

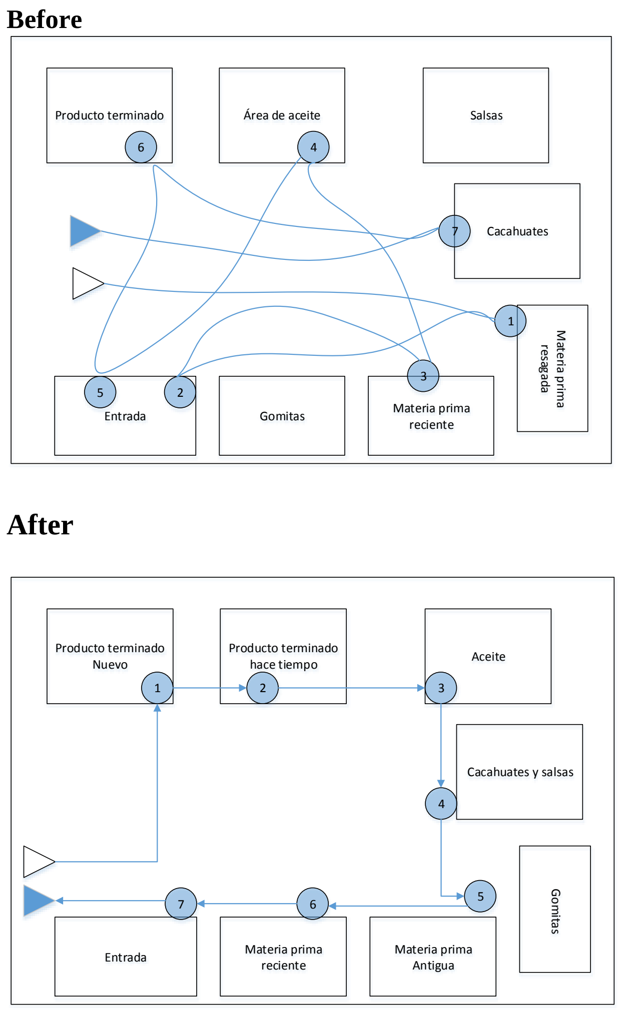


Figure 6 Spaghetti diagram before and after improvement.
Source: Prepared by the company with information from Botanas Macías

He took 30 times again, after having made the improvement of 33.08 min. having the products identified and avoiding searching for each one of them thanks to the implementation and standardization of the warehouse (See Table 6).

MEDIA	33.084
MEDIUM	33.7
FASHION	30.5

Table 6 Time taken after standardization
Source: Own elaboration with information from the company Botanas Macías

A series of calculations were made where it is observed in a quantifiable way the decrease in time when placing orders taking into account that the average time to place each order was 68.09 minutes, once the implementation and standardization of the area is done it is 33.08 minutes, which translates as an improvement of 52% less time than what it took previously.

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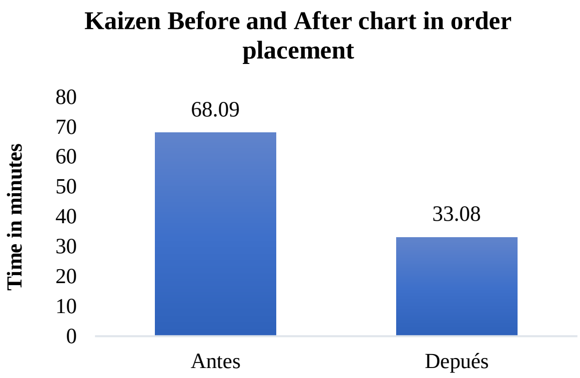
With this we can see that the objective of the project was achieved, since 48.58% of time was reduced when carrying out each of the orders (See Table 9) located in the annexes. In the following bar graph we can see the improvement in percentage of the decrease in time that is now made to perform each of the orders in the warehouse area (See Graph 3).



Graphic 3 Before and after the improvement of cycle times when placing each of the daily orders
(Secretaría del Trabajo y Previsión Social, 1999)Source: Own elaboration with information from Botanas Macias.

The products were ordered with the implementation of warehouse equipment and furniture (racks, pallets, shelves, among others) that the company purchased in order to better optimize resources and eliminate delays in these areas (See Figure 7, Figure 8, Figure 9, Figure 10).

Kaizen 1		
Site: Warehouse	**Purpose:** To assign a specific area for each product in the warehouse.	**Date:** 15/03/2022
Previously	**Then**	
		
Problem	**Result**	
All the frying and the hardboard were in disarray and together with the boxes of raw material.	With the determination of an assigned area for frying and hard products, sections were designed to place such product and achieve a greater optimization of the assigned area.	

Figure 7 Kaizen 1

In the warehouse there was no identification of the old product with the new one, as well as a separation by type of product (See Figure 9).

Kaizen 2		
Site: Warehouse	**Objective:** To organize the potato to keep control of the product in stock.	**Date:** 3/03/2022
Before	**After**	
		
Problem	**Result**	
The potato is not in the right place and there is no control of the material in stock at the moment.	All the potatoes are in the place that was determined so that both visually and with the record kept by the person in charge it is easy to locate the product and have control over it.	

Figure 8 Kaizen 2

The product offered by the company had been mixed up and a shelf had to be purchased for this classification and to have a better control of it (See Figure 10).

Kaizen 3		
Site: Warehouse	**Objective:** To organize the frying and classify it depending on the type of frying.	**Date:** 03/25/2022
Before	**After**	
		
Problem	**Result**	
All the fried food was disorganized and mixed up, which caused a waste of time when looking for the type of fried food requested.	The frying was organized in the racks by type and shape of frying so that no time is wasted looking for the product requested and the search time is optimized.	

Figure 9 Kaizen 3

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The Kaizen that was also performed was the organization of the arrival and departure of products and that the worker can more easily identify the product that has already been in the warehouse for some time with the one that has just entered (See Figure 10).

<table>
<tr><th colspan="4">Kaizen 4</th></tr>
<tr><td>Site:
Warehouse</td><td colspan="2">Objective: To separate and place the boxes of raw materials and sauces for a better location and management of the product.</td><td>Date:
03/25/2022</td></tr>
<tr><td colspan="2">Before</td><td colspan="2">After</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Problem</td><td colspan="2">Result</td></tr>
<tr><td colspan="2">Las cajas de la salsa se encuentran juntas con las frituras y no se tiene una clara visión del tipo de salsa que es.</td><td colspan="2">Se organizaron las cajas de manera que se dejó a la vista del operario el tipo y contenido de salsa que contiene.</td></tr>
</table>

Figure 10 Kaizen 4

Recommendations

Quality standards were established in conjunction with the company to maintain a balance of cleanliness, order and standardization. Over time, this will forge self-discipline in the operators and all the company's personnel in accordance with NOM-04-STPS-1999. This standard applies throughout the national territory and applies to all work centers that by nature of their processes use machinery and work equipment.

Quality policies

The correct execution of activities. The company must let all its personnel know that any activity concerning the company will be carried out by means of objective processes and management, previously marked in the company.

– Encourage the work spirit from the leaders to the workers.

– To elaborate a study to analyze the potential risk generated by the machinery and equipment in which an inventory of all the factors and dangerous conditions that affect the health of the worker (Employer) must be made.

– Train workers for the safe operation of machinery and equipment, as well as the tools they use to develop their activity (Worker).

– Comply with the measures indicated in the Specific Safety and Hygiene Program for the Operation and Maintenance of Machinery and Equipment (Worker).

– Keep the work area clean and tidy.

Acknowledgement

We would like to thank Botanas Macías for their support in improving the inventory control system.

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Grounding System Design of the main Electrical Substation of stones and minerals breaker plant in Campeche State to comply with the NOM-001- SEDE-2012, IEEE-Std-80-2000, and the Código de Red

Diseño del Sistema de Puesta a Tierra de la Subestación Eléctrica principal de una Planta Quebradora de piedra y minerales en el Estado de Campeche para cumplir con la NOM-001-SEDE-2012, IEEE-Std-80-2000 y el Código de Red

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Abstract

This article proposes the design of a grounding mesh for the main electrical substation of 150 kVA in the Breaker Plant in order to obtain a good path to drain overcurrents due to faults and prevent electrical installations from being a danger to connected equipment and users who use electrical installations, allowing voltage control to reduce the risk of shock to people who may come into contact with energized conductors; complying with current regulations NOM-001-SEDE-2012, IEEE-Std-80-2000 and the Código de Red and does not represent a danger of failure for the electrical network supplying CFE. There is a grounding system based on a delta of electrodes already many years after its installation and without maintenance and ineffective that has allowed the passage of overcurrents that have damaged motors. It is intended that the new design of the grounding system be reliable and safe and that, in addition, when an electrical installation verification unit (UVIE) arrives, it provides the Load Center with the Electrical Installation Verification Opinion, signing in agreement that it is complying with the applicable provisions of NOM-001-SEDE-2012, Electrical Installations (use), based on IEEE-Std-80-2000.

Grounding mesh, Substation, Overcurrent, Verification unit

Resumen

En este artículo se plantea el diseño de una malla de puesta a tierra para la subestación eléctrica principal de 150 kVA en la Planta Quebradora con el fin obtener un buen camino para drenar las sobrecorrientes debidas a fallas y evitar que las instalaciones eléctricas sean un peligro para los equipos conectados y los usuarios que usan las instalaciones eléctricas, permitiendo el control de voltaje para la reducción de peligro de descarga a personas que puedan entrar en contacto con conductores vivos; cumpliendo con la normatividad vigente NOM-001-SEDE-2012, IEEE-Std-80-2000 y el Código de Red y no represente un peligro de falla para la red eléctrica suministradora de CFE. Existe un sistema de puesta a tierra basado en una delta de electrodos ya con muchos años de su instalación y sin mantenimiento e ineficaz que ha permitido el paso de sobrecorrientes que han dañado motores. Se pretende que el nuevo diseño del sistema de puesta a tierra sea confiable y seguro y que además cuando llegue una unidad verificadora de instalaciones eléctricas (UVIE) proporcione al Centro de Carga el Dictamen de Verificación de Instalaciones Eléctricas firmando de conformidad que está cumpliendo con las disposiciones aplicables de la NOM-001-SEDE-2012, Instalaciones Eléctricas (utilización), basados en la IEEE-Std-80-2000.

Malla de puesta a tierra, Subestación, Sobrecorriente, Unidad verificadora

Citation: LEZAMA-ZÁRRAGA, Francisco Román, SHIH, Meng Yen, CHAN-GONZALEZ, Jorge de Jesús and SALAZAR-UITZ, Ricardo Rubén. Grounding System Design of the main Electrical Substation of stones and minerals breaker plant in Campeche State to comply with the NOM-001- SEDE-2012, IEEE-Std-80-2000, and the Código de Red. Journal of Technologies in Industrial Processes. 2023. 7-16: 19-27

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Introduction

This article proposes the design of a grounding mesh for the main electrical substation of 150 kVA in the Quebradora Plant in order to obtain a good way to drain the overcurrents due to faults and prevent electrical installations from being a danger to the connected equipment and users who use the electrical installations, allowing voltage control to reduce the danger of shock to people who may come into contact with energized conductors; complying with the current regulations NOM-001-SEDE-2012, IEEE-Std-80-2000 and the Network Code and does not represent a failure hazard for CFE's electrical supply network.

The objectives to be fulfilled by the grounding system of a substation, under normal and fault conditions are:

1. To provide the means to dissipate electric currents to ground without exceeding the operating limits of the network and equipment.
2. To ensure that people inside the substation and in its surroundings are not exposed to the danger of electric shock currents.

The design procedure that is developed corresponds to IEEE-Std-80-2000, allows to obtain safe levels of step and touch voltages inside the substation and in its vicinity. The calculation of the mesh voltage and the maximum step voltage are fundamental to corroborate the efficiency of the mesh.

When the grounding mesh design is square or rectangular, the mesh voltage increases along the mesh from the center to the corners of the grid, depending on its size, the number and location of grounding electrodes, the spacing of parallel conductors, the diameter and depth of the conductors, the soil resistivity and the connections, usually with exothermic welding.

The resistance values of grounding systems, according to current standards are:

a. NOM-001-SEDE-2012 is between 0 and 25 Ω.
b. IEEE-Std-80-2000 is less than 5 Ω.
c. CFE Specification 01J00-01, for the Código de Red, is less than 3 Ω.

Generally the grounding system is composed of a horizontal mesh of buried conductors, supplemented by grounding electrodes connected to the mesh with exothermic welding to penetrate deep layer soils that have lower resistivity. The electrodes are always installed along the perimeter and at the corners of the grid (IEEE, 2000).

Problem Statement

The Breaked Plant addresses the problem of its grounding system based on a delta of electrodes installed 26 years ago and without maintenance, so its operation is ineffective to the passage of overcurrents caused by atmospheric discharges or faults in the supply network, which has caused damage to motors and equipment connected to the low voltage electrical installation.

The grounding system in general is in poor condition; the anomalies found are listed below.

1. The grounding system with delta connected electrodes does not comply with the minimum electrode spacing. According to IEEE-STD-80-2000, a minimum spacing of 2 m is recommended. The electrodes or rods should be copper or copper coated, in our case the rods are very corroded and have a distance between them of 60 cm. See figure 1.

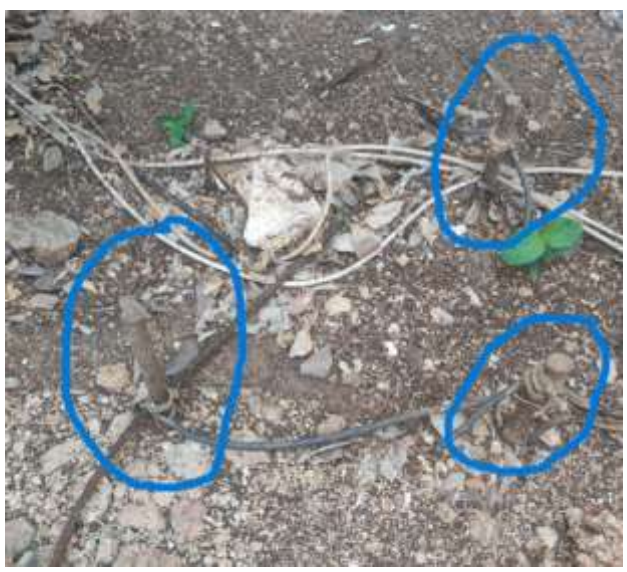

Figure 1 Delta grounding system
Own Elaboration

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2. In the Delta system, the connections between electrodes with the conductor must be made with exothermic welding. Here they are only tied together, only one electrode has a mechanical connector. This prevents optimum contact between electrode and conductor, which means that this is not a good way to drain overcurrents due to faults and is a danger for the connected equipment and the users of the electrical installations. See figure 2.

Figure 2. Connection between the electrode and the grounding conductor; it can be seen that only one of the three electrodes has its mechanical connector
Own Elaboration

3. The grounding conductor that is connected to the electrodes must be completely bare in order to make contact with the surface of the earth to have a real zero potential. In this system the conductor is sheathed.

4. The conductor must be a minimum 2 AWG gauge to ensure that the resistance to ground is less than 3 Ω; the conductor it has is 10 AWG gauge.

The ground resistance of the existing Delta system was measured; it was 26.4 Ω, which is a value not accepted by the NOM-001-SEDE-2012 and IEEE-Std-80-2000 standards. Therefore, the proposal is to design a grounding system based on a copper conductor mesh and electrodes in the corners.

In addition to complying with the provisions of NOM-001-SEDE-2012 and IEEE-Std-80-2000, the optimal design of the mesh is essential for compliance with the provisions of the Grid Code (DOF, 2020).

Methodology

For the design of the grounding grid, a methodology consisting of the following steps was used:

1. Preparation of tools, measuring equipment and personnel who will perform the measurements and field survey.

2. Physical survey in the low voltage installations and in the substation with the help of the electrical plans and one-line diagram, identifying each of the existing grounding systems.

3. Install the ground Megger equipment to obtain the soil resistivity and ground resistance levels of the existing grounding systems.

4. Analyze the information obtained from the survey and measurements to verify if these values comply with current regulations.

5. Define the anomalies found and give proposals for improvement, through a technical report.

6. If anomalies exist, define the efficient design of the grounding system of the main substation of the Quebradora Plant that complies with NOM-001-SEDE, the Código de Red and IEEE-Std-80-2000.

Single-line diagram

The single-line diagram was previously defined by Lezama et al (ECORFAN, Journal Electrical Engineering, 2022). Figure 3 illustrates only the Medium Voltage utility source to the 150 kVA main substation.

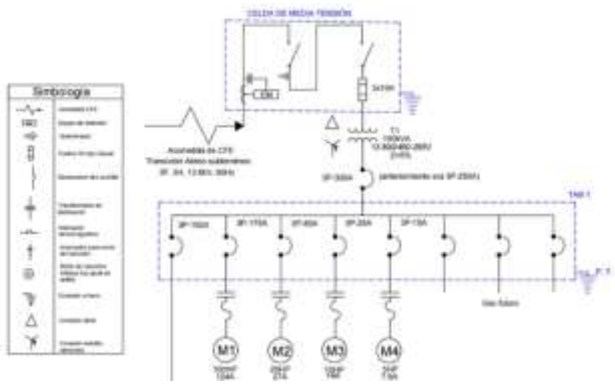

Figure 3 Updated single-line diagram showing the main substation
Own Elaboration

It is essential to keep the single-line diagram updated and to have it always at hand for any revision that may occur.

The following is the methodology for the design of the grounding mesh according to IEEE-Std-80-2000.

Soil resistivity

Soil resistivity measurements were performed in the area where the grounding mesh will be installed, determining the resistivity of the uniform layer by the four-point Wenner method (see figure 4).

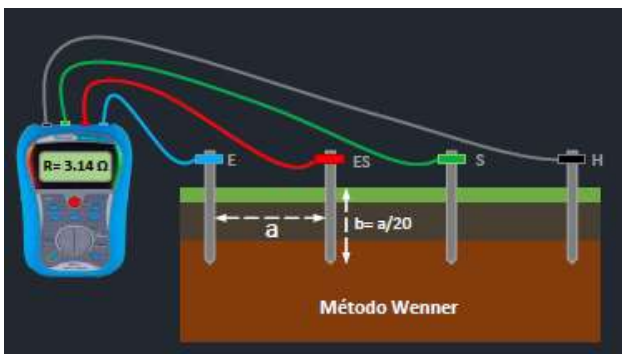

Figure 4 Soil resistivity measurement
Source: Mendoza García, Alan. Blue Energy Ingeniería. 2023

The four electrodes are driven into the ground in a straight line at a depth "b", separated at a distance "a".

If b << a, as is the most common case, the resistivity of the soil is determined through

$$\rho_a = 2\pi a R \qquad (1)$$

where ρ_a is the apparent resistivity in (Ωm), a is the separation distance between electrodes in (m) and R is the measured resistance in Ω.

The results of the measurements with the ground resistance tester are shown in Table 1.

Distance between electrodes (m)	Average Resistivity (Ω-m)
1	3.1
2	5.6
3	7.2
4	12.5
5	22.2
6	26.7
7	27.6
8	29.4
9	31.3
10	32.2

Table 1 Results of soil resistivity measurements of the Breaker Plant
Own Elaboration

The uniform equivalent resistivity ρ_{su} calculated by averaging the data obtained from the above table, *i.e.*, with eq:

$$\rho_{su} = \frac{\rho_1 + \rho_2 + \cdots + \rho_n}{n} \qquad (2)$$

in our case study, the $\rho_{su} = 19.78\ \Omega m$

To observe and analyze the measurements, it is presented in the resistivity curve below.

Graph 1 Soil resistivity curve
Own Elaboration

Grounding mesh design

The design of the grounding mesh is suggested empirically. The dimensions are provided in the following table.

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Design data	
Length short side of mesh Lx (m)	4.5
Length long side of mesh Ly (m)	6
No. of horizontal cond. in X nLx	5
No. of horizontal cond. in Y nLy	4
Grid size D (m)	1.5
Vertical conductor length Lr (m)	3
Vertical conductor diameter 2b (mm)	16
Number of vertical cond. nR	4
Mesh depth h (m)	0.6
Horizontal conductor diameter 4/0 AWG ***2a*** (mm)	13.4
*Mesh area **A*** (m2)	**27**
Total length cond. Horizontal ***Lc*** (m)	**46.5**
No. of total horizontal cond***. nLc***	**9**
Total length of horizontal and vertical cond. ***LT*** (m)	**58.5**

Table 2 Data for the design of the grounding grid of the Breaker Plant
Own Elaboration

The last four data in Table 2 were obtained through the set of equations given in (3):

$$\begin{aligned} A &= Lx * Ly \\ Lc &= Lx * nLx + Ly * nLy \\ nLc &= nLx + nLy \\ LT &= Lc + (Lr * nR) \end{aligned} \quad (3)$$

Mesh conductor sizing

IEEE Std 80-2000 states that, the conductor cross-section, as a function of the short time temperature rise, the magnitude and duration time of the fault and when the conductor material constants are known, can be determined with the equation

$$A = \frac{I_f}{\sqrt{[\frac{TCAP*10^{-4}}{t_c \sigma_r \rho_r}]\, ln[\frac{K_0+T_m}{K_0+T_a}]}} \quad (4)$$

where:

A = Conductor cross section [mm^2].
I_f = Maximum short-circuit current [kA]
Tm = Maximum permissible temperature [°C]
Ta = Ambient temperature [°C].
Tr = Reference temperature for material constants [°C].
σ_0 = Thermal coefficient of resistivity at 0°C [1/°C]
σ_r = Thermal coefficient of resistivity at reference temperature Tr [1/°C]
ρ_r = Resistivity of the grounding conductor at reference temperature Ta [μΩ-cm]
$K_0 = 1/\sigma_r$ [°C]
t_c = Current duration [seconds]
$TCAP$ = Thermal capacity per unit volume [J/cm^3/°C].

For copper conductors at a certain reference temperature and with a conductivity of 97%, the following values are obtained (IEEE,2000)

$\alpha_r = 0.00381\ {}^1/_{°C}, conT_r = 20°C$
$K_0 = 242°C$
$T_m = 480°C$
$\rho_r = 1.78\mu\Omega - cm, conT_r = 20°C$
$TCAP = 3.42\ {}^J/_{(cm^3 °C)}$
$T_a = 35°C$
$t_c = 0.5$ seg

Short circuit current (I_{cc}) will be calculated from the short circuit power provided by the supplying company, CFE Zona de Distribución Campeche, which is 645 MVA.

Since the most critical short-circuit current condition in the substation is produced by a phase-to-ground fault in the Medium Voltage connection of the 13.8 kV, of the Break Plant, the I_{cc} is calculated with the following equation

$$I_{cc} = \frac{MVA_{cc}}{\sqrt{3}(kV)}\ [kA] \quad (5)$$

substituting the data, we have

$$I_{cc} = \frac{645\ MVA}{\sqrt{3}(13.8kV)} = 26.98kA$$

Considering a forward growth factor of the system, *i.e.* f_c=1.3, the effective symmetrical fault current (rms) for the grounding grid design is

$$I_f = f_c * I_{cc} \quad (6)$$

For our system, I_f is

$$I_f = 1.3 * 26.98 = 35.074kA$$

Substituting the data in equation (4), we have the area A of the conductor cross-section

$$A = \frac{35.074}{\sqrt{[\frac{3.42x10^{-4}}{0.5*0.00381*1.78}]\, ln[\frac{242+480}{242+35}]}} = \frac{35.074}{\sqrt{0.1008*0.958}} =$$

$$112.86mm^2$$

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Therefore, for this conductor cross-section area, we have a 4/0 AWG gauge.

This conductor is the one empirically taken in the design section of the grounding mesh.

Resistance of the mesh

It is obtained based on the resistivity of the soil equivalent to a layer by means of Sverak's equation (IEEE Std 837-1989, Appendix B).

$$R_{g2} = \rho_{su}\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)\right] \quad (7)$$

Substituting the values obtained above, we have:

$$R_{g2} = 19.78\left[\frac{1}{57} + \frac{1}{\sqrt{20*18}}\left(1 + \frac{1}{1+0.6\sqrt{\frac{20}{18}}}\right)\right]$$

$$R_{g2} = 2.43\Omega$$

Table 3 shows the grounding resistance values of different types of substations provided by the IEEE-Std-80-2000, in our case it is a substation of an industrial plant and it is observed that the value of R_{g2} calculated is acceptable.

Type of electrical installation	Grounding resistance [Ω]
Subestaciones de gran tamaño (20,000 m^2) y de Transmisión	1 or less
Substations for industrial plants, large commercial buildings and facilities and small substations	Range 1 to 5
Individual electrodes (residential)	25
Individual transmission towers	10

Table 3 Grounding resistance values.
Source: IEEE-Std-80-2000

Mesh current

We will determine the maximum current to be dissipated by the ground mesh to avoid oversizing, according to the following equations:

$$I_G = D_f * I_g$$
$$I_g = S_f * I_f \quad (8)$$
$$S_f = \left|\frac{Z_{eq}}{Z_{eq}+R_{g2}}\right|$$

where:
I_G is the peak current in the mesh [A],
D_f is the decrement factor of the conductor,
I_g is the symmetrical mesh current [A],
S_f is the fault current division factor.
I_f is the ground fault current [A],
Z_{eq} is the equivalent impedance [Ω].
R_{g2} is the equivalent impedance [Ω].

According to our industrial installation, IEEE-Std-80-2000 recommends an *X/R* = 20. Thus, using Table 4 intercepting the column *X/R* equal to 20 with the row of fault duration time *tc* = 0.5 seconds, we obtain the decrement factor *Df* = 1.052. In the stone crusher substation, only one neutral of the CFE distribution circuit and no transmission lines are considered. Applying table 5 we obtain the $Z_{eq} = 1.29 + j0.967\ \Omega$.

Duración de falla t_f		Factor de decremento D_f			
Segundos	Ciclos A 60 Hz	X/R = 10	X/R = 20	X/R = 30	X/R = 40
0,00833	0,5	1,576	1,648	1,675	1,688
0,05	3	1,232	1,378	1,462	1,515
0,10	6	1,125	1,232	1,316	1,378
0,20	12	1,064	1,125	1,181	1,232
0,30	18	1,043	1,085	1,125	1,163
0,40	24	1,033	1,064	1,095	1,125
0,50	30	1,026	1,052	1,077	1,101
0,75	45	1,018	1,035	1,052	1,068
1,00	60	1,013	1,026	1,039	1,052

Table 4 Driver decrement factor
Source: IEEE-Std-80-2000

Table 5 Some approximate equivalent impedances of transmission line guard cables and distribution neutrals (feeders). *Source: IEEE-Std-80-2000.*

Number of transmission lines	Neutral distribution numbers	Zeq. Rtg=15, Rdg=25
1	1	0.91+j0.485
1	2	0.54+j0.33
16	0	0.163+j0.037
0	1	1.29+j0.967
0	2	0.643+j0.484
0	4	0.322+j0.242
0	8	0.161+j121

Table 5 Some approximate equivalent impedances of transmission line guard cables and distribution neutrals
Source: IEEE-Std-80-2000

We apply eq. (8) and obtain our design values:

$$S_f = \left|\frac{1.29 + j0.967}{1,29 + j0.967 + 2.43}\right| = 0.42$$

$$I_g = 0.42 * 35,074\ A = 14,731.08\ A$$

$$I_G = 1.052 * 14,731.08\ A = 15,497.096\ A$$

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Tolerable touch and step stresses

We start with the touch stress for a 50 kg person, which is given by

$$E_{\text{contacto}} = (1000\Omega + (1.5C_s * \rho_s)\frac{F_p}{\sqrt{t_s}} \quad (9)$$

Similarly, the touch stress for a person weighing 50 kg is calculated with the equation

$$E_{\text{paso}} = (1000\Omega + (6C_s * \rho_s)\frac{F_p}{\sqrt{t_s}} \quad (10)$$

The equation of the surface layer shrinkage factor (C_s), is introduced here, which is considered as a correction factor to calculate the effective resistance of a person's foot in the presence of a surface material of finite thickness; it is given by

$$C_s = 1 - \frac{0.09\left(1-\frac{\rho_{su}}{\rho_s}\right)}{2h_s+0.09} \quad (11)$$

where:
C_s is the surface layer shrinkage factor,
ρ_{su} is the soil resistivity [Ω-m],
ρ_s is the resistivity of the surface layer [Ω-m],
h_s is the thickness of the surface layer [m],
t_s is the maximum failure release time [s],
F_p is the maximum failure release time.

Calculating the surface layer shrinkage factor, we have:

$$C_s = 1 - \frac{0.09\left(1-\frac{2.43}{1000}\right)}{2(0.8)+0.09} = 0.946$$

The contact voltage is now determined:

$$E_{contacto} = \left(1000 + (1.5 * 0.946 * 10{,}000)\right) * \left(\frac{0.116}{\sqrt{0.5}}\right)$$

$$E_{contacto} = 2{,}491.9\ V$$

The step voltage is obtained with: $E_{paso} = \left(1000 + (6 * 0.946 * 10{,}000)\right) * \left(\frac{0.116}{\sqrt{0.5}}\right)$

$$E_{paso} = 9{,}475.45\ V$$

Ground potential rise and touch voltage evaluation

When a voltage is transferred from the substation grounding mesh to a remote external point near the grid, the *GPR* ground potential rise must be minimized:

$$GPR = I_G * R_{g2} \quad (12)$$

Substituting the data obtained above, we have:

$$GPR = 15{,}497.096\ A * 2.43\ \Omega = 37{,}657.94\ V$$

When comparing GPR with the $E_{contacto}$ obtained previously, it is observed that GPR is very excessive so we must perform some additional calculations.

Mesh tension and maximum step tension.

Because $GPR \gg E_{contacto}$, the mesh efficiency must be corroborated with the following set of equations:

$$E_m = \frac{\rho_{su} * I_G * k_m * k_i}{L_m}\ ;\ E_p = \frac{\rho_{su} * I_G * k_s * k_i}{L_s}$$
$$L_m = L_c + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2+L_y^2}}\right)\right] L_R$$
$$L_s = 0.75\ L_c + 0.85 L_R$$
$$k_m = \frac{1}{2\pi}\left[ln\left(\frac{D}{16hd} + \frac{(D+2h)^2}{8Dh} - \frac{h}{4d}\right) + \frac{k_{ii}}{k_h} ln\left(\frac{8}{\pi(2n-1)}\right)\right] L_R \quad (13)$$
$$k_h = \sqrt{1 + \left(\frac{h}{h_0}\right)}\ ;\ k_i = 0.664 + (0.148n)$$
$$k_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}(1 - 0.5^{n-2})\right]$$
$$n = n_a * n_b\ ;\ n_a = \frac{2 * L_c}{L_p}$$

where:
ρ_{su} is the soil resistivity [Ω-m],
I_G is the maximum current in the mesh [A],
k_m is the geometrical value of mesh spacing,
k_i is the irregularity factor,
k_s is the geometrical mesh factor,
L_m is the effective buried length [m],
L_s is the length of horizontal and vertical conductors,
L_c is the total length of horizontal conductors [m],
L_r is the vertical conductor length [m],
L_x is the length of the short side of the mesh [m],
L_y is the length of the long side of the mesh [m],
L_R is the total length of vertical conductors [m],
k_{ii} is a correction factor that adjusts for the effects of the conductors on the corner of the mesh,

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k_h is a correction factor that takes into account the effects of the depth of the mesh,
k_i is the irregularity factor,
h_0 is the reference depth, it is 1m.
n is the number of parallel conductors of an equivalent rectangular mesh,,
n_a y n_b are the geometrical factors of the mesh,
L_p is the length of the perimeter of the rectangular mesh [m].

We apply equation (13) and obtain:

$$L_m = 46.5 + \left[1.55 + 1.22\left(\frac{3}{\sqrt{4.5^2+6^2}}\right)\right] * 12$$

$$L_m = 70.95\, m.$$

$$k_h = \sqrt{1 + \left(\frac{0.6}{1}\right)} = 1.264$$

$$n_a = \frac{2*L_C}{L_p} = \frac{2*46.5m}{21m.} = 4.429 = 5$$

$$n = n_a * n_b = 5 * 1 = 5$$

$$k_m = \frac{1}{2\pi}\left[ln\left(\frac{1.5}{16*0.6*0.0134} + \frac{(1.5+(2*0.6))^2}{8*1.5*0.0134} - \frac{0.6}{4*0.0134}\right) + \frac{1}{1.264} ln\left(\frac{8}{\pi*((2*5)-1)}\right)\right]$$

$$k_m = 0.4985$$

$$k_i = 0.664 + (0.148 * 5) = 1.404$$

The mesh tension is:

$$E_m = \frac{15*15{,}497.096*0.4985*1.404}{70.95}$$

$$E_m = 2{,}293.09\, V$$

In addition, we calculate:

$$L_s = 0.75 * 46.5 + 0.85 * 12 = 45.075m.$$

$$k_s = \frac{1}{\pi}\left[\frac{1}{2*0.6} + \frac{1}{1.5+0.6} + \frac{1}{1.5}(1 - 0.5^{5-2})\right]$$
$$k_s = 0.603$$

Then, the maximum step voltage is:

$$E_p = \frac{15*15{,}497.096*0.603*1.404}{45.075}$$

$$E_p = 4{,}366.06\, V$$

According to IEEE-Std-80-2000, to define if the grounding grid design of the 150 kVA electrical substation of the stone crusher plant is optimal, the provisions of Table 6 must be complied with.

$E_m < E_{contacto}$	$E_p < E_{paso}$
2,293.09 V < 2,491.9 V	4,366.06 V < 9,475.95 V

Table 6 Comparison and evaluation of voltajes
Source: Own Elaboration

Therefore, our design complies with the specification. If in one case the limits of the step or touch voltages are exceeded, the grounding system design is required to be modified and can be improved by increasing the mesh area and smaller spacings in horizontal and vertical conductors.

Figure 5 illustrates the design of the grounding mesh that complies with the specifications of the current standards.

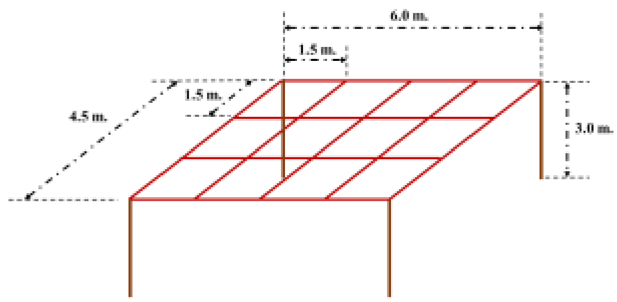

Figure 5 Grounding grid design
Own Elaboration

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Conclusions

The design of the grounding mesh in the stone and mineral crushing plant provides a methodology to obtain a robust grounding system for a distribution substation in the industrial, commercial and service sectors. It complies with NOM-001-SEDE-2012, IEEE-Std-80-2000 and the Código de Red.

Likewise, now there are electrical installations with voltage control, reducing the danger of shock to people who may come into contact with live conductors and avoiding damage to equipment such as motors, since there is a safe way to drain overcurrents.

As future work, the implementation of a lightning rod system against atmospheric discharges is recommended.

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Design of a model for the correct reporting of unproductive times in production lines

Diseño de un modelo para el correcto reporteo de tiempos improductivos en líneas de producción

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Abstract

The research carried out was conducted in a metal-mechanical company, where there were reporting problems from the operational staff, as well as productivity indicators that did not allow for the reliable analysis of the root cause of unproductive times, preventing continuous improvement in the production area. Therefore, a model had to be defined to prevent certain events that affected productivity. The research conducted was quantitative in nature since the hypotheses proposed were tested through data collection, based on numerical measurement and statistical analysis to establish patterns of behavior and test theories. Data collection focused primarily on the most frequently used unproductive time codes according to the stipulations in the quality management system. Additionally, productivity calculations were made comparing deductive codes with non-deductive ones to have a reference. The collected data was analyzed using descriptive statistics to obtain actions and reach the conclusion of the desired model to implement in the production area.

Statistical analysis, Quality, reliability, Root cause, Deductibility, Indicators, Production lines, Productivity, Reporting, Quality management system, Downtime

Resumen

La investigación desarrollada se realizó en una empresa de giro metal mecánico; en donde se presentaban problemas de reporteo de parte del personal operativo, además de indicadores de productividad que no permitían analizar la causa raíz de los tiempos improductivos de manera confiable que evitaba la mejora continua en el área de producción, por lo que se tuvo que definir un modelo que evitara que ciertos eventos que afectaban la productividad. La investigación realizada fue de tipo cuantitativo, ya que a través de la recolección de datos se probaron las hipótesis planteadas con base en la medición numérica y el análisis estadístico, para establecer patrones de comportamientos y probar teorías. La recolección de datos se enfocó principalmente en las claves de tiempo improductivo que se utilizaban con mayor frecuencia de acuerdo con lo estipulado en el sistema de gestión de la calidad, aunado al cálculo de productividad con comparativos de claves deducibles de las que no lo eran, para estar en la posibilidad de tener una referencia. Los datos recabados se analizaron mediante estadística descriptiva para la obtención de acciones y llegar a la conclusión del modelo que se quería lograr para implementar en el área de producción.

Análisis estadístico, Calidad, Confiabilidad, Causa Raíz, Deducibilidad, Indicadores, Líneas de producción, Productividad, Reporteo, Sistema de gestión de la calidad, Tiempos improductivos

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Introduction

The objective of companies is profitability; behind this concept are recognized other no less important concepts such as quality and productivity (Evans & Lindsay, 2020), but through whom is the achievement of the objectives set in an organization achieved? The answer would be: through the different areas and departments that make up the organization and, in turn, the human factor, which is the one that must make the right decisions, establish work methods and ensure that everyone is aware and convinced of the role they play and how they contribute to the achievement of goals and results.

Description of the problema

The problem of study began with a deficient reporting of unproductive times on the part of the production operators, since, through time, personnel from other areas at the staff level, had realized that this was not objective and most of the time, it was used for the convenience of manufacturing supervisors to present productivity indicators within the established parameters without facing the problems that commonly occurred in the production line.

In the same way, in the unproductive time table that was registered in the quality management system, there were keys that allowed deducting time from the total working hours.

A problem derived from what was mentioned in the previous paragraph is that the processes could not be optimized with statistical data based on criteria that were not correctly based and that presented deficiencies in their application, which did not contribute to the continuous improvement of the productive process.

The main problem to be eradicated through the implementation of a methodology was to get the operating personnel (both operators and supervisors) to change their way of thinking and to properly report the problems that arose during their work shift in order to improve the process and contribute to the profitability of the business.

The company where the research was carried out belongs to an international group where the indicators must be compared under the same criteria, in order to be able to benchmark and solve problems that affect the production lines globally.

Objectives

To determine if the current way of reporting unproductive times is correct, and also if it contributed to the decision making and strategic planning of the company. This being the general objective of the research.

In particular, the following objectives were proposed: to determine the deficiencies of the method that was being used at that time, as well as to investigate the causes of why production supervisors avoided reporting real problems, as well as productivity indicators out of context, and finally, to define a correct model for reporting unproductive times in order to have reliable productivity indicators for accurate and adequate decision making.

Justification

The definition of a downtime reporting model in the production lines was necessary, since it had been detected that the problems reported to the maintenance and engineering areas were not congruent with the productivity indicators reported by the different entities within the company.

The ideology of the production personnel was to obtain a certain productivity index, since this way, their performance was evaluated, which was completely detrimental to the company because the root causes that caused the problems or that the process was not optimized were not attacked.

By establishing a well-defined model, we wanted to contribute to the productivity and awareness of the operating personnel, with the objective of developing a continuous improvement process that would allow achieving the objectives and that each area would be responsible for the failures and errors that could occur (Robbins & Coulter, 2018).

Hypotheses and research questions

Among the hypotheses that could be obtained according to what was observed and to the previous knowledge in this research topic were: Process problems that occurred in the production lines were continuously reported with deductible keys to avoid off-target productivity indicators. More experienced and therefore older personnel used deductible nonproductive time keys more frequently.

At production reports with completely true data, the actions taken were more accurate (since the problem was known) and improved the process.

Some of the questions that were defined to study the problem were:

What were the reasons for production supervisors to manipulate the information stated in the production reports?

What was the impact of not having a defined model for the proper reporting of non-productive time?

By what percentage would productivity indicators be affected if deductible downtime keys were eliminated?

What was the disadvantage of reporting work shifts less than the actual work time?

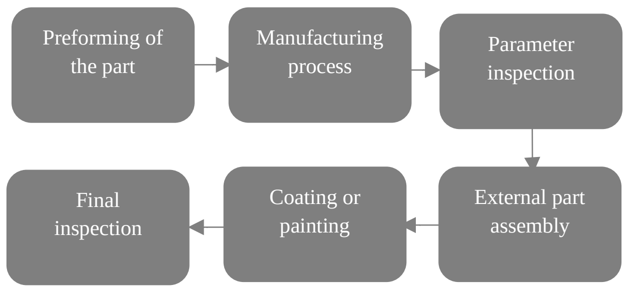
How could personnel safety be affected by continuing to report incorrectly?

Could machining and machinery problems be minimized on all production lines if they were reported, even if they only occurred in a particular area?

Process flow on production lines

A process flow structure refers to the way a factory or industry organizes the flow of material using one or more technologies (Freivalds & Niebel, 2014). Hayes and Wheelwright (1984) have identified four main structures in process flow: job shop, batch shop, assembly line or assembly line, and continuous flow.

The field of study for this research is the production line which refers to an assembly line or assembly line; where the production of parts moves from one workstation to another in a controlled rate, following the sequence necessary to manufacture the product. When other in-line processes are employed along with assembly, it is commonly referred to as a production line (Freivalds & Niebel, 2014), as exemplified in Figure 1:



Graph 1 Production Procedure
Source: Own Elaboration

Current model of non-productive time reporting

The fundamental purpose of work measurement is to establish time standards for a job. These are necessary for four reasons:

a) To schedule work and allocate capacity. All scheduling methods require an estimate of how much time is needed to do the work that has been planned.

b) To provide the basis for a target in order to motivate workers and measure their performance. Measured standards are particularly important when production-based incentive plans are employed.

c) To bid for and win new contracts and evaluate the performance of existing contracts. Questions such as: Can we do it? and How are we performing? Assume the existence of standards.

d) To provide benchmarks for improvement. In addition to internal evaluation, benchmarking teams regularly compare work standards in their company with similar work in other organizations.

Table 1 of non-productive times shows the following classification differentiated by numbers and letters:

Password	Concept	Example
I	Raw material supply.	Lack of prepared material.
II	Obstructed flow.	Material without the correct temperature, empty line or full line.
III	Machine failure.	Controls, sensors, failures in the main machine elements.
IV	Auxiliary equipment failure.	Hoist, cranes, lack of fluids.
V	Personal activities.	Training, meetings, absenteeism, delayed transportation of personnel.

Table 1 Non-productive times
Source: Own Elaboration

Productivity indicators

As stated at the beginning of this research, the main problem was that the measurement of work in the production lines was not reliable, due to the productivity calculation model that could be manipulated and have deductible type unproductive time keys.

According to Jacobs and Chase (2019), standard time is obtained by adding normal time and tolerances for personal needs; unavoidable delays in work (due to failures or breakdowns), as well as worker fatigue (physical or mental).

The equation representing the above statement is defined as:

Standard time = Normal time + (Tolerances x Normal time) (1).

Normal time = Observed performance time per unit x Performance index (2)

In the production lines where this research was carried out, the cycle time to determine productivity is calculated in the same way as the normal time. The productivity indicator is defined as follows (see table 2):

Indicator	Calculation
Productivity	Total Efficiency Index
Formula	Theoretical time / Time worked in a work shift. Theoretical time = Parts accepted per cycle time.
Unit of measure	Percentage.
Range	From 0 to 100%.
Objective	Measure operational effectiveness over a time interval.
Results	The total efficiency index shows the performance of a production line. If the data is not correct, the indicator will give a false picture.

Table 2 Productivity indicator
Source: Own Elaboration

Manufacturing data management system

The model to be developed must be compatible with a manufacturing data management system. Currently with Industry 4.0, manufacturing and production processes are based on database technology. Companies keep this information on finished goods, raw materials and inventories, and goods in transit that can be used in supply chain management. The manufacturing process employs numerous supplier, work progress, product component, quality, and cost databases (Laudon & Laudon, 2016).

The electronic recording of production batches or data, enables manufacturing completely free of paper reports. On the other hand, it optimizes production, because it reduces workload and increases accuracy, improves batch release time and reduces manufacturing errors.

A manufacturing data management system has the following characteristics: reduction in work in process, cycle times, product in process, overtime and order issuance and, on the other hand, increases throughput, timely deliveries and customer satisfaction.

Training and awareness

The implementation of a data management system requires the involvement of several areas and departments of a company, mainly in this case (Laudon & Laudon, 2016):

Production: It will use a new reporting model and a technological system for real-time capture of stoppages or unproductive times.

Information technology: To adapt the current system and install the necessary communication networks and execute software updates.

Maintenance: To repair and support equipment.

Purchasing: To establish contracts, warranties and supplier scope.

At this point, it was necessary to train, educate, raise awareness and break paradigms of all participants and users of the project to change the traditional way of working to the new reporting model to calculate the productivity indexes of the production lines.

Type of research

The research project that was developed required a quantitative type of research, since in order to define the non-productive time reporting model we could count on indicators or statistics, which provided data such as scores or numerical values. Additionally, we also relied on qualitative research as it is a type of formative research that offers specialized techniques to obtain in-depth answers about what people think and what their feelings are. This allowed program managers to better understand the attitudes, beliefs, motives and behaviors of a given population.

On the other hand, the type of design had to be non-experimental, due to the fact that it is not intended to "choose or perform an action and then observe the consequences" (Hernández-Sampieri et al., 2014, p. 129). What was intended was to develop a study without deliberate manipulation of the variables and in which only the phenomena were observed in their natural environment and then analyzed.

For this research, by having a reference and being able to evaluate the result of the productivity indicator at different points in time to make inferences about the change, its causes and effects, it was determined that the design was longitudinal.

The field of study of the project was two production lines, so the longitudinal design was of the panel type. An advantage of this type of design is that it was possible to know when group and individual changes occurred.

Sampling plan

In this research process, a non-probabilistic sample was selected, due to the fact that the choice of the elements depends on the causes related to the characteristics of the research or of the person making the sample.

It was determined to select this type of sample because sometimes it is necessary to take into account particular criteria or characteristics of each area of study. For example, one production line in comparison with the other is faster because of the type of material it uses or the dimensions it processes, noting that the problems of lag and deductible keys in the faster line would not represent a reliable sample to corroborate the hypothesis of finding a relationship between these two variables.

An advantage of a non-probabilistic sample (from the quantitative view) should be mentioned, according to Hernández-Sampieri et al. (2014), it is useful for a certain study design that does not require a representativeness of elements of a population, but a careful and controlled choice of subjects with certain characteristics previously in the problem statement.

For this case study, eight production operators who are the ones who perform the reporting of unproductive time regardless of their years of experience in the position had to be sampled.

Measuring instruments

The data collection used to record data on the variables we had in mind were surveys, which were applied to the workers mentioned in the previous point, where we quantified the perceptions of the personnel in relation to how they used the unproductive time keys and the considerations they made when using them, as well as reaching a conclusion on the way operators report with different characteristics such as: age, work experience, schooling and assigned work area.

The quantitative analysis allowed us to observe the behavior of the personnel when faced with a change in the methodology of the non-productive time reporting keys.

The databases were very useful for conducting studies that, through content analysis, were able to communicate positively, systematically and classify the elements.

Likewise, categories were assigned to a possibility of events that could occur in the production lines (unproductive times) and that were catalogued in keys, categories and groups so that the model would be reliable.

If we had been able to clearly identify the groups of downtime keys, the analysis of productivity indicators would have been more comprehensive and would have provided us with more information for proper decision making to attack and try to minimize each category.

In the table used to consult the downtime keys, there were some codes that referred to technical defects of the product such as: poor finish, roughness, vibration, stains, sharp edges, etc., but these could be caused by deficiencies in the operation (Production), machinery failure (Maintenance), lack of criteria or information (Quality) or failures in the tools and design programs (Engineering).

With the methodology to be developed, it was intended that each problem would be well identified and that each key could be assigned to a single responsible area to avoid confusion and address them properly.

If the above was implemented, the operator and production supervisor would be relieved of some responsibility, because, in the absence of a correct classification, they tried to invent or report what they thought was best, resulting in false indicators and false problems in the manufacturing process.

Characteristics of the application

The data obtained from the applicable measuring instruments were analyzed using descriptive statistics tools for each variable and frequency distributions were elaborated and represented by histograms and pie charts.

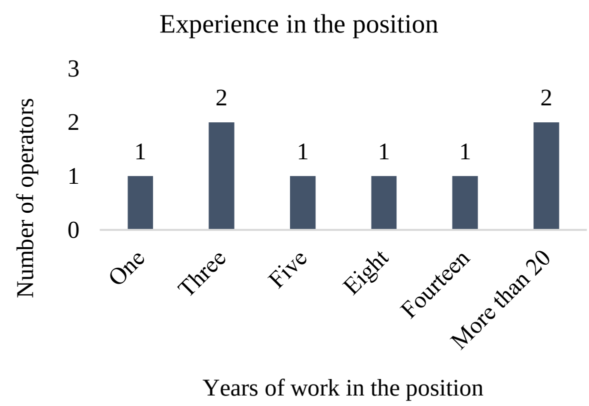
The implementation of the methodology had to be practical, homogeneous, easy to apply and unwavering; that is to say that, over time, it would not be distorted and would continue to meet the objectives that had been set at the beginning of the research.

Collection, processing and analysis of information

A survey was applied to the total sample to find out their opinion of the unproductive time keys they use, how they use them and their general perception of them. The data obtained from the survey were analyzed by means of the quantitative matrix, and then a graph was made to analyze the results in a practical way.

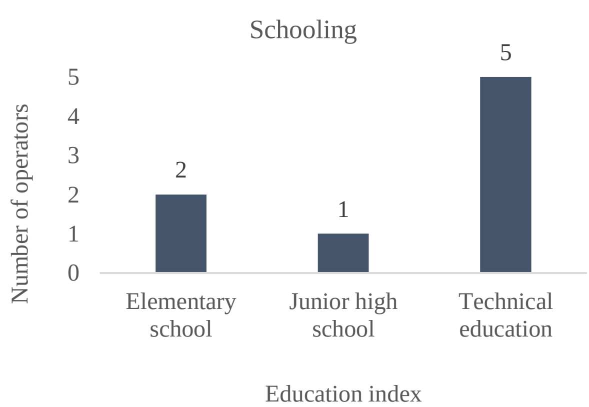
The general data are represented by the following bar graphs.

We can observe in graph 2 that most of the operators have been in the position for eight years or less, which would facilitate the application of a new reporting model.



Graph 2 Work experience
Source: Own elaboration

Another factor that will contribute to the implementation of a new methodology is that most of the operators have a technical degree, which means that they have more precise concepts about quality, productivity and continuous improvement (see Graph 3).



Graph 3 Education index
Source: Own Elaboration

The results of the survey were as follows:

69% of the operators considered that they do not know the application of all the non-productive time keys. The conclusion is that there is a lack of a table of criteria for the use of each one of them; it also gave us the possibility to provide training to all the operators focusing on the new methodology.

Seventy-seven percent of the operators stated that there are unproductive time keys that they have never used, which made us think that certain keys do not have a specific function and their description generated confusion or was simply obsolete, because at some point they were used, but it was no longer necessary.

All the operators surveyed stated that events have occurred in which there is no downtime key defined for that situation, so it is determined that keys have been used that have not reflected the real problem, generating bad decision making by the support and service areas.

Eighty-five percent of the operators stated that deductible downtime keys have been used in stoppages of one hour or more, which made us accept our hypothesis about machine failures and machining problems that are not reported with the appropriate keys, so as not to affect the calculation of the productivity index.

Finally, the operators unanimously agreed that reporting through an electronic system would benefit them, a situation that might be surprising, since it would be thought that operators with more than ten years of experience would not accept a technological system to support their daily activities.

Non-productive time reporting methodology

The problem that was posed to be solved was that unproductive times were not reported with deductible keys that reduced the total work time to obtain fictitious productivity indicators, and that the real root cause of the problems was not found.

The existing model contained the following information (see figure 1):

- 12 key groups.
- 160 codes chosen by the production area.
- 16 deductible codes.
- 52 keys with area of responsibility.

Category	Codes	Deductible codes
Lack of material supply	10	1
Obstructed flow	18	0
Machine failure	22	0
Auxiliar equipment failure	15	1
Operational failure	8	1
Tools failure	5	0
Inspection failure	7	0
Set up	12	2
Testing	4	4
Technical failure	49	0
Personal activities	6	6
Several	4	1
Total	160	16

Figure 1 Undeclared non-productive time.
Source: Own elaboration

The proposed model considered creating groups of keys or modifying some of the existing ones according to the information available and taking into account the knowledge acquired through the experience of repetitive events occurring in the production line.

In the same way, the codes of the non-productive time keys were changed according to the name of the group to which they belong, in order to be better understood by the operator. In a historical utilization analysis, a table was made with the keys from those that were most used to those whose time was definitely not considerable (see figure 2).

Codes	% of codes reported	Code type
Personal activities	4.91%	Non deductible
Training	4.34%	Deductible
Meeting	3.37%	Deductible
Testing	3.18%	Deductible
Set up	1.36%	Non deductible
Scheduled stopped	1.31%	Deductible
Machine failure	1.01%	Deductible
More than 63 codes	0.02% - 1.00%	5 deductible codes
90 codes	0 – 0.01%	6 deductible codes

Figure 2 Keys to unproductive time
Source: Own Elaboration

The new methodology considered the following information (see figure 3):

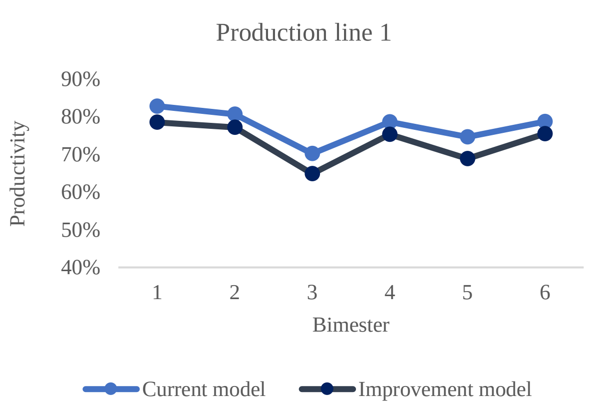
– 13 key groups.
– 90 codes chosen by the responsible area.
– 05 deductible codes.
– All keys with area of responsibility.

Category	Codes	Deductible codes
Lack of work orders	1	1
Testing	5	5
Preventive maintenance	5	5
Training	4	0
Fine tunning	6	0
5S - TPM Methodology	4	0
Personal activities	2	0
Lack of raw material	5	0
Absenteeism	3	0
Set up	9	0
Machine and operational equipment failure	30	0
Non quality process	16	0
Total	90	11

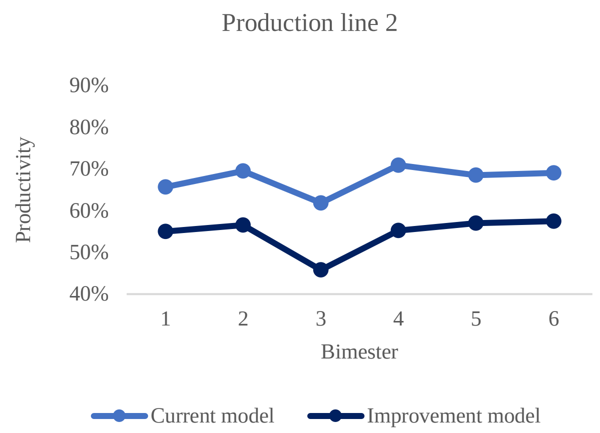
Figure 3 New methodology
Source: Own Elaboration

Results

Developing a new model that would directly affect the company's production indicators was not a simple and challenging task to achieve a paradigm shift. However, it was the beginning of a new era where the lost productivity points generated a new objective, so that in a time horizon of two years they would be recovered and would be solving real and specific problems. In graphs 4 and 5 you can see the productivity increases during one year of analysis, after implementing the improvement methodology.



Graph 4 Production line 1
Source: Own Elaboration



Graph 5 Production line 2
Source: Own Elaboration

Conclusions

After the research carried out, it was possible to conclude that process problems that took an hour or more were reported with deductible time keys so as not to affect the productivity indicator. It was also possible to confirm that the most experienced personnel reported their unproductive times in the correct way, but showed willingness to receive technological support for their daily activities.

The production supervisors reported with incorrect time keys because they felt that they did not have the support of the management or the service areas and they felt committed to deliver good indicators to the corporate.

The work area with the fastest pace in its work rhythm, the impact of the application of the new methodology only represented 5%; on the other hand, the slowest area had an impact of up to 15% less productivity in some bimonthly periods.

The activities carried out for the design of this new model made it possible to raise awareness in all the areas that were jointly responsible for the productivity indicators, working to generate strategies to reduce the impact on the production process.

After informing and training all the personnel in this new model and mainly in communicating its objective, a new project was started to select a supplier that would allow the reporting to be done in real time through automation.

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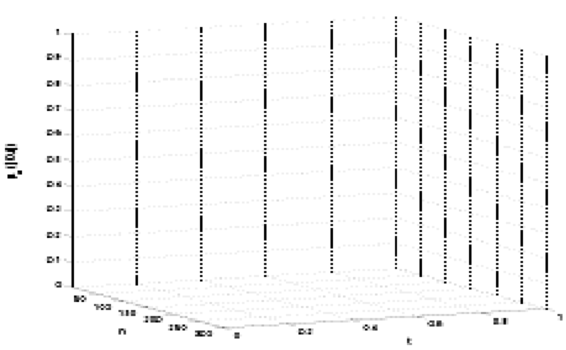

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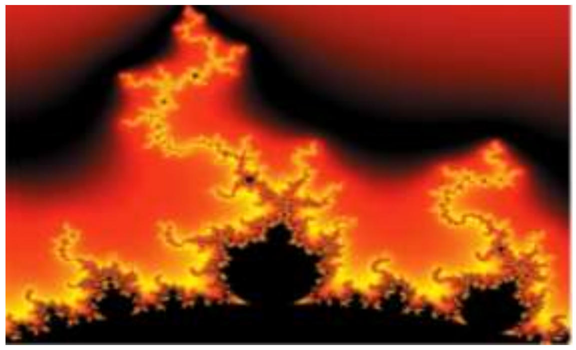

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