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Journal of Research and Development

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Presentation of the Content

In the first chapter we present, *Energy efficiency using Distributed Generation; Cafeteria of Engineer Faculty Campeche*, *Mexico*, by CHAN-GONZALEZ, Jorge J., SARAVIA-PÉREZ, Isaac A., LEZAMA-ZÁRRAGA, Francisco and SHIH, Meng Yen, with adscription in the Universidad Autónoma De Campeche, as next article we present, *Lean Manufacturing: Efficiency improvement application in multi-product area of the Aerospace Industry*, by CANO-CARRASCO, Adolfo, FORNÉS-RIVERA, René Daniel, VÁSQUEZ-TORRES, María del Carmen and GUERRERO-PORTILLO, Arlene Amalia, with adscription in the Instituto Tecnológico de Sonora, as next article we present, *Ergonomic culture level in managers and supervisors in manufacturing centers*, by LÓPEZ-ACOSTA, Mauricio, CHACARA-MONTES, Allán, VELARDE-CANTÚ, José Manuel and RAMIREZ-CARDENAS, Ernesto, with adscription in the Instituto Tecnológico de Sonora, as next article we present, *Proposals to improve the coaxial cable assembly process in an aerospace company*, PORTUGAL-VÁSQUEZ, Javier, SANDOVAL-GAMEZ, Melissa, LAGARDA-LEYVA, Ernesto Alonso and NARANJO-FLORES, Arnulfo Aurelio, with adscription in the Instituto Tecnológico de Sonora.

Content

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Energy efficiency using Distributed Generation; Cafeteria of Engineer Faculty Campeche, Mexico

Eficiencia energética con Generación Distribuida Fotovoltaica (GD-PV); Cafetería de la Facultad de Ingeniería de la Universidad Autónoma de Campeche, México

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Abstract

In the present work, an integral design of the cafeteria located at Faculty of Engineering of Autonomous University of Campeche is carried out. Four scenarios of Photo Voltaic (PV) generation have been studied. A 14 PV modules arrangement of 440 each, with azimuthal angle of 180º and a slope angle of 15º; the other is similar to the previous, but the slope angle was 19.85º. The following was a 24 PV modules arrangement of 440, with an azimuthal angle of 218º and a slope angle of 15º. The last arrangement consists of 24 PV modules arrangement of 440, with azimuthal angle of 218º and a slope angle of 19.85º. Where all of them are associated with the economic aspect to obtain greater efficiency of the plant with minimum recovery time. The free software System Advisor Model (SAM) developed by the National Renewable Energy Laboratory (NREL) has been employed. Complete seasonal analysis has also been performed considering Gran Demanda Media Ordinaria en México (GDMO de CFE in Mexico) within the period January 2020 to March 2021. The best results are energy generation 17,570 kWh. Capacity factor 19%. Energy performance 1,671 kWh/kW. Performance relation 0.74. Leveled cost 5.39 ¢/kWh. And return on investment in 0.6 years. The GD-PV plant prevents the emission into the atmosphere of 778.85 kg of CO_2 equivalent.

Distributed generation, Energy efficiency, Grid-connected photovoltaic systems, Photovoltaic distributed generation

Resumen

En el presente trabajo se realizó un diseño integral de eficiencia energética en la cafetería de la Facultad de Ingeniería de la Universidad Autónoma de Campeche, México. Se analizaron 4 esquemas diferentes: un arreglo fotovoltaico de 14 módulos de 440 cada uno, ángulo azimutal de 180º y ángulo de inclinación de 15º; el otro fue similar al anterior pero con ángulo de inclinación de 19.85º. El siguiente fue de 24 módulos de 440, ángulo azimutal de 218º y ángulo de inclinación de 15º; por último arreglo fotovoltaico de 24 módulos de 440, ángulo azimutal de 218º y ángulo de inclinación de 19.85, asociados al aspecto económico, para obtener la mayor eficiencia de planta en el menor tiempo de recuperación. Se empleó el software libre System Advisor Model (SAM) desarrollado por el National Renewable Energy Laboratory (NREL). Contempló las tarifas económicas con análisis temporal completo, horario en tarifa Gran Demanda Media Ordinaria en México (GDMO de CFE en México). Los datos de facturación de la Comisión Federal de Electricidad fueron de enero de 2020 a marzo de 2021. Los mejores resultados son: Generación de energía, 17,570 kWh. Factor de capacidad 19%. Rendimiento energético 1,671 kWh/kW. Relación de desempeño 0.74. Costo nivelado 5.39 ¢/kWh. Retorno de inversión 0.6 años. La planta GD-PV previene la emisión a la atmósfera de 778.85 kg of CO_2 equivalente.

Generación distribuida, Eficiencia energética, Sistemas fotovoltaicos interconectados a red, Generación distribuida fotovoltaica

Citation: CHAN-GONZALEZ, Jorge J., SARAVIA-PÉREZ, Isaac A., LEZAMA-ZÁRRAGA, Francisco and SHIH, Meng Yen. Energy efficiency using Distributed Generation; Cafeteria of Engineer Faculty Campeche, Mexico. Journal of Research and Development. 2021. 7-20: 1-12

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Introduction

The Faculty of Engineering of the Universidad Autónoma de Campeche currently has an outdoor cafeteria. It currently has a transparent polycarbonate roof. However, the accrediting institutions of the Bachelor's degree programs have made the recommendation that the Faculty should have a more adequate cafeteria with, among other things, an air conditioning system. A multidisciplinary cabinet projected the construction of a new cafeteria that has all the amenities for a healthy recreation and relaxation of students, teachers and administrative staff. In this work an integral design was made to guarantee energy efficiency in the cafeteria of the Faculty of Engineering of the Autonomous University of Campeche, Mexico.

The architectural project consists of designing an enclosed space with capacity for approximately 80 people (diners and dependents). For these infrastructure dimensions, the number of people contemplated and that the building was planned with few windows that are exposed to solar radiation. It is considered to have a total heat gain of approximately 16 kW-thermal (4.5 TR, 54,000 BTU/h). So with 2 units of 10.6 kW-thermal (3 TR, 36,000 BTU/h, commercial capacities) we will have a total of 21.2 kW-thermal (6 TR, 72,000 BTU/h) sufficient to remove the total heat from the cooler.

During the engineering project development stage, it is very necessary to visualize different possible scenarios in the installation of a photovoltaic generating plant, such as the optimal inclination, the minimum height of the modules with respect to the surface, among others, and in turn all of them invariably associated to the economic aspect, in such a way that the highest plant efficiency is obtained in the shortest recovery time. To plan all these scenarios is an arduous task that requires the help of a computer program. In this sense, we used the System Advisor Model (SAM) software developed by the National Renewable Energy Laboratory (NREL) of the United States of America, for two important reasons: it is free and contemplates the economic rates that allow us to analyze the optimal performance of the plant, as well as its return on investment. The SAM program allowed the complete temporal, hourly analysis of the Gran Demanda Media Ordinaria en México (GDMO of CFE in Mexico) tariff during the 8760 hours of the year.

The tariff part is the most complex part of the programming, but it allows to do it; other similar programs do not have this analysis capacity. It allowed a finer analysis by relating the energy yield equations to an economic analysis (cash flow, net present value, payback time, cost benefit and internal rate of return). Distributed Generation (DG) from renewable energies has increased worldwide as an efficient tool to lower electric energy costs, since it reduces transmission costs, as well as increases the electric efficiency of the Load Center where it is installed. It represents a direct help to companies and governmental institutions to be more competitive on the one hand and to reduce their operating expenses on the other hand; this favors economic development.

Distributed Photovoltaic Generation (DG-PV) has become one of the main ways to generate electricity with renewable sources (Pinargote, D. F. G., et al 2021). In addition to delivering electric power directly to the grid, it provides other added values such as mitigating greenhouse gases and performing as a thermal barrier on the roofs of the buildings that house them. In other words, they prevent solar radiation gain in buildings, a fact that is especially relevant in hot-humid climates such as that of the state of Campeche, Mexico. By taking advantage of DG-PV in an educational institution in the state of Campeche where the reduction of energy consumption for air conditioning is imperative, and one of the main challenges to overcome is to curb heat gains from solar radiation, it becomes very attractive.

These actions generate net economic benefits to justify the payment of the initial investment. Distributed Generation (DG) is defined as: "the generation of electric energy that is interconnected to a distribution circuit containing a high concentration of Load Centers (CRE 2017)", according to the Electricity Industry Law and the Interconnection Manual of DG Plants with capacity less than 0.5 MW. DG includes that which is performed by an exempt generator, in other words, the owner of one or more power plants with capacity less than 0.5 MW that do not require a permit to generate electric power. DG can be located in the facilities of Load Centers or outside them (SENER, 2016). It is estimated that the world distributed solar PV, will establish itself at more than twice its capacity in the next lustrum.

It accounts for almost half of the total solar PV expansion. DG-PV installations in educational and government institutions, residential homes, commercial buildings and industry will bring major changes to electrical systems. The accelerating expansion in the ability of consumers to generate their own electricity represents a niche opportunity for service providers.

Justification

Electricity consumption for air conditioning in educational institutions in Campeche and in general with hot humid climates represents one of the highest costs during operation. During the last five years, electricity consumption at the Universidad Autónoma de Campeche represents 60% of the total consumed each month.

In Mexico, in recent years, the contracting of DG-PV has increased considerably. Up to 2019, 35,661 new PV-GD contracts were signed, which is equivalent to just over 233 MW new installed in Mexico; this represents an average annual growth rate of approximately 20%.

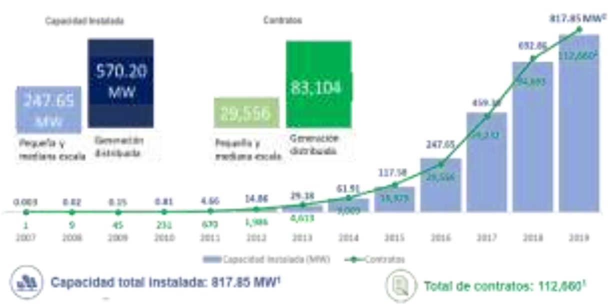

Figure 1 Evolution of contracts and installed capacity in Mexico
Monitor of commercial information and price index of Distributed Solar Generation in Mexico, March 2019

(Monitor of commercial information and price index of Distributed Solar Generation in Mexico, 2020). Figure 1.

Taking as a reference the Monitor of commercial information and price index of Distributed Solar Generation in Mexico, March 2020, from 2017 to the first semester of 2019, we present the regions that installed the largest amounts of DG-PV where it is very clear that the states of the Mexican Republic with the largest accumulated installed capacity are Jalisco, North Gulf, North, Bajio and South Valley of Mexico, Figure 2.

We also observe from Figure 2 that the state of Campeche has a very small accumulated installed capacity, less than 5 MW. However, the state of Campeche has a good solar radiation resource, with irradiation ranging from 4.5 to 6 kWh/m^2 per day. Data provided by NREL.

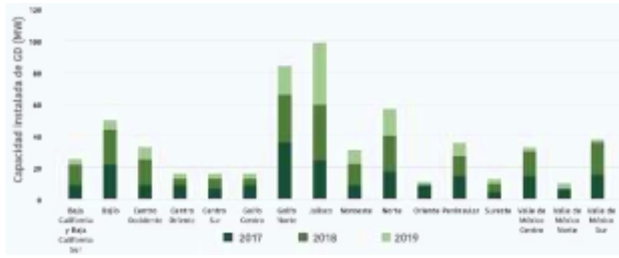

Figure 2 Evolution of DG-PV capacity in Mexico by region of the country
Commercial information monitor and price index for Distributed Solar Generation in Mexico, March 2021

The conditions of good irradiance in the state of Campeche as well as the energy needs and a small accumulated installed capacity, leads us to the conclusion that there is a large niche of opportunities for the installation of Photovoltaic Distributed Generation Systems.

On the other hand, the state of Campeche has a humid-warm climate; therefore, it is very necessary to use large amounts of electrical energy for high, medium and low temperature refrigeration processes. In a study conducted by the Autonomous University of Campeche to the Secretary of Economic Development of the state of Campeche in 2020 (Victor-Lanz et al), indicates that at least 60% of electricity consumption in small and medium industries, homes, schools and universities, is due to cooling processes in any of its forms. Particularly the state's educational institutions spend large amounts of their annual budget for the payment of electricity for air conditioning.

For example the Faculty of Engineering of the Autonomous University of Campeche, during 2019 had an average monthly billing of 150,000 Mexican pesos (approximately 7,500 U.S. dollars). Data taken from CFE receipts). In that sense, a circumstance that is very relevant is to avoid excessive heat gain from solar radiation on roofs and walls. It is known (Victorio Santiago Díaz et al, 2005) that approximately 50 to 60% of the total gain in buildings is due to solar radiation from roofs and walls.

In air conditioning engineering applications, an average solar gain per roof of 550 w/m^2 can be considered as the energy captured in a square meter of surface, in a horizontal position with the sun at the zenith and considering a clean atmosphere with a low degree of turbidity.

We conclude that GD-PV systems have an added value in hot-humid climates, and installed on roofs; they operate as thermal barriers that absorb direct solar radiation, avoiding excessive heat gains from solar radiation in buildings. As a direct consequence of the above, less electrical energy is required for air conditioning processes. In this way, energy efficiency is promoted.

With regard to energy efficiency, according to Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ-2014) in its guide of good practices for energy saving and efficient use of energy, it is defined as: obtaining the same energy goods and services, but with much less energy, with the same or higher quality of life, with less pollution, at a lower price than at present, extending the life of resources and with less conflict.

Objective

To demonstrate that by implementing Distributed Generation with photovoltaic systems (DG-PV) together with aspects of bioclimatic architecture, energy efficiency is achieved in the cafeteria of the Faculty of Engineering of the Autonomous University of Campeche.

Hypothesis

By implementing a GD-PV plant, with its most optimal configuration, in the cafeteria of the Faculty of Engineering of the Autonomous University of Campeche, energy efficiency and reduction of its production costs are achieved; as well as avoiding the emission of CO2 equivalent to the atmosphere.

Problem Statement

It is desired to reduce the energy consumption of the cafeteria located in the Faculty of Engineering of the Autonomous University of Campeche, in the state of Campeche.

The state of Campeche is geographically located in the Yucatan Peninsula between parallels 17°49' and 20°51' north latitude; and between meridians 89°06' and 92°27' west; air conditioning processes demand high energy values to be carried out. The environmental conditions at the site are important adverse factors during this process.

The location of the cafeteria is in the Faculty of Engineering of the Universidad Autónoma de Campeche. It is geographically right at 19°.84'58" north latitude, -90°.47'74" longitude (west), less than 1000 meters from the coast with an average temperature of 31±0.1ºC and a relative humidity of 75±1%, also average (INEGI, 2015), at 50 meters with respect to sea level. The architectural project consists of design an enclosed space with capacity for approximately 80 people (diners and dependents).

For these infrastructure dimensions, the number of people contemplated and that the building was planned with few windows that are exposed to solar radiation. It is considered to have a total heat gain of approximately 16 $kW_{thermal}$ (4.5 TR, 54,000 BTU/h). So with 2 units of 10.6 $kW_{thermal}$ (3 TR, 36,000 BTU/h, commercial capacities) we will have a total of 21.2 $kW_{thermal}$ (6 TR, 72,000 BTU/h) sufficient to remove the total heat from the cooler. The cafeteria has 2 cassette type air conditioning units, which allow a better distribution of the cold air conditioning, which have an elegant presentation, which are very quiet (53/51/48 dB(A) continuous ambient noise level should not exceed 68 decibels, measured at the worker's ear position through the use of a sound level meter). According to, 01-13-95 Mexican Official Standard NOM-081-ECOL-1994, which establishes the maximum permissible noise emission limits for fixed sources and their measurement method.

Two 16 SEER high energy efficiency mini-split condensing units are also installed for this project. Ceiling mounted, with ecological refrigerant R410a. It also has lighting and miscellaneous equipment. Given this situation of energy demand, the possibility of installing a Photovoltaic Distributed Generation plant (GD-PV) was considered.

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Description of the Photovoltaic Distributed Generation System (GD-PV)

This is an electric power generating plant produced with photovoltaic modules. It is installed on a flat roof of 89.10 m^2. The first photovoltaic array (AFV) has two strings of seven modules, each of 440 Wp. This results in a total of 14 photovoltaic modules connected in series (Canadian brand), a total installation of 7.56 kWp installed. It has an anti-island voltage inverter for interconnection to the grid of the brand and model Fronius Symo of 8 kWp figure 3. Each photovoltaic module has an area of 2 m^2. Figure 4 shows the one-line diagram of the system.

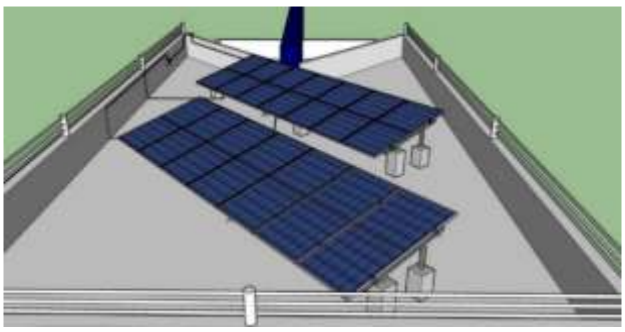

Figure 3 The photovoltaic array (AFV) has a total of 14 photovoltaic modules connected in series (Canadian brand) and an anti-islanding voltage inverter for interconnection to the grid of the Fronius Symo 5kWp brand and model
Own Elaboration.

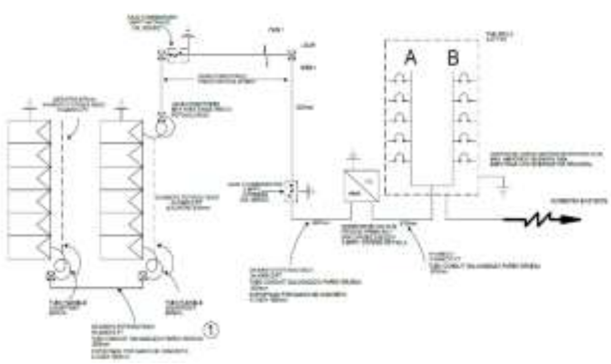

Figure 4 One-line diagram of the Distributed Photovoltaic Generation plant. It consists of 14 modules with a total installed capacity of 5.18 kWp
Own Elaboration

The next proposed photovoltaic array was to place 24 modules of 440 each, with an azimuthal angle of 218º, aligning them parallel to the side walls of the building and an inclination angle of 15º, a total installation of 10.56 kWp. It has an anti-islanding voltage inverter for interconnection to the grid of the brand and model Fronius Symo of 10 kWp.

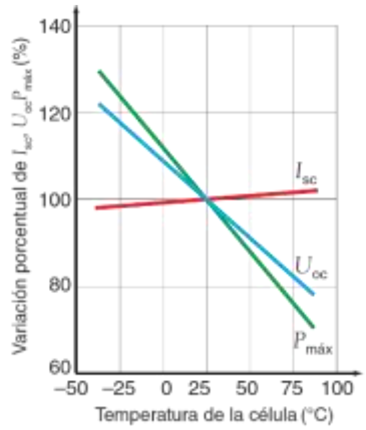

Figure 5 Percentage variation of open circuit voltage, short circuit current and maximum power of a photovoltaic module with respect to temperature
Castejón 2012

The PV installation was designed with an inclination of 15 degrees with respect to the horizontal plane to optimize the PV performance with respect to mechanical stresses (Rayenari-D.C. et al., 2015); hence each module shades an area of 1.93 m2. The total PV installation produces a shaded roof area of about 27 m2. The photovoltaic plant is fully oriented to the south, its azimuthal declination is correct. The photovoltaic modules are placed at a height of 0.60 m with respect to the roof, in order to favor air circulation under them, thus ensuring that they do not overheat and considerably increase their production efficiency (Agustín Castejón-2012, Cruz Arellano, M. & Castillo Téllez, M. 2021). Figure 5, recalling that as the modules heat up, taking as a reference the value of 25 ºC, their open circuit voltage (Voc) decreases linearly and with a steep slope. Power in turn is intimately influenced by Voc. In such a way that if the temperature is increased to values higher than 75 ºC, more than 20% of the nominal power is lost.

Similarly Rayenari D. C. et al, (2015) recommend for higher photovoltaic efficiency in the months of March to August, the tilt should be readjusted to 10 or 5 degrees. Up to 5% efficiency gain is possible. In addition, stagnation zones are avoided due to no wind circulation Potter et al (2011).

Mathematical modeling of heat gain through the freezer roof

According to Victor Lanz G. et al (2018), in hot humid climates heat gain in building roofs represents 40% and another 10% by walls facing the direct solar radiation received by a building throughout the day.

Therefore, it is very important to quantify the heat gain from roofs. The following equations are presented to quantify roof heat gains as a combined effect of conduction, convection and radiation (Çéngel et al-2012).

$$\dot{Q} = \dot{Q}_{habi-techo,conv+rad} = \dot{Q}_{cond,techo} = \dot{Q}_{techo-amb,cond+rad} \quad (1)$$

$$\dot{Q}_{habi-techo,conv+rad} = h_i A(T_{habi} - T_{s,int}) + \varepsilon A\sigma(T_{habit}^4 - T_{s,int}^4) \quad (2)$$

$$\dot{Q}_{cond,techo} = kA\frac{T_{s,int} - T_{s,ext}}{L} \quad (3)$$

$$\dot{Q}_{techo-alrededor,cond+rad} = h_o A(T_{s,ext} - T_{amb}) + \varepsilon A\sigma(T_{s,ext}^4 - T_{amb}^4) - \alpha\dot{q}_{solar} \quad (4)$$

Where $\dot{Q}$ is the total heat flux, k thermal conductivity, α absorptivity, $h=kW/m^2\ ^oC$ convective heat transfer coefficient, σ the Steffan-Boltzman constant, A heat transfer area, $\dot{q}_{solar}$solar radiation and T temperature. It is estimated that, each square meter of roof receives a radiation of 550 w/m^2 x day, and there are 27 and 46.32 m2 of area shaded by the PV plant for the cases of 14 and 24 modules respectively. It can then be estimated that a daily roof heat gain of approximately 14.85 kW is avoided for the 14-module case and 25.48 kW for the 24-module case. As a reference, mini split air conditioners of one ton of refrigeration have a thermal capacity to remove heat of 3.54 kWh. The shaded area represents approximately 30% of the total roof for the case of 14 modules and 51% when we have 24 modules.

Bioclimatic aspects of energy efficiency in the cafeteria

Another aspect considered to increase the energy efficiency of the cafeteria was to place green roofs and walls in the areas with the highest incidence of solar radiation. The proposal for green roofs and walls was made with vegetation native to the Yucatan Peninsula that can withstand the climatic conditions of the region.

Figure 6 Overall view of the cafeteria with the proposed SFV, roofs and green walls
Own Elaboration

Figure 7 View of the rear wall of the cafeteria with the SFV proposals and green wall
Own Elaboration

Proposed methodology for the analysis of photovoltaic electric energy production.

In this work we used the free software called System Advisor Model (SAM) created by the National Renewable Energy Laboratory (NREL) of the United States of America. With this program we evaluated the energy capacity of several photovoltaic configurations to compare them and decide which one is the most optimal for installation.

During the engineering project development stage, it is very necessary to visualize different possible scenarios in the installation of a photovoltaic generating plant, such as the optimal inclination, the minimum height of the modules with respect to the surface, among others, and in turn all of them invariably associated to the economic aspect, in such a way that the highest plant efficiency is obtained in the shortest recovery time. To plan all these scenarios is an arduous task; this task is easier with the help of a computer program. In this sense, we use the SAM software for two important reasons: it is free and it contemplates economic rates.

This allows us to analyze the optimal performance of the plant, as well as its return on investment. The SAM program allowed the complete temporal analysis of the Great Ordinary Mean Demand in Mexico (GDMO of CFE in Mexico) during the 8760 hours of the year. The tariff part is the most complex part of the programming, but it allows to do it; other similar programs do not have this analysis capacity. It allowed a more accurate analysis by relating the energy yield equations to an economic analysis (cash flow, net present value, payback time, cost benefit and internal rate of return). Four different schemes were analyzed, firstly, it was a photovoltaic array of 14 modules of 440 each, with an optimal azimuthal angle (Castejón & Santamaría, 2010) of 180º (i.e. aligned to the true north-south axis) and a tilt angle of 15º (Rayenari-D.C. et al., 2015), the other was similar to the previous one but the tilt angle was 19.85º equivalent to the latitude of Campeche.

The next was to place the PV array of 24 modules of 440 each, with an azimuthal angle of 218º, aligning them parallel to the side walls of the building and a tilt angle of 15º and finally the PV array of 24 modules of 440 each, azimuthal angle of 218º and tilt angle of 19.85º. The program was fed with the billing data issued by the Federal Electricity Commission (CFE), in GDMO tariff, for the period from January 2020 to March 2021. It corresponds to the consumption of the Faculty of Engineering during that period, Table 1. Costs are expressed in U.S. dollars.

Billing month	Total consumption (kwh)
January 2020	21,238
February 2020	22,803
March 2020	30,881
April 2020	28,791
May 2020	9,469
June 2020	10,752
July 2020	10,124
August 2020	10,686
September 2020	10,938
October 2020	14,400
November 2020	15,788
December 2020	15,996
January 2021	14,418
February 2021	15.441
March 2021	13.953

Table 1 Details of the energy consumption used in the SAM Program to make the economic estimates. Taken from CFE receipts
Own Elaboration

Two subarrays:	1	2
Strings	1	1
Modules per string	7	7
String Voc (DC V)	340.90	340.90
Tilt (deg from horizontal)	15.00	15.00
Azimuth (deg E of N)	180	180
Tracking	no	no
Backtracking	-	-
Self shading	no	no
Rotation limit (deg)	-	-
Shading	no	no
Snow	no	no
Soiling	yes	yes
DC losses (%)	4.44	4.44

Table 2 Details of the photovoltaic installation with 14 modules of 440 each, azimuth angle of 180º and tilt angle of 15º. SAM program.

The first two options considered were because they were placed at the optimum azimuthal angle. However, arranged in this way and for space reasons, only 14 modules fit. The last two options allow a greater number of modules to be placed, although a small percentage of efficiency is lost (5%).

Analysis of the information and results obtained

After the four scenarios were proposed and the program was fed with the necessary data, we proceeded to run the program with each of them. The results obtained are presented in the following tables.

Metrics	Values
Annual energy (year 1)	10.451 kWh
Capacity factor (year 1)	19.40%
Energy yield (year 1)	1.696 kWh/kW
Performance ratio (year 1)	0.77
COE level (nominal)	5.40 ¢/kWh
Electricity payment without the system (year 1)	$314,513
Electricity payment with the system (year 1)	$303,184
Net savings with system (year 1)	$11,329
Net present value	$202,761
Simple return period	0.6 años
Net capital cost	$8,256

Table 3 Simulation results, PV installation with 14 modules of 440 each, azimuth angle of 180º and tilt angle of 15º. *SAM program.*

Metrics	Values
Annual energy (year 1)	10.465 kWh
Capacity factor (year 1)	19.40%
Energy yield (year 1)	1.699kWh/kW
Performance ratio (year 1)	0.77
COE level (nominal)	5,39 ¢/kWh
Electricity payment without the system (year 1)	$314,513
Electricity payment with the system (year 1)	$303,156
Net savings with system (year 1)	$11,357
Net present value	$203,283
Simple return period	0.6 años
Net capital cost	$8.256

Table 4 Simulation results, PV system with 14 modules of 440 each, azimuth angle of 180º and tilt angle of 19.85º. *SAM program.*

Metrics	Values
Annual energy (year 1)	17.649 kWh
Capacity factor (year 1)	19.10%
Energy yield (year 1)	1.671kWh/kW
Performance ratio (year 1)	0,78
COE level (nominal)	5.48 ¢/kWh
Electricity payment without the system (year 1)	$314.513
Electricity payment with the system (year 1)	$295.398
Net savings with system (year 1)	$19.115
Net present value	$342.210
Simple return period	0.6 años
Net capital cost	$14.153

Table 5. Simulation results, PV system with 24 modules of 440 each, azimuth angle of 218º and tilt angle of 15º. *SAM program.*

Metrics	Values
Annual energy (year 1)	17.570 kWh
Capacity factor (year 1)	19.00%
Energy yield (year 1)	1.664 kWh/kW
Performance ratio (year 1)	0.78
COE level (nominal)	5,50 ¢/kWh
Electricity payment without the system (year 1)	$314,513
Electricity payment with the system (year 1)	$295,467
Net savings with system (year 1)	$19,046
Net present value	$340,946
Simple return period	0.6 años
Net capital cost	$14,153

Table 6. Simulation results, PV installation with 24 modules of 440 each, azimuth angle of 218º and inclination angle of 19.85º. *SAM program.*

Some of the results obtained in this section are specified.

Capacity factor (CF) is defined by NREL as:

$$CF = \frac{Annual\ energy\ production \left[\frac{kWh}{year}\right]}{Installed\ capacity\ x\ 24 \left[\frac{hours}{day}\right]\ x\ 365 \left[\frac{day}{year}\right]}$$

Energy yield is given by (Theristis et al., 2018) as the energy produced between each installed peak kilowatt.

The performance or performance ratio (performance ratio) is a magnitude, independent of the location, of the quality of a PV installation. It is a quality factor. It is expressed as a percentage and shows the ratio between the actual yield and the nominal yield of the PV system. It indicates what proportion of the energy is actually available after deduction of energy losses (thermal and cable losses) and own consumption for operation. The coefficient of performance provides information on the energy efficiency and reliability of the PV system.
The levelized cost (LCOE) is given by (Lai et al., 2019), equation 6.

$$LCOE = \frac{sum\ of\ whole\ life\ costs}{sum\ of\ the\ electrical\ energy\ produced\ in\ its\ entire\ useful\ life}$$

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (6)$$

Where:
I_t: Investment expenses in year t.
M_t: Operating and maintenance expenses in year t.
F_t: fuel expenses in year t.
Et: electric power generated in year t.
r: discount ratio.
n: expected life time.

From the comparative tables, from 7 to 13, we observe that, of the proposed configurations, the one that produces the most annual energy is the one with 24 modules with an azimuth angle of 218º and an inclination angle of 15º. That is, the installation is not at the angles considered optimal for this latitude. It is evident that, for this configuration, the fact of having 10 more modules with respect to the installation of 14 panels results in a higher energy production, but the paradigm of installing according to the established canons was broken, even with the understanding that we would have a 5% of total losses. Table 7.

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
10,451 kWh	10,465 kWh	17,649 kWh	17,570 kWh

Table 7 Simulation results, PV installation. Energy generation. *SAM program.*

In Table 8, we observe that the configurations of 14 modules with an azimuthal angle of 180º and inclination angles of 15 and 19.8º, are the ones with the highest capacity factor. This result is congruent if we consider the definition previously presented. In other words, we have higher energy production with less installed kW.

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
19,40%	19,40%	19,10%	19,00%

Table 8 Simulation results, PV installation. Capacity factor. *SAM program.*

From Table 9, we observe that the installation of 24 modules, azimuth angle of 218º and tilt angle of 15º, is the one with the highest energy yield.

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
1,696 kWh/kW	1,699 kWh/kW	1,671 kWh/kW	1,664 kWh/kW

Table 9 Simulation results, PV system. Energy yield. *SAM program.*

In Table 10, we observe that the installation of 24 modules, azimuth angle of 218º and tilt angle of 15º, is the one with the highest performance ratio factor. This indicates that this configuration has the lowest number of thermal and wiring losses and therefore the highest energy efficiency.

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
0,77	0,77	0,78	0,78

Table 10 Simulation results, PV installation. Performance ratio. *SAM program.*

On the other hand, in Table 11, we find that the installation of 14 modules with an azimuthal angle of 180º and an inclination angle of 19.8º, is the one with the best levelized cost value. That is, it is the configuration that will offer the highest energy production at the lowest cost throughout its useful life.

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
5.40 ¢/kWh	5.39 ¢/kWh	5.48 ¢/kWh	5.50 ¢/kWh

Table 11. Simulation results, PV installation. Levelized cost. *SAM program.*

Tables 12 and 13 provide information on net money savings and payback periods and what can be seen is that the configuration of 24 modules, azimuth angle of 218º and tilt angle of 15º, delivers the highest amount of money saved in one year of operation. And all configurations have the same payback time.

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
$11,329	$11,357	$19,115	$19,046

Table 12 Simulation results, PV installation. Net savings. *SAM program.*

14 modules, azimuth angle 180, inclination 15º.	14 modules, azimuth angle 180, inclination 19.8º.	24 modules, azimuth angle 218, inclination 15º.	24 modules, azimuth angle 218, inclination 19.8º.
0.6 años	0.6 años	0.6 años	0.6 años

Table 13 Simulation results, PV installation. Return period. *SAM program.*

Energy produced by the DG-PV

The energy produced by the DG-PV, E_prod in the 5.5 hours of solar radiation of a solar day (NREL, 2010), is given by equation 7.

$$E_{prod} = W_{peak} \cdot hr_{rad} \cdot No_{m\acute{o}dpv} \quad (7)$$

where W_{peak} is the peak power of a PV module in Watts, hr_{rad} is the hours of solar radiation in a day, and $No_{m\acute{o}dPV}$ represents the number of PV modules included in the DG-PV plant. From the above, the energy produced by the DG-PV, in both configurations, is given by:

$$E_{prod} = 0.440\ kW\ (5.5\ hr)\ (14\ m\acute{o}d) = 33.88\ kWh/day$$

$$E_{prod} = 0.440\ kW\ (5.5\ hr)\ (24\ m\acute{o}d) = 58.08\ kWh/day$$

Estimated CO_2 avoided to be sent to the environment due to DG-PV

Within an energy efficiency study, the amount of carbon dioxide (CO_2) emissions released into the environment due to electricity generation must be included. In Mexico, the Energy Regulatory Commission (CRE) and the Ministry of Environment and Natural Resources (SEMARNAT) annually estimate the National Electric System Emission Factor based on Article 12 of the Energy Transition Law Regulation (Chamber of Deputies, 2017). The last factor published in the Official Journal of the Federation was in 2017 being this of:

0.582 kg de CO_2 / kWh

In addition, an emission factor caused by the production of energy with photovoltaic modules has been considered; an analysis model called Global Emissions Model for Integrated Systems (GEMIS, 2018) was used in the calculations, which applies a factor of:

0.135 kg de CO_2 / kWh

And Reich, et al. (2007), invites to choose a value from a range of emissions between:

0.030-0.317 kg de CO_2 / kWh

Empirically we choose the GEMIS factor for our calculations, because it is within Reich's range. During a billing month, the total energy consumed by the Faculty of Engineering and purchased from DG-PV is:

$$E_{cons} = 58.08 \frac{kWh}{day} (30\ days) = 1742.4\ kWh$$

Then, the CO_2 emissions avoided to be sent to the ϵ_{cons}ϵ_cons by the energy consumed through DG-PV is:

$$\epsilon_{cons} = 0.582 \frac{kg\ CO_2}{kWh} (1742.4\ kWh) = 1014.07\ kg\ CO_2$$

The CO_2 emissions producedϵ_{prod} caused by energy production with DG-PV are:

$$\epsilon_{prod} = 0.135\ \frac{kg\ CO_2}{kWh} (1742.4\ kWh) = 235.22\ kg\ CO_2$$

Finally, the net CO_2 emissions ϵ_net avoided to be sent to the atmosphere is the difference between ϵ_{cons} y ϵ_{prod}:

$$\epsilon_{net} = \epsilon_{cons} - \epsilon_{prod} = 1014.07\ kg\ CO_2 - 235.22\ kg\ CO_2 = 778.85\ kg\ CO_2$$

This is a significant figure, as it shows that 778.85 kg of CO_2 are no longer being emitted into the environment, which is a significant contribution to the reduction of the carbon footprint.

Conclusions

This article presents an energy efficiency study of the Cafeteria of the Faculty of Engineering of the Autonomous University of Campeche with the proposal of a Photovoltaic Distributed Generation plant (GDF-PV) analyzing several proposed configurations with the help of the open program called System Advisor Model (SAM) developed by the National Renewable Energy Laboratory (NREL).

Four different schemes were analyzed: one PV array of 14 modules of 440 each, with an azimuthal angle of 180º and a tilt angle of 15º, the other was similar to the previous one but the tilt angle was 19.85º equivalent to the latitude of Campeche. The next two were arrays of 24 modules of 440 each, with azimuthal angles of 218º and inclination angles of 15º and 19.85º.

– It is estimated that a daily roof heat gain of 14.85 kW is avoided in the case of 14 modules and 25.48 kW in the case of 24 modules. The shaded area represents approximately 30% of the total roof for 14 modules and 51% for 24 modules.

– The best annual energy generation of the DG-PV plants is obtained with a value of 17,649 kWh in the configuration of 24 modules of 440 W, with azimuth angle of 218º and tilt angle of 15º. According to the simulations with the SAM program.

– The 24-module photovoltaic system, with an azimuth angle of 218º and an inclination angle of 15º, has the highest energy yield with a value of 1,671 kWh/kW, understood as the energy produced for each kilowatt peak installed.

- The 24-module photovoltaic plant, with azimuth angle of 218º and tilt angle of 15º, is the one with the highest performance ratio factor, indicating that it has the lowest number of thermal and wiring losses and is therefore the one with the highest energy efficiency.

- All four DG-PV plant configurations have the same payback time of 0.6 years.

- The best PV plant configuration was the 24-module configuration, with azimuth angle of 218º and tilt angle of 15º, which has the highest number of favorable factors and is therefore the most energy efficient.

- The GD-PV plant avoids the emission of 778.85 kg of CO2 equivalent into the atmosphere.

- To increase the energy efficiency of the cafeteria, green roofs and walls were installed in the areas with the highest incidence of solar radiation. The roofs and green walls were built with vegetation native to the Yucatan Peninsula to withstand the climatic conditions of the region.

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Lean Manufacturing: Efficiency improvement application in multi-product area of the Aerospace Industry

Manufactura esbelta: Aplicación de mejora de la eficiencia en área multiproducto de la Industria Aeroespacial

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Abstract

This research addresses the problem of leveling workloads in a multi-product final assembly area. In which it was found that 27.4% of the time is used for set up and the current distribution presents areas of opportunity. The target was to implement improvement actions to make use of resources more efficient in the production process in the aforementioned area through Lean Manufacturing tools. The results obtained consist of eight products generated with the support of lean manufacturing support tools such as SMED, Workload Balancing and MUDA waste identification, achieving important results among which productivity in the area stands out from 109% to 125%, as well as a reduction in set-up time from 17 min to 4.4 min.

Lean, Productivity, Kaizen, Manufacturing

Resumen

Esta investigación aborda el problema de nivelar cargas de trabajo, en un área de ensamble final de multiproducto. En la cual se encontró que un 27.4 % del tiempo es utilizado para set up y la distribución actual presenta áreas de oportunidad. El objetivo fue implementar acciones de mejora para eficientar el uso de los recursos en el proceso de producción dicha área a través de herramientas de Manufactura Esbelta. Los resultados obtenidos consisten de ocho productos generados con el apoyo de las herramientas de soporte de la manufactura esbelta tales como SMED, Balanceo de cargas de trabajo, e identificación de desperdicios MUDA, logrando importantes resultados entre los que sobresale una productividad en el área que va de 109 a 125 %, así como una reducción del tiempo de set up de 17 a 4.4 min.

Esbelta, Productividad, Kaizen, Manufactura

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1. Introduction

Sonora has 53 manufacturing companies for blades and components for turbines and wind motors. This entity stands out due to the unique activities that are carried out in it, such as die casting, lost wax and sand mold, as well as heat and surface treatments. (De la Madrid, s/f).

The level of Lean Manufacturing Implementation in the maquiladora industry of Hermosillo and Guaymas-Empalme, Sonora (Piña et al., 2018) presents 14 common practices: level production, continuous flow, product quality, continuous improvement, order and cleanness, process control, lead time reduction, standardization, delivery on time, flexible production system, line balancing, direct personnel training, adherence to the production plan and customer satisfaction. Likewise, benefits are consequently reported in the areas of increased productivity, scrap reduction, cost reduction in quality, inventories, customer guarantee, raw material, improvement in deliveries on time, among others. (Monge et al., 2013).

The company under study manufactures electrical connectors, coaxial cables, fiber optic cables and communication antennas, its main customers are Boeing Company, Airbus S.E., Embraer S.A. and Safran Aircraft Engines (PRO MÉXICO, 2016). The object under study is the area of Final Assembly "Coaxial, Packaging and Others"; this has the objective of assembling a great variety of coaxial connectors, accessory packaging, installation of screws in rails and the elaboration of other varied products.

P	E	P	S	U
Warehouse	• Kanban, • Manufacturing orders (MO)	• Laser marking, • Rail, • Coaxial - Manual press, • Coaxial - Pneumatic press, • Resin for coaxial, • Painted, • Riveting, • Screw installation, • Accessories packaging • Parts packaging	, Products (Different part no.), • Packaging	• End customer, • Sub-assembly, • Warehouse

Table 1 PEPSU diagram of the final assembly area

Regarding personnel, the number of necessary operators has not been established, nor their leveling of workloads. There are 9 operators on shift 1, 6 on shift 2 and a leader. The times of change and preparation of the "laser marking" bottleneck, is approximately 3 hrs causing less production and capacity.

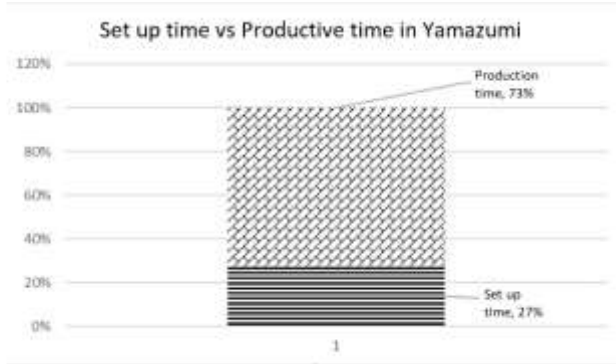

Figure 1 Current situation of laser marking set up times

In figure 1 the time required to set up on average is an approximate value of 8 min/order, the company has 11 hours of production time, of which 27% is to set up and 73% to produce. Most of the operations start with laser marking and there are crossings and setbacks in the production process.

Based on what has been described, it was detected that there is no balance that allows operators to have a leveled work load, nor to work at a constant pace. The problem has been defined as: "The area of final assembly Coaxials, Packaging and others presents deficiencies in the use of human resources, time and space in the production process."

1.1 Objective

Implement improvement actions to make the use of resources more efficient in the production process through Lean Manufacturing.

2. Theoretical framework

Lean manufacturing can be defined as a combination of multiple tools to help eliminate activities that do not add value to the product, service and/or process by increasing the value of each activity, aiming to eliminate or reduce waste and improve operations. (García-Alcaraz, Maldonado-Macías, & Cortes-Robles, 2014). Womack defines lean production as a system that creates added value using less of each input, which is based on the Japanese concept of waste, hence the definition of waste is conceived as anything that requires more than the minimum of resources necessary to create products with value and high quality (Womack & Jones, 1990).

Lean Manufacturing seeks to reduce or eliminate waste in a production system in which the human element can be involved (Rahman, Sharif, & Esa, 2013) (Manzouri, Ab-Rahman, Zain, & Jamsari, 2014). In other words, the main intention of the Lean approach is to reduce cost, increase quality, maximize the product contribution margin and value for the customer or end user. (Nallusamy, 2020) (Arunagiri & Jayakumar, 2020). Such wastes are made evident through the MUDAS system and recognized by Japanese manufacturing. In other words, something that does not add value to the final product becomes a type of waste, therefore, it must be reduced or eliminated to reduce the cost of production and increase the contribution margin.

The concept of lean manufacturing is commonly associated with the application of technical tools such as 5S, Kanban supermarkets, as well as Kaizen boards, Poka Yoke among others. This comparison is too simple and does not reflect the different concepts and techniques that the Toyota Production System (TPS) relies on to run a complex product manufacturing system and why the whole “toolbox” is needed. (Rüttimann & Stöckli, 2016)

Thus, the Toyota Production System gives special emphasis to the production system, reducing the delivery time of the process (Process lead time) and the toolbox constitutes the structure under which the maximization of production will be achieved, seeking to guarantee quality at the work station. TPS, through careful observation and evaluation determines the best way to eliminate any waste and optimize the process performance.

The MUDA constitutes an element for the optimization of the process that is complemented by the Mura (variation) and Muri (overload), that is, it smoothes the unevenness. In addition to the underlying tools (SMED, Heijunka-pitch) to create a smooth production schedule, as well as the simple technique to control the start of production (Kanban), TPS has also originated the continuous improvement approach (Kaizen). The search for perfection through the use of the “hidden” knowledge of the operators at the base, where production takes place (Gemba). (Rüttimann & Stöckli, 2016)

A fundamental aspect in a production system is the management of supplies, this has different objectives, but its common base lies in the seven “Rights”: (1) Product, (2) Quality, (3) Time, (4) Quantity, (5) Location, (6) People and (7) Cost, in the correct quantity and form; Traditionally, some authors only propose the use of the first 5, but the inclusion of the last 2 factors allows an adequate assessment of the system when considering an approach “lean”. (Hofbauer G et al, 2012), (Helmold M. , 2013), cited by (Helmold & Terry, 2017).

The above means that achieving a correct product requires compliance with customer requirements through specifications and with the correct quality, quantity, at the right time and location, considering the time constraints implicitly stated in the distribution with the support of trained operators. (Helmold & Terry, 2017). A transformation of the production system to TPS is basically Womack's proposal (Womack & Jones, 2003) which consists of the following (1) Identifying the flow of value, (2) Showing the flow of value and eliminating waste, (3) Transforming the flow of value by implementing flow in customer attraction, (4) Training people, (5) Striving for perfection. Thus, the challenge is constituted by the last three steps in which the system goes from being a PUSH system to a PULL system where production is driven by customer demand.

The Toyota house is credited to Taiichi Ohno's disciple, Fujio Cho, who developed the model for teaching TPS to suppliers. The model is cognitive in nature, structuring the components of the TPS. The two pillars on which the Toyota production system rest are oriented towards flow and quality, with support from Kaizen to reduce MUDA (Rüttimann & Stöckli, 2016) (Rüttiman, 2018) (Liker, 2004).

A model that proposes the interaction of tools and stages through which the TPS is developed is proposed by (Rüttiman, 2018) in it, the goals, techniques and means are appreciated according to the level of complexity in manufacturing. The model first presents a single-product production system in which the goals consist of going to the Gemba with floor equipment and eliminating bottlenecks, having as ideal zero defects, equipment availability, reproducibility and optimization of work, as well as on-time delivery, through Balancing, Jidoka TPM, Standard Work, 5S and TAKT.

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Second, for a multiproduct system the goals lie in the area of leveling, flexibility and lay out, through Heijunka, SMED and Cellular Design. A third place is meant for Complex Products in which the goals reside in the use of cells and the logistics of decoupling through the creation of supermarkets, finally, the Supply Chain level in which the goals reside in Linked Cells, Production Activated and Just in Time through 7's Rights and Kan Ban systems.

To achieve survival, an organization needs to be competitive; it is through improving various aspects such as costs, quality, delivery service and flexibility. One of the approaches to achieve improvement is provided by Lean Manufacturing (Shah & Ward, 2002). Implementing Lean Manufacturing generates observable benefits in various areas and sectors, therefore, Lean Manufacturing emerges as an approach that provides ways to improve quality, meet customer expectations, reduce every form of waste, improve the employees satisfaction and shorten delivery times (Braglia, Carmignani, & Zammori, 2006) (Bakas, Govaert, & Van Landeghem, 2011)

In the research from (Ghizoni Pereira & Luz Tortorella, 2018) is noted that the application of Lean Manufacturing practices occurs within companies at the strategic, tactical and operational levels regardless of the size of the organization. The key is to identify the appropriate practices for the objective context in which the company finds itself. Among the most frequent practices found are: (1) Pull system, (2) Total Productive Maintenance, (3) Kaizen Continuous Improvement, (4) 5s, (5) Just in Time, (6) Cycle Time Reduction, (7) Total Quality Management , (8) Cellular Manufacturing, (9) Rapid Changes, (10) Staff Empowerment, (11) Value Stream Mapping, (12) Standardized Work, (13) Six Sigma, (14) Cross Functional Teams, (15) Statistical Process Control, (16) Visual Management, (17) Continuous Flow (18) Poka Yoke and (19) PDCA.

3. Methodology to be developed

Object of study

The object under study is the Final Assembly Area "Coaxials, Packaging and Others".

Materials

Digital stopwatch, Microsoft Excel, Camera, Flexometer, AutoCAD Software, Solidworks Software.

Procedure: (1) Analyze the production process. An 80-20 analysis was made to obtain the parts with the highest contribution in the area (High runners). (2) Determine average operating times. At this stage, the High runners' times were taken. (3) Balance. The Takt, the contribution percentage of each part and time weighted was calculated:

$$Weighted\ Time\ =\ (Contribution\ Percentage)\ (Operation\ Time) \qquad (1)$$

The number of operators was obtained and subsequently the balancing was carried out assigning tasks to each operator. (5) Reduce change and preparation times. In this step, the SMED methodology was followed (Socconini, 2019) with the support of the Yamazumi tool; the new method was finally standardized. (6) Redistribute the area under study. The waste and areas of opportunity were detected, the redistribution proposals were designed where the families of parts, crossings, setbacks, areas of opportunity and waste found were considered.

4. Results

Result of the 80/20 analysis, the High Runners of each product family were obtained with their average times shown in table 2.

P/N	Family	Laser marking	Center pin assembly and insulator on body	Screw installation	Accessories packaging	Grommet Assembly	O-ring Assembly	Painting	Assembly of coaxials and outlets	Final inspection	Final packaging
617075058	COAXIAL	15.83			36.21					4.01	2.80
620075010	COAXIAL	13.90								5.80	10.50
620175010	COAXIAL	13.90								5.80	10.50
67403652A	COAXIAL	13.88	11.20							5.01	2.36
67403700c	COAXIAL	13.10	36.33							4.83	5.86
617175088	COAXIAL	14.88			20.96					4.86	3.22
617921011	Back shell			11.85						5.03	9.57
617924619	Back shell	11.87								4.89	11.87
617922009	Back shell	11.28								3.22	10.74
617924518	Back shell	8.99								4.15	11.07
617929022	DUMY	7.19				15.83				8.64	10.03
617929061	DUMY				11.82					6.22	8.56
617309656	Insert								73.82	1.69	29.53
617203002	PACK				8.58					1.89	0.39
67403198b	PACK				12.25					1.89	1.48
67450187A	PACK				15.25					1.88	1.48
617221001	PACK				21.74					8.29	1.38
617300002	PACK				1.01					2.17	0.83
617220	PACK				0.88					1.04	2.36
617320001	PACK				1.01					1.84	0.71
617900811	RIEL	12.07		27.22						10.26	15.20
617900807	RIEL	13.47		36.56						8.36	15.29
617900818	RIEL	16.90		30.38						16.81	14.08
617900731	RIEL	16.90		30.36						16.91	16.10
617900815	RIEL	16.90		37.10						16.81	14.83
617900116	RIEL	14.10		38.49						8.18	14.75
617900804	RIEL	14.02		37.07						8.18	14.78
69175090C	SIC	13.91				38.73				4.89	5.67
691750932	SIC				8.08					1.88	2.14
691750526	SIC	17.77			21.48					5.29	1.70
691750020	SIC	17.77			27.23		8.41			7.21	3.88
691750010	SIC	17.77			32.28		12.88			6.82	3.88
691750610	SIC	17.77			21.48					5.95	3.88
67400182a	subassy			11.44						3.09	2.40
67400182a	subassy			11.75						3.09	2.40
77406788b	SLIDE LOCK							4.72		3.88	
77407036e	SLIDE LOCK							4.47		3.86	
QR	SLIDE LOCK							2.31		3.86	

Table 2 Matrix of average operating times

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Once the average operating times were obtained, the weighted time calculations were made. The Takt Time obtained from turn 1 is as follows:

$$Tiempo\ Takt = \frac{28739.7\ seg}{8274\ piezas} = 3.473495\ Seg/Piece \qquad (2)$$

The calculation of operators per shift is seen in table 3.

Operation	Time	Operators No.
Laser marking	1.386139	0.399062
Center pin and insulator assembly on body	0.223958	0.064476
Screw installation	1.048069	0.301733
Accessories packaging	4.944549	1.423508
Gromet Assembly	0.283489	0.081615
O'ring Assembly	0.034272	0.009867
Painting	1.134049	0.326487
Assembly of coaxial and outlets	0.075834	0.021832
Final inspection	3.239812	0.932724
Final Packaging	2.285850	0.658083
Total		4.21939

Table 3 No. of operators required for shift1

The calculation for shift 1 gave a result of 4.21939 operators and was adjusted to five, The activities assigned by operator are:

Operator 1	Laser marking, Accessories packaging	
Operator 2	Accessories packing, center pin assembly and body insulator, screw installation, o'ring assembly, coaxial and outlets assembly	
Operator 3	Accessories packing, Gromet assembly, painted	
Operator 4	Final Inspection	
Operator 5	Final packaging, accessories packaging	
Operator	Time	Takt Time
Operator 1	2.81920	3.47350
Operator 2	2.81520	3.47350
Operator 3	2.85060	3.47350
Operator 4	3.23981	3.47350
Operator 5	2.93120	3.47350

Table 4 Balancing operations for shift 1

In table 4, a margin for fluctuation of 0.5 sec has been left in the total time assigned with respect to the Takt Time, this due to a possible increase in demand or variation of time in the process, the flexibility criterion was used, seeking that the operators are certified in different operations that are carried out in the area; lastly, it was considered not to assign operations to the final inspector because he has to fulfill other responsibilities. Due to these criteria and because of an engineering request, a support operator was assigned to each shift, in the case of shift 1 this is fully available for any operation.

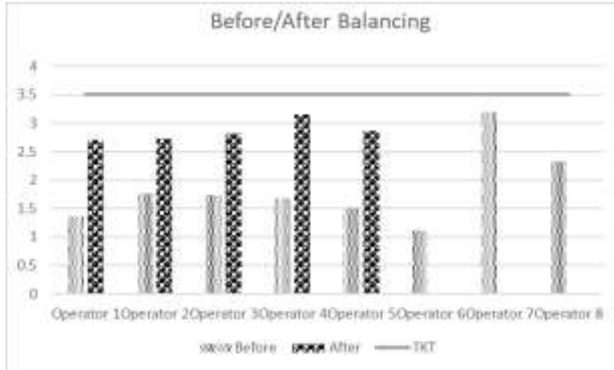

Figure 2 Operator before/after Line Balancing shift 1

The comparison of the balancing before and after went from 8 operators, which are 1.64 sec in average below the Takt allowing for leisure, to a more balanced assignment with 5 operators and a fluctuation margin of 0.54 sec.

To reduce Set-up times, a SMED was carried out in which the activities that could be performed while the machine was working were identified, as well as the activities that were could be eliminated because they did not add value and the internal activities that could be converted into parallel activities. Once the changes had been made, a reduction of the total time to 5.29 min was achieved, see table 5.

	Before (min)	After (min)	Saving
Backshell	11.18	5.38	52%
Coaxial	11.68	5.78	51%
Dummy	17.63	5.28	70%
Rail	16.35	5.2	68%
Sic	17.1	3.32	81%

Table 5 SMED results per family

In order to do the conversion of activities in parallel, Yamazumi was made, see figure 3.

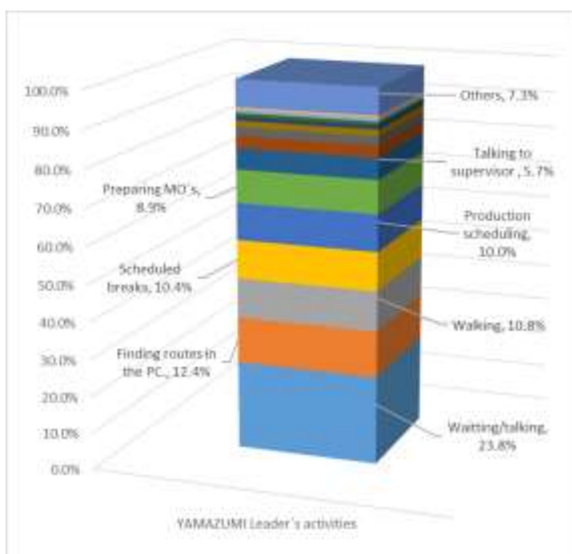

Figure 3 Area Leader Yamazumi

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The ratio of percentages and activities that were developed throughout the 11-hour shift of the leading area, the highest percentage of time is in waiting and talks, therefore it was possible to assign activities converted in parallel in the *set up.*

For the redistribution of the area, the Spaghetti Diagram was used, the lack of process flow was detected, which resulted in 21 recurring crosses that occur mainly in the Laser Marking, Teak Print, Quality and Packaging operations, 10 Setbacks that put the operator and the product at risk due to congestion in the aisles, which caused collisions between them, see figure 5.

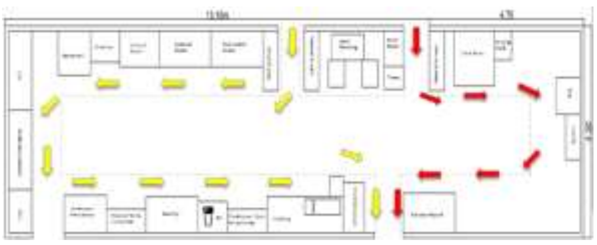

Figure 4 New distribution area and process flow

Completing the final packing table as it was redesigned, facilitated the relocation of the area; the unnecessary transportation and movements caused by the requirement of materials located in the racks were eliminated. In the new redistribution, two entrances and two exits were placed for safety reasons, as well as to ease the flow of materials. The area was relocated to enable the overseeing of the engineering supervisor, which results in greater control of the operators. The achievements after completing this project are summarized in the following table 6.

Results matrix				
Resource	Before	After	Saving	Increase
Operators	14	11	21%	
Set up time (min)	17	4.4	74%	
Space m2	60	53.71	10%	
Crosses	21	0	100%	
Setbacks	10	0	100%	
Theoretical Capacity (Units Produced)	2017	2371		17.57%
Productivity	109%	125%		16%

Table 6 Results matrix

5. Conclusion

During the development of the project, eight documents were generated that were essential for the fulfillment of the objective:

(1) Matrix of Processes for the Identification of Product Families, (2) Matrix of Times for High Runners, (3) Matrix of Weighted Times for Balancing Workloads, (4) Balancing Operations for Shift 1 and 2, (5) SMED standardized Diagram, (6) SMED Staff Training, (7) Lay out with Process Flow and (8) Savings Matrix. With this result, the intervention of the Lean Manufacturing at the operative level is evident (Ghizoni Pereira & Luz Tortorella, 2018) (Piña et al., 2018) and (Monge et al., 2013) when carrying out the practices described in this topic.

In the balancing, it was obtained that there were two more operators in shift 1 and one in shift 2, which were relocated to other areas of the company, with this the productivity of the area increased by 16% and generated savings of USD 21,000 per year, while the distribution of operations made operators more flexible. With the implementation of SMED in the laser marking machine at the beginning, the switching times were greater than what it was thought with a change time of 8 min on average, when analyzing the videos an average change time of 17 min was obtained, this is due to the fact that the times provided by the company did not count the kit revision time and from here we started to make a Yamazumi diagram for the leader of the area to see if he had the available time to support the *set up* activities.

A 74% decrease was achieved, which represents an increase in its capacity of 17. 57% since the time available to produce increased. With the redistribution of the area, a reduction of 10% of the used space was obtained, this favored its relocation since the room used for this was smaller, this could be achieved through the redesign of the packing table which implied the elimination of two racks of components adapting the material to the operator's reach and optimizing the space of the table. In this redistribution, an adaptation was made to a "U" manufacturing cell which allowed a process flow eliminating crossings and setbacks in the process and transports detected in the SMED. The changes made produced greater productivity at the operator level due to the decrease in distractors by reducing the approach among workstations.

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Ergonomic culture level in managers and supervisors in manufacturing centers

Nivel de cultura ergonómica en supervisores y alta direccion en una empresa manufacturera

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Abstract

The purpose of the following project is to measure the level of ergonomic culture of a manufacturing company that is dedicated to the development of cables, fiber optics, cabling systems and related services for the automotive sector and cable systems; To carry out this study, the ergonomic culture questionnaire in work centers (CCE-T) was used as a tool and it was applied to a sample of 26 people between supervisors and managers. This questionnaire made it possible to measure the level of development of ergonomic culture in work centers from the perspective of supervisors and senior management (managers) and to know their perception of the development and application of ergonomics in their company. Therefore,

Ergonomic Culture, Management, Evaluation

Resumen

El siguiente proyecto tiene como propósito medir el nivel de cultura ergonómica de una empresa manufacturera que se dedica a la elaboración de cables, fibra óptica, sistemas de cableados y servicio relacionados para el sector automotriz y sistemas de cable; para realizar dicho estudio se utilizó como herramienta el cuestionario de cultura ergonómica en centros de trabajo (CCE-T) y fue aplicado a una muestra de 26 personas entre supervisores y gerentes. Este cuestionario permitió medir el nivel de desarrollo de la cultura ergonómica en centros de trabajo desde la óptica de los que supervisores y la alta dirección (gerentes) y conocer la percepción que tienen sobre el desarrollo y aplicación de la ergonomía en su empresa. Por consiguiente, este instrumento se considera un elemento valioso como mecanismo de realimentación de procesos en salud colectiva y como herramienta diagnóstica.

Cultura Ergonómica, Dirección, Evaluación

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† Researcher contributing as first author.

Introduction

The automotive industry has a high production volume, meaning that components are assembled at a speed of 50 seconds per workstation and even when this industry is technology-based, parts of the process persist where the assemblies are manual or almost artisanal. Making the calculations based on this data and assuming that a component is assembled or used every five seconds, in total: every second 18 million components would be used, only for the industry in Mexico, this can be interpreted as that every second moving the workers' upper extremities 18 million times; fingers, hands, elbows, shoulders, neck and back (Millán, 2016).

Postural overload is an important factor for the appearance of musculoskeletal injuries in the worker, it is characterized by the fact that the body is out of the neutral position for a certain time, which favors the presence of symptoms of pain, inflammation, dysesthesia, paresthesia and limitation to carry out their work, preventing them from carrying out daily activities. (Tapia, Buenrostro, Cabrera, Pérez and Malagón (2017).

Faced with the real demand for these needs, industrial society demands from production engineering and ergonomics an effort to work together to provide solutions through concepts, methods, techniques and tools (Gomes, 2014).

The International Ergonomics Association (IEA) defines ergonomics as a scientific discipline that deals with understanding the interactions between users and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize the well-being and performance of the system (IEA, 2021)

In this way, the aim of ergonomics is that employees are comfortable in their workplaces. This objective is not only an ethical premise, but it will also have to do with the optimization of the usual processes of a company. If in a company the precise conditions are given so that its workers are comfortable in their positions, an increase in their performance will lead to an increase in productivity. Consequently, the company will be the main beneficiary of the implementation of ergonomic measures, which will be profitable over time (ARSAM, 2020).

Some reviews have provided data on the benefits that ergonomic interventions bring to these factors, underlining the importance of including not only workers, but also supervisors and senior management in these intervention strategies. That said, a company is then expected to develop a high degree of ergonomic culture, as the cornerstone of what is considered the primary intervention in ergonomics (Guzmán, 2010).

The term ergonomic culture is understood as "the set of forms and expressions applied to transform work, which characterize an organization" therefore, for a true ergonomic culture to exist, a "favorable environment, a thought collective and social reaffirmation of needs in the workplace "(Gómez, 2002).

Ardila & Rodríguez, (2018) after a review of the literature, they made a theoretical construct based on the Scott, Kogi and McPhee model and that contemplates the macro-ergonomic and micro-ergonomic dimensions and the organizational design, facilities design, training / education components, job title, task design, equipment / products and tools. They obtained a questionnaire of 26 items with Likert-type responses, validated by 5 experts (who made adjustments for relevance and adequacy), an analysis was carried out by main components (KMO, 0.804) and with a Cronbach's alpha of 0.901 in its internal consistency. The questions are outlined so that they can be answered in any business context. The definitive name of the instrument was assigned as:

For the assignment of values, the categories taken from the Likert scale raised in the questionnaire lead the evaluator to weigh each item. Thus, the total of the totally agreed answers are multiplied by one; partially agree, by two; partially disagree, by three; and totally disagree, by four. To determine the classification, from the results the total of the sum of responses of each of the four categories is taken, and it is transferred to a weighted table that allows, finally, to give the result of the level at which the worker classifies your company.

When evaluating the level of ergonomic culture, it is expected that a company can develop four levels of ergonomic culture: low, medium, high and very high, product of the sum of the partial totals already weighted.

This categorization allows the company to be guided on what its workers consider in terms of ergonomics actions and to compare the results with what exists.

The objective of this study is to determine the level of culture of supervisors and managers in a manufacturing company by applying the Questionnaire of Ergonomic Culture in Work Centers.

Methodology to be developed

A. Study subject

The study subjects were the supervisors and line managers of a manufacturing company. For the application of the questionnaire, it was taken into account that the company has 21 supervisors and 7 managers in all its areas from prototype, preparation, production and molding and to carry out a study a sample size calculation was made using a statistical tool, to know the number of questionnaires to be applied in order to measure the level of ergonomic culture in the company.

For the sample size, it was taken into account that it is a finite sample, with a confidence level of 95%; Obtaining that the necessary sample size is 26 subjects (supervisors and managers) to whom the questionnaire will be applied in order to know their perception of the development and application of ergonomics.

B. Procedure

Next, the steps that were carried out for the application of the ergonomic culture questionnaire in CCE-T work centers will be described.

– Instrument reliability

In this activity, the reliability of the instrument was determined by determining Cronbach's Alpha.

– Questionnaire application.

In this activity, a questionnaire was applied to the supervisors and managers of the company to find out their perception of the development and application of ergonomics.

– Analysis of results.

According to the data collection, the responses were analyzed to know the level of ergonomic culture that the company has.

C. Materials

The materials used to carry out the project were the following:

– SPSS software.
– Ergonomic culture questionnaire in CCE-T work centers of (Ardila & Rodríguez, (2018).

Results and their discussion

The applied instrument has 26 items and shows an Alpha Cronbach reliability of 0.897, which is considered acceptable. The sample (n = 26) consisted mainly of 16 men (61.5%) and 10 women (38.5%). Their average age was 34.4 years, and 73% had a Bachelor's degree and 27% a Master's level, with an average age of 3.2 years working in the company, a minimum of 8 months and a maximum of 7 years in the company. the company, of which 19 are supervisors and 7 managers.

The maximum value registered of the level of ergonomic culture obtained a value of 60 pts and the minimum of 45, with an average of 52.1 pts., And according to the scale used of 40-52, it considers that the Level of Culture is High, of 53-78 is Medium, and 79-104 is Low. In this way, being grouped according to level, 46% of the participants were high level and 54% of the participants medium level, see figure 1, highlighting that the managerial level is 100% high, in table 1 the data is disaggregated by position and gender.

Position	total	Culture Level					
		High		Half		Come Down	
		H	M	H	M	H	M
Managers	7	**5**	2	0	0	0	0
Supervisors	19	2	**3**	9	5	0	0
	26	7	5	9	5	0	0
Totals	100%	26.9%	19.2%	34.6%	19.2%	0.0%	0.0%

Table 1 Level of culture by type of position and gender

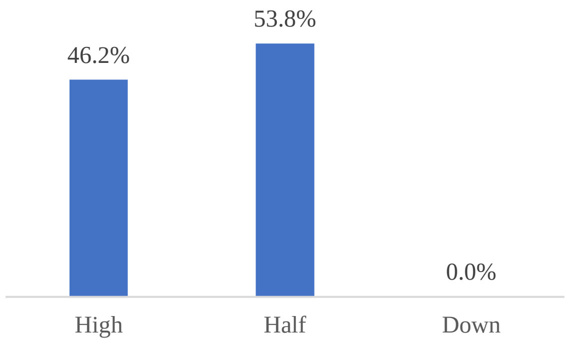

Figure 1 CCE level by category

Which means that:

High Level: The worker recognizes specific and organized actions in the development of the Ergonomic Culture in the company

Medium Level: The work recognizes some important points that denote an incipient development of an Ergonomic Culture in the company.

Analysis by question of the most relevant results of the study:

Question numberfour of the questionnaire: "Have measurements been made of the parts of your body to make adjustments to your job during the time you have been working in this company?" presents a result that shows that 100% is in "Totally disagree", this indicates that the organization does not have the anthropometric characteristics of its collaborators, which could affect decision-making to adjust their workstation or tools of work to your anthropometric measurements.

Question number eleven of the questionnaire: Have you received reinduction of the work you do? " presents a result that shows that 50% are in "Partially disagree" and the other 50% is "Partially agree" as shown in Figure 2, this indicates that only half of the subjects under study have received some reinduction in the work carried out in the company.

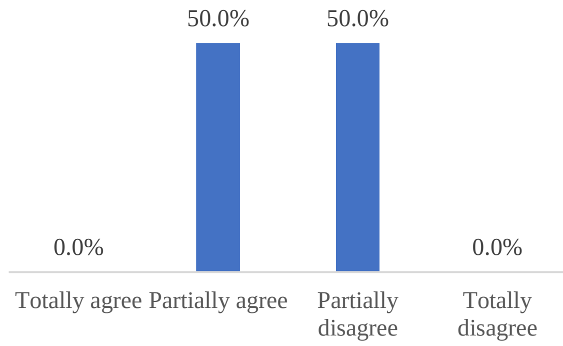

Figure 2 Percentage of reinduction of the task performed

Question number twelve of the questionnaire: "Do you receive training to improve the work you do?" presents a result that shows that 61% are in “Partially disagree”, 31% are “Partially agree” and 8% are “Totally agree” as shown in Figure 3, this means that their majority of the subjects under study (61%) do not receive adequate training to improve the work they do, while the other (39%) receive adequate or regular training to improve the work they do.

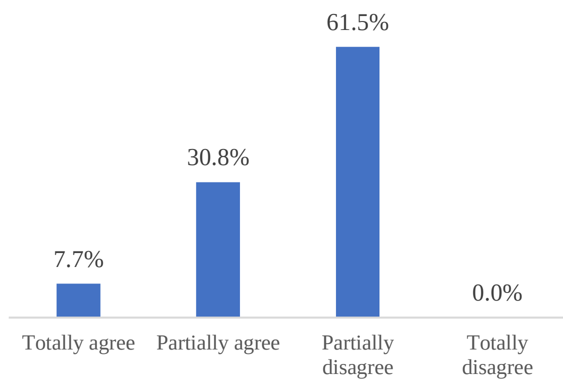

Figure 3 Percentage of training to improve the task performed

Question number seventeen of the questionnaire: "Are evaluations made of the conditions in which your physical workspace is located?" presents a result that shows that 69% agree "Partially agree" and 31% show "Partially disagree" as shown in Figure 4, this indicates that evaluations about the conditions are not carried out frequently or regularly of the physical work space of the subjects under study.

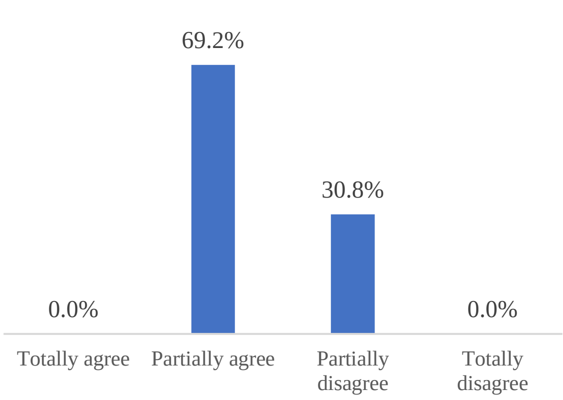

Figure 4 Percentage of people who have been considered, to improve their work area

Question number eighteen of the questionnaire: Have changes been made in the tasks that you carry out in a way that generates less risk of illness or injury? " presents a result that shows that 69% agree "Partially agree", 23% are "Partially disagree" and 8% are "Totally agree" as shown in Figure 5, this indicates that in the Most of the subjects under study have made changes in the tasks they perform on a regular basis changes in the tasks they perform in a way that generates less risk of illness or injury while only 23% show that no changes are made in the tasks regularly.

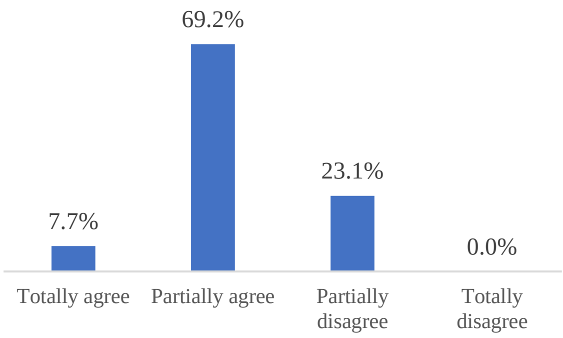

Figure 5 Percentage of workers who find less risk in the task performed

Question number twenty of the questionnaire: "Have adjustments been made to the functions and tasks in your position in order to reduce the risk of illness or accident?" presents a result that shows that 65% are "Partially agree", 27% are "Partially disagree" and 8% are "Totally agree" as shown in Figure 6, this tells us that their majority of the subjects under study (73%) have made adjustments to the functions and tasks in their position in order to reduce the risk of illness or accident while 27% have not made adjustments to their functions or tasks on a regular basis in your position in favor of reducing the risk of illness or accident.

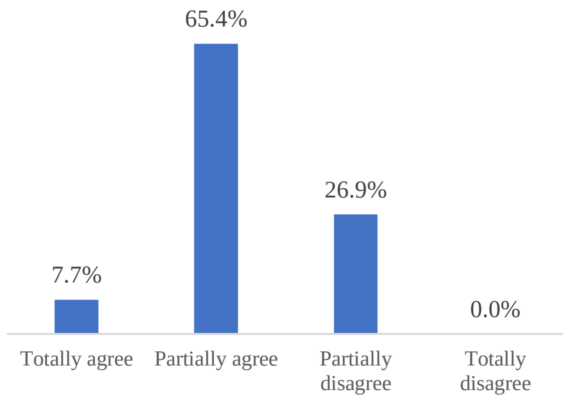

Figure 6 Percentages of perception of risk or illness of the worker in the work area

Question number twenty two of the questionnaire: "Have evaluations been made to determine the need to use elements that facilitate the work you do?" presents a result that shows that 54% are in "Partially disagree" and the other 46% are "Totally disagree" as shown in Figure 7, this indicates that more than half of the subjects under study do not agree. An evaluation has been made to determine if they have the need to use elements that facilitate the work they do, while the remaining (46%) have had no evaluation to determine the need to use elements that facilitate the work they do.

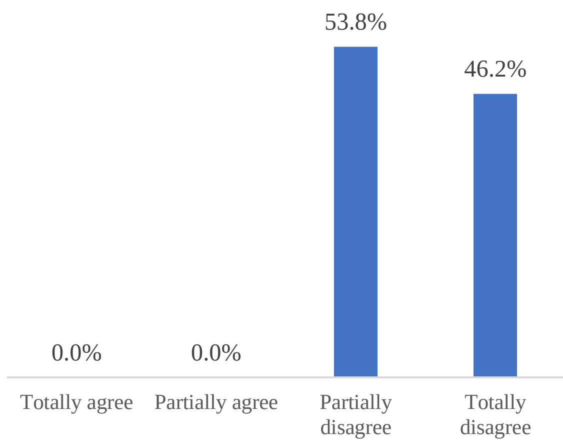

Figure 7 Percentage of workers who have not been evaluated to facilitate or reduce risk In tasks performed.

Question number twenty-three of the questionnaire: Do you use elements that facilitate the work that you do? " presents a result that shows that 96% are in "Totally disagree" while 4% are "Partially disagree" as shown in Figure 8, this indicates that a large part almost entirely (96%) of the Subjects under study do not use elements that facilitate the work they do, while the remaining (4%) have used very little elements that help them to facilitate the work they do.

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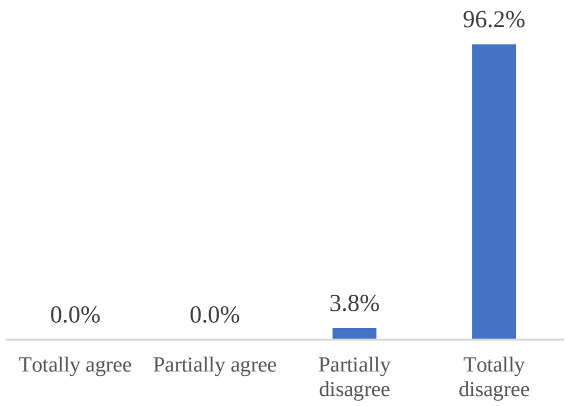

Figure 8 Percentage of workers who use a support tool in their work

Conclusions and recommendations

As a conclusion about this project, it can be said that the results of the survey are significant and show important results for the organization. In general, the results of the ergonomic culture in supervisors and managers in the company obtained a "High" rating, however it is important to make adjustments in processes and identify if the jobs, equipment and tools are suitable to develop their activities, with The purpose of reducing the risk that the employee suffers from a musculoskeletal disorder (MSD) disease or an occupational accident. Here are some recommendations:

Carry out an anthropometric study in order to have the information required to adapt the jobs to the capacities and limitations of their users (adapted to their anthropometric characteristics).

Carry out more frequently or more regularly the reinductions on the work carried out by the staff since it was shown that 50% do not receive reinductions in their work on a regular basis or in a way that is not entirely satisfactory.

Carry out more training or training since more than half of the subjects under study showed dissatisfaction with the training or training provided to improve their performance at the time of carrying out their work. Increase the number of evaluations that are made to the workspace, in the procedures, functions and tasks in order to find improvements to develop their tasks and reduce possible risks of illness or accidents.

It is also recommended to be constantly conducting inspections of areas, equipment and facilities seeking to identify the greatest number of conditions that represent the greatest risk to your safety and health in the workplace.

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Proposals to improve the coaxial cable assembly process in an aerospace company

Propuestas para mejorar el proceso de montaje de cables coaxiales en una empresa aeroespacial

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Abstract

For any company it is of utmost importance to have quality processes and products to deliver to its customers and that they are satisfied with them. In the same way, take care of your economy and the expenses that you have for this. This project revolves around the quality that is presented in the products. In the company under study there was a problem specifically in the area of coaxial cable assembly, in which a considerable number of defects were identified from the electrical and continuity test. To solve the problem, the objective is to develop an improvement proposal that helps to minimize the defects found in the aforementioned area. Regarding the applied method, the modified Six Sigma DMAIC procedure was followed. Statistical tools were used to analyze the results obtained, to have evidence of their behavior for the problem posed and that the best decision could be made to improve the coaxial cable assembly process. Having as a main result a proposal to improve the coaxial cable assembly process which will significantly reduce the defects generated in the electrical and conductivity test.

DMAIC, Continuous improvement, Quality

Resumen

Para cualquier empresa es de suma importancia el tener procesos y productos de calidad que entregarles a sus clientes y que estos estén conformes con ellos. De igual manera cuidar su economía y los gastos que se tiene por esto. El presente proyecto gira entorno a la calidad que se presenta en los productos. En la empresa bajo estudio se presentó un problema específicamente en el área de ensamble de cables coaxiales, en la cual se identificaban una cantidad considerable de defectos provenientes de la prueba eléctrica y continuidad. Para resolver el problema se plantea el objetivo de desarrollar propuesta de mejora que ayuden a minimizar los defectos que se encuentran en el área antes mencionada. En cuanto al método aplicado se siguió el procedimiento DMAIC de Seis Sigma modificada. Se utilizaron herramientas estadísticas para analizar los resultados obtenidos, para tener evidencias del comportamiento de los mismos para el problema planteado y que se pudiera tomar la mejor decisión para mejorar el proceso de ensamble de cables coaxiales. Teniéndose como resultado principal una propuesta de mejora al proceso de ensamble de cables coaxiales la cual reducirá significativamente los defectos generados en la prueba eléctrica y conductividad.

DMAIC, Mejora continua, Calidad

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Introduction

The manufacturing industry according to the National Institute of Statistics and Geography (INEGI, 2014) defines as the economic activity that transforms raw materials into different items for consumption. According to the type of product that is made, they are classified into 10 types of activity: Food Products, beverages and tobacco, Machinery and Equipment, Petroleum and coal derivatives, chemical industries of plastic and rubber, Metal industries, Products based on non-metallic minerals, Textile industries, clothing and leather industries, Paper, Printing and related industries, Other manufacturing industries, Wood industry, Manufacture of furniture and related products.

Within the manufacturing industry, specifically in the type of machinery and equipment, several activities are included, such as agricultural activities, extractive industry, aerospace industry, among others. The aerospace industry is engaged in the construction, design, operation, and maintenance of equipment that is intended to be used within the Earth's atmosphere and outside it. Having a worldwide value of 450, 000 million dollars. (Medina, 2012).

In Mexico, the aerospace sector is made up of companies that are dedicated to the manufacture, repair, adaptation, engineering, design, and auxiliary services of commercial and military aircraft. The country has managed to consolidate itself as a global leader in this sector. (Pro-Mexico, 2014).

According to the Mexican Federation of the Aerospace Industry (FEMIA, 2012), the aerospace sector is related to continuous innovation and the development of new technologies and cutting-edge materials, to contribute to the economic and social development of the countries in which it is developed. This sector is a key point for the generation of jobs and wages.

In Mexico, the aerospace industry is made up to a greater extent of foreign companies (Forbes, 2014), because the country focuses this activity on supplying the international market. During the period 2004-2013 Mexico had a 17% increase in its annual exports, representing revenues of 4,412 million dollars in 2013.

In Mexico, there are 287 industries in the aerospace sector, most of which have AS9100 Quality certifications, which is an adaptation of ISO 9001, with additional considerations for companies in this sector. Industries are mainly located in five states of the country. (Pro México, 2014).

According to the Council for Economic Promotion in Sonora (COPRESON, 2012) in Sonora, there are more than 45 manufacturing industries in the aerospace sector, all of the foreign investment, mainly of North American, British and French origin. These industries represent 50% of manufacturing activity in Mexico in the sector.

The company under study is a global manufacturer of interconnection components, offers products such as connectors, fiber optics, coaxial cables, multipin, antennas, space components, among others. The company is present in 3 continents and 13 countries, with specialized centers, offering its customers innovative products, personalized attention, and superior logistics.

The company produces a wide variety of products that are used in the aerospace industry, the area under study is that of Coaxial Cables. In this area, a great variety of them is assembled, which are semi-rigid or flexible. Each cable is different, but in general, they all contain connectors and cable.

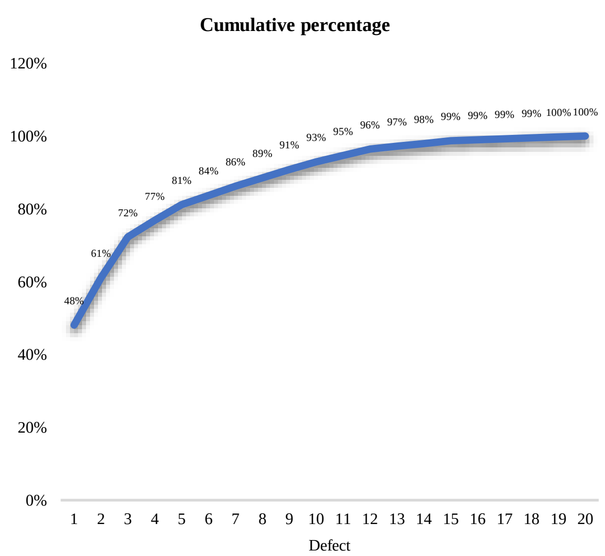
For the area under study, it is essential to control the process of assembling the cables, because it is an artisanal process carried out by the operators. Within the process, it is of utmost importance to be checking the cables during each season before passing them to the next stage of the process, in order to identify if there is any defect, since if they reach the final stage it may be difficult or impossible to correct it.

Despite the efforts to control the quality in the assemblies, defects have occurred during the last year, which compromises the quality of the product and also leads to not reaching the level of its main indicator, which is parts per million (ppm). Table 1 shows the different types of defects in cables. As can be seen, the electrical and conductivity test is the one that represents the highest percentage of appearance with 48.09%.

The electrical test is one of the last activities that are carried out in the process of assemblies of cables, it causes the rework or production. Which translates into a 20% increase in raw material cost.

No.	Defect	Cumulative Percentage	Percentage
1	Electrical Test and Conductivity	48.09%	48.092%
2	External Welding Spill	61.07%	12.977%
3	Interface Changed	72.26%	11.196%
4	Problems Epoxico (spill, foul)	76.84%	4.580%
5	Problems with the external conductor (braid)	81.17%	4.326%
6	Missing accessories	83.72%	2.545%
7	No splint pressing	86.26%	2.545%
8	Out-of-specification stripping	88.55%	2.290%
9	Splint damage	90.84%	2.290%
10	Damaged connector	92.88%	2.036%
11	Internal weld spill	94.66%	1.781%
12	Other	96.44%	1.781%
13	Damaged cable protector	97.20%	0.763%
14	Poor box labeling	97.96%	0.763%
15	Poor tube/marker shrinkage	98.73%	0.763%
16	Damaged external conductor	98.98%	0.254%
17	Marker with cut or gaps	99.24%	0.254%
18	Bad Pin Presser (Contact)	99.49%	0.254%
19	Hole in internal welding	99.75%	0.254%
20	No torque (Connector body)	100.00%	0.254%

Table 1 Different types of defects in cables
Prepared by the authors



Graph 1 Pareto Chart
Prepared by the authors

At the same time, it generates poor customer service, since your order is not delivered in the time you agreed, due to the rework that is made by the failure in the electrical test and conductivity, translating for the client into poor quality service. Figure 1 shows the Ishikawa Diagram where the possible causes that can cause defects in the product are shown, highlighting in red the causes that are considered the main ones.

The main causes found in the Ishikawa diagram are stripping measurements, the amount of welding, the lack of attention of the operators, the method of welding the connector, and the lack of maintenance of the tools that are used for the development of the process.

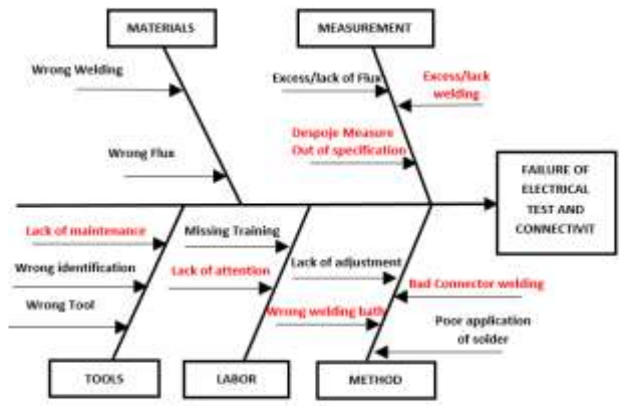


Figure 1 *Ishikawa diagram*
Prepared by the authors

The company produces a wide variety of products that are used in the aerospace industry, the area under study is that of Coaxial Cables. In this area, a great variety of them is assembled, which are semi-rigid or flexible. Each cable is different, but in general, they all contain connectors and cable. The process is different for each type depending on the client and the utility it will have. The electrical and conductivity test is performed on the cable to determine its resistance and if there is conductivity in it. In case of failure of the test, it indicates that the previous operations are not being carried out as required and the failure in the product.

Problem Statement

Quality is the characteristic of a product or service that has to satisfy implicit or explicit needs, and in this way obtain the satisfaction of the client that is the perception of the same about whether their needs have been met. (Gutierrez Pulido & De la Vara Salazar, 2013). In the area under study (Coaxial Cables) it is very important to carry out their quality and without defects, so there is quality control in each season of the process. Even with this in the process, you find defects in the cables as mentioned in the previous section. Therefore, we want to carry out actions that reduce the causes that cause defects in the cables. Which brings us to the following approach: How to reduce the defects that cause failure in the electrical test and conductivity in the process of assemblies coaxial cables?

Objective

Develop proposals for improvements to the coaxial cable assembly process, using the Six Sigma methodology, to reduce product defects that cause failure in the electrical test and conductivity.

Justification

With the above, the company will be able to reduce the defects of the Coaxial Cables product that cause electrical failure and conductivity, significantly reducing the production time of the same by eliminating rework and additional production, and in this way, the company will be able to increase its efficiency in production by being able to increase the number of orders it serves per day. In the same way, the company will have a reduction in its costs production.

Theoretical Foundation

SixSigma is a philosophy that is oriented to customer satisfaction, using facts and data to generate solutions to problems that affect them. It is aimed at improving customer satisfaction, reducing cycle time and defects. (Pande & Holpp, 2002). Six Sigma is a statistical measure of the level of performance of a process or product, which aims to achieve almost perfection, providing a management system to achieve leadership in the business where it is applied to have world-class quality. (Pande & Holpp, 2002)

It is a disciplined approach that is based on the use of statistics to improve business performance, by eliminating defects in an organization's products, processes, and transactions, by decreasing the cost of operation and that of products sold, and by increasing customer satisfaction. (Cantú Delgado, 2011). It is a methodology that is focused on eliminating the defects of a process or product, and in this way reduce the costs of the company where it is applied and most importantly exceed the expectations of the client.

The name Six Sigma is due to the one that refers to six standard deviations from the mean, which is a goal to reduce defects by 99.9997%, or in other words to achieve no more than 3.4 defects per million opportunities (DPMO).

One of the pin companies in the application of the six-sigma methodology was Motorola managed to reduce defects in electronic products and save about 1,000 million dollars during 3 years after implementation and won the Malcolm Baldrige quality award in 1988. At that time, it was adopted, enriched, and generalized by a large number of companies.

In addition to Motorola, two companies contributed significantly to the consolidation of the strategy, Allied Signal that first implemented it in 1994 achieving savings of more than 2,000 million dollars between 1994 and 1999, and General Electric (GE), which made its implemented in 1995 who managed to save around 2,570 million dollars in the following 3 years. In Latin America, the company MABE is the one that has managed to carry out and implement one of the most successful Six Sigma programs. (Gutierrez & De la Vara, 2013)

There are many reasons that can justify implementing Six Sigma in companies. (Cantu Delgado, 2011)

1. It helps improve the way the business is operated.
2. It helps to visualize the company as an interrelated system of processes and customers.
3. Troubleshoot problems.
4. Decision-making is made based on data.
5. Establish a system that can generate significant revenue, in order to satisfy both internal and external customers. With the above, better competitiveness is ensured and benefits are obtained in less time.
6. You can increase employee productivity with the same resources.
7. Revenue is improved.
8. Customer expectations are exceeded.
9. Give your staff a culture of quality, so they support the changes and be able to maintain the results.
10. If a process has a quality level of Six Sigma, this means that it is capable of generating no more than 3 or 4 defects per million opportunities.

Six Sigma has a wide variety of tools that serve as support in the implementation of the methodology, according to Gutierrez & De la Vara, (2013) and Pande, Neuman & Cavanagh, (2004) the basic tools are shown below:

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DMAIC Project Chart Worksheet: This helps the team understand what they want to achieve and identify areas where further clarification is required from the project sponsor.

Pareto Chart: This is a graph that aims to help identify the vital problems you have, as well as the possible causes of them. It helps to prioritize the causes to focus first on the main one and so on to analyze the causes. The usefulness of it is based on the so-called "Pareto Principle", which is known as "Law 80-20" or "Few Vital, Many Trivial", which establishes that few elements (represented by 20%) generate most of the effect (representing 80%), and the rest of the pampering has a smaller contribution. Stratification: Stratification means analyzing problems, failures, complaints, or data, classifying them according to the factors that are inferred that may be affecting them, and in this way identify the best ways to solve the problems that arise in a process. This tool makes it easier to understand how the different factors that generate a problematic situation influence.

Ishikawa Diagram: Also called Cause-Effect. This is a graphical method that helps to relate a problem (Effect) with the possible causes that generate it. The diagram forces us to look for different causes under analysis and thus avoids looking directly for solutions without analyzing the true causes.

Method of the 6M: This is the most common to build an Ishikawa diagram, it consists of grouping the possible causes into 6 main branches: Working Methods, Labor, Materials, Machinery, Measurement, and Environment. These six elements represent the entire process in a global way since each one contributes part of the variability of the final product.

SIPOC Diagram: The acronym SIPOC comes from suppliers, inputs, processes, outputs, and customers. This diagram aims to analyze the process and its environment, by them the suppliers, inputs, process, outputs, and the customers must be identified. This helps us to know in detail the process that is being analyzed, by identifying what is needed for it to work correctly, the specifications of the users of the process, identify who will provide what is necessary for the process and that is expected to leave the process studied. (Gutierrez, Quality and Productivity, 2014)

CTQ Tree: This helps to relate the measurements to an important output of the process; it is used in data collection to ensure that the information obtained is important for the project.

Hypothesis Testing

The interest in performing a hypothesis test lies in comparing the strength of two formulations (null and alternative hypothesis), one with the equal variable and the other with the modified variable. It is used to test a hypothesis, for this, it is necessary to perform a procedure to take a random sample, calculate a test statistic that is appropriate, and then reject or not reject the null hypothesis. You must specify the set of test statistic values that will be the rejection region. (Montgomery, 2016)

Design of Experiments

The design of experiments is the application of the scientific method to generate knowledge about a system or process, through planned tests. This methodology has been consolidated as a set of statistical and engineering techniques, which allow a better understanding of situations of cause-and-effect relationship.

Methodology

For the realization of this project and the fulfillment of the proposed objective, the DMAIC methodology was followed. The following points describe the activities that were carried out at each stage and the products that were obtained from each of them.

Define the opportunity areas of the coaxial cable assembly process

First, a meeting was held with the stakeholders of the project to collect the relevant information, where the problem that arose in the process of assembling coaxial cables and why it was wanted to be addressed was exposed. With the information obtained, the project charter (Project Charter) was made and the work team was formed. After this, a tour of the area of assembly of coaxial cables was carried out in order to know in detail what is done and identify the workstations, and based on this a SIPOC map was elaborated. The main variables that affect the process and that cause the problem of failure in the electrical test and conductivity were identified.

Finally, the customer who was affected was identified and their needs and complaints were identified. With the above, a table was made that contained the declaration of the client's requirements of the problem raised.

Measure the critical variables of the coaxial cable assembly process

Once the project was defined, the work team carried out an analysis of the possible causes that caused the problem, for this an Ishikawa diagram (Cause-Effect) was made. After this, the relationship between the customer requirements, raised in the previous stage, and the causes that were identified, were identified through a CTQ tree (Critiques for Quality). After this, a mapping of the coaxial cable assembly process was carried out to analyze what the true magnitude of the problem was, all the process variables and the outputs of the same that could affect the electrical test and conductivity were identified, and a cause-and-effect matrix was made, where the critical variables that were had within the process were found.

After this, a verification of the MEFAs of the process stations was carried out and an EFSM of the preparation station was created and with this, the critical variables of the process were obtained. Finally, the plan for the collection of data was made, which consisted of a database where all the defects they presented were placed, analyzing them with the microscope to identify the possible cause of it. With the data obtained, the performance of the CTQ of the process was measured. The results obtained from the data collection are shown in a table.

Analyze data from critical variables of the coaxial cable assembly process

In this stage, the data obtained in the measurement phase were taken and analyzed to determine which connectors were what had the highest percentage of appearance in the problem, for this a Pareto diagram was made, where the connectors with the highest percentage of appearance of the problem were found, which are connector A and B. As a result of this phase, you have a Pareto chart and the most important causes that contribute to the problem. To later perform the statistical analysis of the CTQ, from which the variables that were related to the output variable were obtained.

Implement improvement actions for the coaxial cable assembly process

At this stage, solutions that could help achieve the stated objective were established, this was done through brainstorming with team members and identifying changes that could be made to the process. A Design of Experiments was carried out to verify the behavior of different factors on the variables that affect the process. The executions of the design of experiments were carried out. And after this, proposals for improvement were developed for the process of assemblies coaxial cables. Having as a result of this phase the definition of the Designs of Experiments and proposals for improvement to the process.

Results

Definition of the areas of opportunity of the coaxial cable assembly process.

Through meetings with interested persons and observation of the coaxial cable assembly area, the results were the Project Charter, a SIPOC map of the coaxial cable assembly process, and the identification of the client and his requirements. Table 2 shows the Project Charter summarized.

Project Charter	
Business Case: Find and reduce the causative variation that causes products to fail at the electrical and conductivity test station	**Team Members:** Quality Engineer Process Engineer
Problem/Opportunity Statement: Variations in assembly in the area of cables have contributed to the increase in electrical failure, increasing the level of ppm, production costs and delivery times, according to quality records.	**Objective Statement:** To reduce to 70% the defects of the assembly process in the area of coaxial cables in order to control the failure in the electrical test in the electrical test station and conductivity.
Project Scope: The project will be carried out in the Coaxial Cables Area specifically the Welding and Preparation stations. Aspects of the project will be reviewed daily and whether it will have a progress meeting on Mondays.	**Stakeholders:** Supervisor of the area. Process Engineer AVP Manager

Table 2 Project Charter (summarized)
Prepared by the authors

After the tour of the coaxial cable assembly area, the SIPOC Map was obtained, which is divided by the activities carried out throughout the process. Table 3 shows the SIPOC map of the Contact Welding (PIN) process.

Suppliers	Inputs	Process	Outputs	Costumers
External Suppliers	Welding specified in MO	**Contact welding (PIN)**	Cable with welded contact	**External Customer Correct delivery of your product** **On-time delivery** **Quality product**
Contact placement	Flux specified in MO		No spills	
Human resources	Cable with suitable contact		Contact glued to the insulator	
Tooling	Operator		Inspection window full of welding	
	Welding tweezers			

Table 3 SIPOC Map, Contact Welding Process (PIN)
Prepared by the authors

Customer Requirements Statement

In this section, the client who was affected by the problem was identified, being the Electrical and Conductivity Test Station, and based on this the Client's Requirements statement was obtained, which requires a cable with transmission and continuity. Table 4 shows the Voice of the Customer.

The Customer Says	Meaning	Requirement
There is no transmission in the cable.	The central conductor is making physical contact with the body or with the braid. The central conductor does not make contact with the connector.	Perform cable assembly processes properly to avoid the existence of the problem.
When the high-voltage discharge is realized the cable has no continuity.	The ideal distance between the connector and the braid is not being respected.	Perform the process of assembling the cable taking care of the distance between the connector and the central conductor.

Table 4 Voice of the Customer
Prepared by the authors

Measurement of the critical variables of the coaxial cable assembly process

In this phase, through observation of the process and active participation of those involved in the coaxial cable process, an Ishikawa diagram was obtained with the possible causes that generate the problem, a CTQ tree (Critics for quality, for its acronym in English), and the database where the defects that were presented are shown.

Ishikawa diagram making

This section shows the Ishikawa diagram that was obtained from the observation of the coaxial cable assembly process, as well as questions, were asked to the operators about what could cause the failure in the electrical test.

Figure 2 shows the Ishikawa diagram of the possible causes that generate the failure. The diagram shows a view of all the possible causes that affect the Failure of Electrical Test and Connectivity With this vision we can analyze in detail each cause and the effect it has on the process.

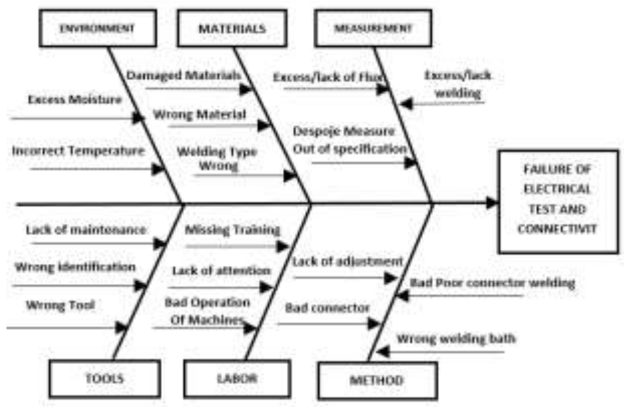


Figure 2 Ishikawa diagram of the process
Prepared by the authors

Elaboration of a tree of criticisms for quality.

After determining the client's requirements, an analysis was carried out to know what relationship they have with the causes found in the Ishikawa diagram. Figure 5 shows the CTQ tree that was validated by the Process Quality Engineer.

Failure in electrical test and conductivity	**Cable cutting**	Excess Welding	
		Bad cable preparation	
	Open electrical conductor	Lack of welding	
		Bad cable preparation	
	Electric arc generation	Electrical distance not respected between connectors	Lack of welding
			Bad cable preparation
			Despoje Insufficient

Figure 5 CTQ Tree. Prepared by the authors

Mapping of the process of assemblies of coaxial cables

At this point, a process mapping was carried out to identify all the variables that existed in each workstation, as well as their outputs, which could affect the electrical test and conductivity. Table 6 shows the variables and outputs of the process

X's	Process Variables	Y's	Process Outputs
X1	Lack of operator training	Y1	Strip wrong ends
X2	Wrong raw material	Y2	Damaged external protector
X3	Forward speed cutting machine	Y3	Damaged external conductor
X4	Calibration of cutting machine	Y4	Damaged connector
X5	Stripping machine calibration	Y5	No Welding Bath
X6	Rotary knife cutting speed	Y6	Poorly placed central conductor
X7	Welding type	Y7	C.C. Damaged
X8	Amount of welding	Y8	C.C. with excess welding
X9	External welding application time	Y9	C.C. with hollow or lack of sun
X10	Tipo de flux	Y10	Misplaced pin (out)
X11	Amount of flux	Y11	Melted insulator
X12	Soldering iron temperature	Y12	Cut insulator
X13	Power (temperature) of welding clamps	Y13	No contact pressing
X14	Pressing dimension	Y14	Poor contact pressing
X15	Torque force	Y15	External welding (Hollow, Missing)
X16	Wrong tool	Y16	External Welding Spill
X17	Lid pressing height	Y17	Internal Welding Spill
X18	Burn gun temperature	Y18	Excess External Welding
X19	Wrong Pressing Given Tool	Y19	No body torque
X20	Braid hairstyle	Y20	Damage from body torque
X21	Splint placement	Y21	No splint pressing
X22	Placement of PIN	Y22	Poor splint pressing
X23	Type of flux	Y23	Splint and connector space
X24	Cutting knife condition	Y24	short circuit between CC and CE
X25	Damaged raw material	Y25	Open between contacts
X26	Distance between dielectric and central conductor	Y26	Open between connector body
X27	Braid waste	Y27	Leakage current greater than specification

Table 6 Process variables and outputs
Prepared by the authors

Elaboration of cause-and-effect matrix

In this step, an array was made where the variables (X's) of the coaxial cable assembly process are compared with the process outputs (Y's). Likewise, the total that each input variable was calculated, based on this, the critical variables for the process were determined. As a result, the variables with the highest percentage of contribution were: Amount of welding (X20) with a percentage of 6,044%, followed by the placement of the connector (X37) with a percentage of 4,925%. Of the total of the variables that appear in the cause-and-effect matrix within 80% is the amount of welding, connector placement, wrong raw material, length of offal, PIN placement, braid combing, and amount of flux.

Analysis of the data of the critical variables of the coaxial cable assembly process

In this phase, the data obtained in the measurement phase were taken and a Pareto Diagram of the connectors with the greatest contribution to the generated problem was obtained, as well as the statistical analysis of the data.

Pareto Chart Elaboration

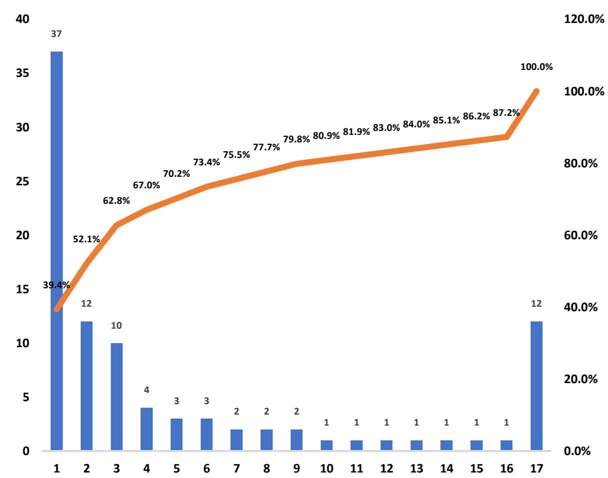
In this step, the Pareto diagram was obtained where the connectors that had the most appearance in failures in the electrical test and conductivity are shown.

Table 7 shows the types of connectors with the percentage of appearance of each of them, which contribute to the electrical failure, also in graph 2 is represented graphically.

No.	Connector	Occurrence	Cumulative Percentage	Percentage
1	A	37	39.36%	39.36%
2	B	12	52.13%	12.77%
3	C	10	62.77%	10.64%
4	D	4	67.02%	4.26%
5	E	3	70.21%	3.19%
6	F	3	73.40%	3.19%
7	G	2	75.53%	2.13%
8	H	2	77.66%	2.13%
9	I	2	79.79%	2.13%
10	J	1	80.85%	1.06%
11	K	1	81.91%	1.06%
12	L	1	82.98%	1.06%
13	M	1	84.04%	1.06%
14	N	1	85.11%	1.06%
15	O	1	86.17%	1.06%
16	P	1	87.23%	1.06%
17	Other	12	100.00%	12.77%
	Total	94		

Table 7 Types of connectors
Prepared by the authors

As can be seen in graph 6, connector A is the one that contributes the most to the electrical failure by having 39.36% of appearance, in second place, connector B with 12.77%.



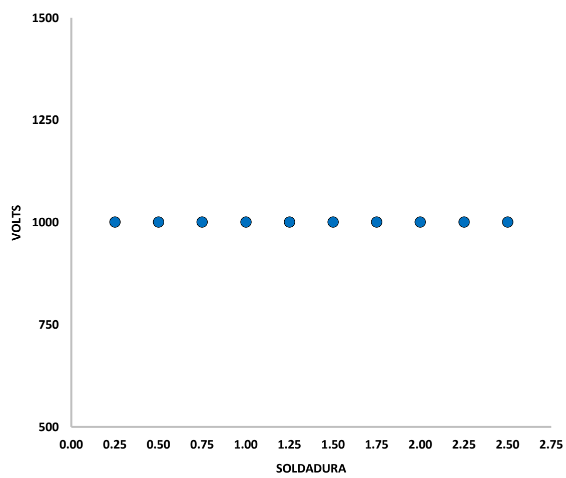
Graph 2 Pareto graph of connectors
Prepared by the authors

Behavior analysis of variables

In this step, statistical tests were performed on the variables that were identified as critical, to analyze them by regression and determine the relationship they had with the failure in the electrical test.

Behavior analysis of the variable welding quantity

A sample of 10 cables was established to which a different amount of welding was applied, giving higher and lower values than the nominal established in the work route that is 0.75 inches of welding. And the volts that the cable-supported were measured as a result to corroborate that they passed the electrical test by having to withstand 1000 volts. Graph 3 shows the behavior that was obtained from this analysis.

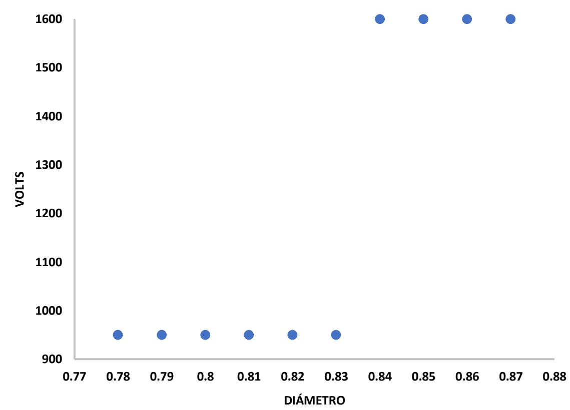


Graph 3 Plot Volts Vs Welding
Prepared by the authors

As can be seen in the graph above, the volts that each cable supports with the different amounts of welding does not have a significant effect on the number of volts they support. Therefore, the variable Welding Quantity is discarded when it is found that it has no relation to the output variable that is the failure in the electrical test because all the cables supported 1000 volts which was the minimum required.

Behavior analysis of the measured variable of the spoils.

To carry out this analysis, the diameter between the central conductor and the braid was taken as a reference. Modifications are made to the stripping of the nominal diameter that is 0.82 inches, giving it greater and lesser values. Taking, as a result, the volts that these supported, having to withstand 1000 volts to pass the electrical test. Graph 4 shows the behavior of this variable.



Graph 4 Plot of Volts vs. Diameter
Prepared by the authors

As can be seen in the graph above, 7 of the 10 cables did not withstand the minimum number of volts required to pass the electrical test, which indicates that the separation diameter is related to the voltage that the cables support by having a smaller diameter of separation the cables support less voltage. With the above, it is determined that the variable measures of stripping are related to the output variable that is the failure in the electrical test.

Implementation of improvement actions for the coaxial cable assembly process

In this phase, the data of the connectors with the highest contribution of occurrences established in the Pareto diagram of the Analysis Phase were taken, as well as the critical variables that were obtained after the behavior analysis of the variables. The type B connector was taken for the design of experiments due to the availability of materials that were within the area. Obtaining a Design of Experiments and the implementation of this.

Planning for Design of Experiments connector type B

In this section, the design of experiments to be carried out for the type B connector with the stripping measurement and pressing method factors was carried out. Table 8 shows the factors to be considered, as well as the levels that were granted to each of them

Factor	Unit of Measurement	Level (-)	Level (+)
Despoje Measure	Inch	0.45	0.55
Pressing Method		Pressing	Non-Pressing

Table 8 Design Factors of Experiments connector type B
Prepared by the authors

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In the table above it is observed that two levels were given to each factor within the design of experiments, for the Measure of the Despoje 0.45 and 0.55 inches, and the Method of Pressing, pressing, and not pressing.

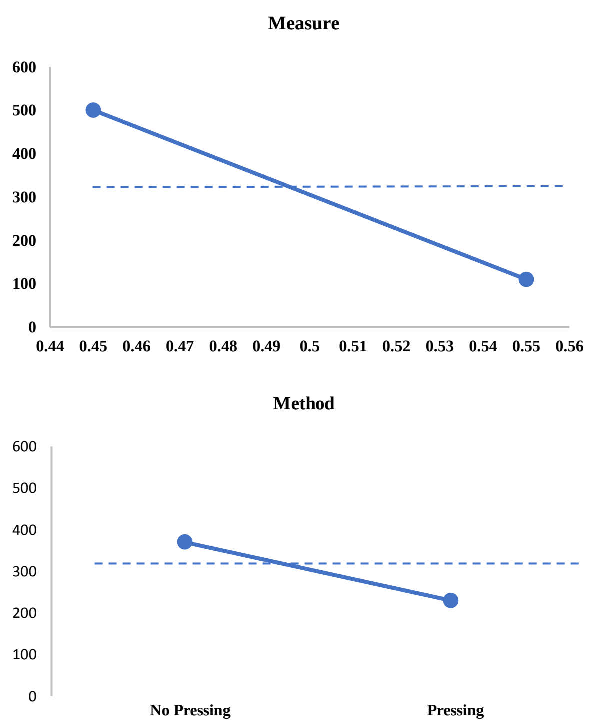
Design Result of Experiments type B connector

After the execution of the design of experiments proposed in the previous point, Table 9 shows the results that were obtained.

Source	gl	Sc Adjusted	MC Adjusted	Value F	Value p
Model	3	687500	229167	11.00	0.001
Lineal	2	625000	312500	15.00	0.001
Measure	1	562500	562500	27.00	0.000
Method	1	62500	62500	3.00	0.109
Interactions of 2 Terms	1	62500	62500	3.00	0.109
Measure*Method	1	62500	62500	3.00	0.109
Error	12	250000	20833		
Total	15	937500			

Table 9 Experiment Design Results
Prepared by the authors

As shown in the table above, the Measurement factor, since its p-value is less than 0.05, indicates that the hypothesis that the means are equal is accepted, that is, there is no significance between them. On the other hand, the Method factor having a p-value greater than 0.05 indicates that the hypothesis that the means are equal is rejected, that is, there is statistical significance between them. Graph 5 shows the behavior of the factors on the Volts output variable.



Graph 5 Main effects graph for volts
Prepared by the authors

The graph above shows that the Non-Pressing Method is better than the Pressing Method, likewise indicating that the measure of 0.45 is better than 0.55. Therefore, the best yields are found in non-pressing and a stripping measure of 0.45 inches.

Development of proposals for improvement to the area of assembly of coaxial cables

After the execution of the design of experiments and the interpretation of the results that were obtained from it, it is taken as an improvement proposal for the process of assemblies of coaxial cables is that a change is made in the measure of stripping that is had for the cables that carry the connector type B, reducing this to 0.45 inches, so that a greater separation between the central conductor and the braid is obtained. With the above, the possibility of a short in the cable is reduced and with this the failure in the electrical test.

Conclusions

During the time in which the present project was developed in the company under study, to analyze and find solutions that help reduce the defects that affect the electrical test and conductivity, it was found that there were a high number of variables present in the process of assemblies of coaxial cables that could contribute to the presentation of the fault.

To find proposals that help improve the process, it was necessary to make exhaustive observations of the process, to identify each of the variables that affected it and in turn specify these in each season of the process. Thus, generating a list of all the variables of the process.

Continuing with an analysis of the variables to determine which were critical to the process, that is, which had a greater effect on the failure of the electrical test. Since it is very important to discard the variables that do not significantly affect the problem. At the moment that the significant variables of the project are had, the design of experiments is carried out to know the behavior of these variables on the expected result, which is that the cables pass the electrical and conductivity test. Obtaining from this a proposal to improve the process that consists of modifying the stripping measure from 0.55 inches to 0.45 inches for the type B connector.

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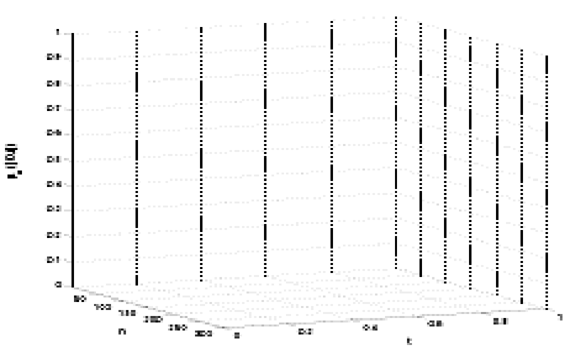

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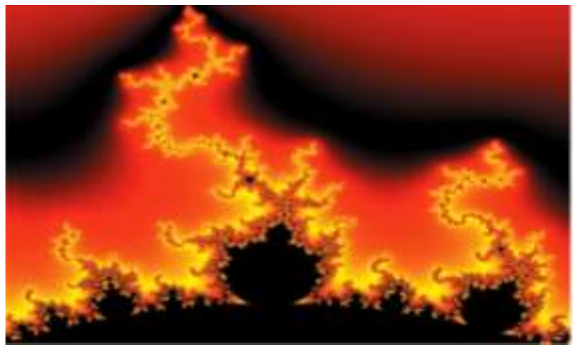

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