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Knowledge Area

The works must be unpublished and refer to topics of Economy, Regional Development, Business, Management of SMEs and other topics related to Social Sciences.

Presentation of the Content

In the first article we present, *Supply model in academic workshop of coffee bean roasting*, by Ramírez-Román, Adolfo, Rodríguez-Rodríguez, Luis Alberto, Suárez-Álvarez, Ángel and Chabat-Uranga, Jacqueline, with adscription at the, Universidad Veracruzana – Facultad de Ingeniería Mecánica y Ciencias Navales, as following article we present, *Global port supply chain management*, by Cruz-Ramirez, Christian, Cruz-Gomez, Marco Antonio, Espinosa-Carrasco, María del Rosario and Mejia-Perez, José Alfredo, with adscription at the, Benemérita Universidad Autónoma de Puebla, as following article we present, *Diagnostic, analysis and management of the routes of a Distribution Center of a dairy producer in the State of Mexico*, by Zenteno-Bonola, Ana Luisa, Calderón-Ríos, Norma Otilia, Palomar-Fuentes, María del Pilar and Benitez-Vallejo, Juan Carlos, with adscription at the, Tecnológico Nacional de México- Instituto Tecnológico de Toluca, as following article we present, *Optimization of production processes through the Kaizen philosophy to reduce time*, by Hernández-Anaya, Luisa Fernanda, López-Garza, Esmeralda, Garza-Moreno, Jesús Cruz and Espíndola-Álvarez, Jorge Antonio, with adscription at the, Universidad Autónoma de Tamaulipas, as following article we present, *Optimization of photovoltaic panels through machine learning algorithms linked to predictive maintenance*, by Ruiz-Garduño, Jhacer Kharen, Flores-Serrato, Leonel, González-Ramírez, Claudia Teresa and Viñas-Álvarez, Samuel Efrén, with adscription at the, National Technological Institute of Mexico, as the last article we present, *Parallel computing for efficient calculation of multidimensional Bernstein copulas in modeling nonlinear dependence between random variables*, by Hernández-Maldonado, Victor Miguel, Erdely, Arturo and Diaz-Viera, Martin Alberto, with adscription at the Dirección Adjunta de Innovación y Conocimiento (DAIC), Universidad Nacional Autónoma de Mexico and Instituto Mexicano del Petróleo (IMP) Ciudad de México. CDMX.

Content

ECORFAN-Journal Republic of Cameroon 10[18]1-10: e11018110
Article

Supply model in academic workshop of coffee bean roasting

Modelo de suministro en taller académico de tostado del grano de café

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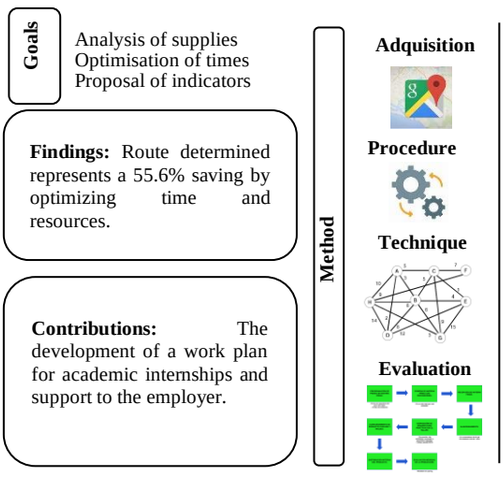
Abstract

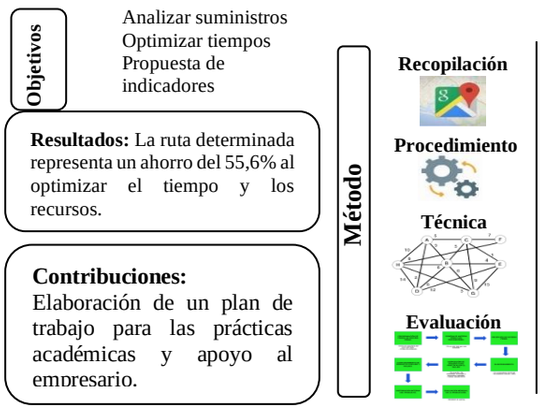
In the international market, companies encourage the generation of ideas to enter the environment and gain competitive advantage. Consequently, supply models are the combination of technology and good business practices from the industrial sector, including the information systems required to check activities. The aim of this study is to analyze the supply of operations in the production process of a coffee roasting workshop. Indicators and operations strengthen the development and execution of supply chain planning, organization and management. With field work in coffee farms, profits and companies found in the main producing regions of central Veracruz: Coatepec, Ixhuatlan del Coffee, Huatusco and Cordoba.



Supply chain, coffee bean, process optimization

Resumen

En el mercado internacional, las empresas fomentan la generación de ideas para entrar en el entorno y obtener ventaja competitiva. Como consecuencia, los modelos de suministros son la combinación de tecnología y buenas prácticas de negocios del sector industrial, que incluye los sistemas de información requeridos para monitorear las actividades. Con la finalidad de analizar el suministro de las operaciones del proceso productivo de un taller para el tostado del café. Los indicadores y las operaciones fortalecen el desarrollo y ejecución de la planificación, organización y gestión de la cadena de suministro. Con trabajo de campo en fincas Cafetaleras, beneficios y empresas ubicadas en las principales regiones productoras del centro de Veracruz: Coatepec, Ixhuatlán del Café, Huatusco y Córdoba.



Cadena de suministros, grano de Coffee, optimización del proceso

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Introduction

Supply activities involve the movement of goods from the supply of raw materials to the final consumer. This includes choice, buying, production scheduling, order processing, inventory control, transportation, storage and customer service. (Hernandez-Marquina et al., 2024).

In the Faculty workshop has a mortar machine, toaster, mill, sealant, and tools for roasting, grinding and packaging coffee bean. It is a proposal for standard operations to be conducted for the workshop supply chain, from planning to execution, The availability of machines and tools for use and process optimization (Ratanasanya, et al., 2022).

The coffee processes in the farm include pulping, fermentation, washing, drying, and storing. Among these, fermentation requires special attention given that the biochemical changes that occur in the coffee mucilage affect the flavor and aroma precursors of the final product (Rosero & Pantoja, 2021).

In this paper, we present the identification of an analysis model through the Dijkstra algorithm. Refers Edsger Dijkstra, who first described it in 1959.

“Dijkstra's algorithm uses the greedy principle, which is looking for the shortest path from one node (point / vertex) to another in the same direction (directed graph) starting from the origin node to the destination node. The calculated nodes are obtained from several strategic locations that can be known in general, such as offices, crossroads or public locations that are easily remembered by the public. The supporting data for the calculation of the Dijkstra's algorithm uses data derived from the user information about the user's name and location, while the location coordinate data is obtained from Google Maps” (Jason, et al., 2023).

There are studies, consider a vertical coffee supply chain where processors buy the raw coffee beans from planters, process them to convert them into green coffee beans, and sell them to firms or retailers who in turn sell the roasted or powdered coffee to consumers. Farmers or planters are price takers, and processors may enjoy oligopsonistic power vis-a-vis farmers.

The retailers may exercise oligopsony power vis-a-vis processors, or processors could also enjoy oligopoly power over retailers (Tanushree Haldar, 2022).

The impact of exports on economic development is more than imports as it is more closely related to domestic activities. The world growth significantly depends upon export share of the world. The export share has a close connection with the growth of a country as well (Sultan & Munir, 2015).

Historical data on coffee bean

The worldwide spread of the genus Coffea started in the African tropics, but it was not until the 14th century that the Arabs brought the plant to Yemen and there appeared the first plantations. By 1510 its production and consumption had already spread to Cairo and in 1555 to Istanbul, so that its advance continued in the Islamic world between periods of prohibition and tolerance.

By the early 17th century coffee had already been introduced into India and by the end of the same century, the Dutch brought the Yemeni coffee to the island of Java, where the climatic conditions and fertility of the land allowed coffee to adapt perfectly in the East Indies (Granados, 2018).

Although coffee was known in Europe from 1450, only until its arrival in Venice in 1615 and Marseille in 1644, its consumption expanded, and its commercial importance increased. By the mid-18th century, coffee consumption had become widespread throughout Europe and even coffee trees had been planted in the main botanical gardens.

But, in America, coffee was introduced during the eighteenth century by the French Captain Clieu, who was commissioned to bring a bunch of coffee to the island of Martinique, to propagate its production and consumption in the French colonies. From that island in the Antilles, the plant spread through the Caribbean and the Continent.

In 1727 coffee was introduced to Brazil and in 1731 to Jamaica and Santo Domingo, from where its cultivation spread to the rest of the present producing countries of America. With the industrial revolution and the growth of the world population during the 20th century, coffee became practically a universal drink (Díaz, 2015).

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Before entering Mexico, coffee travels from the Guyanas through the Antilles, Martinique, and finally Cuba. It is known that in 1796, it was Don Juan Antonio Gómez who brought from Cuba to the region of Córdoba, state of Veracruz, the first coffees that existed in the country, and that on May 16, 1808, coffee arrived in Coatepec, Veracruz, coming from Havana, Cuba, as described by Mariano Contreras (Ruiz-López & Calleja, 2021).

The coffee-growing region of Veracruz is distributed in 842 communities and 82 municipalities, where there are about 86,000 producers, some of them indigenous inhabitants belonging to the Nahuatl, Totonac and Popoluca ethnic groups.

Most processes including Source, Manufacturing, Delivery and Return have a small performance value with a lower class. Costs and Agility have the lowest score. (Nguyen, et al., 2021)

Box 1

Figure 1

Coffee-producing regions in the state of Veracruz

Source: Pronatura México

Where the northern zone involves Huayacocotla, Papantla and Zozocolco; in the central zone Atzalan, Misantla, Coatepec, Huatusco, Ixhuatlan del Coffee, Cordoba and Zongolica; and in the southern zone Tezonapa and Los Tuxtlas.

Although the "local demand for specialty coffee is growing, however, and coffee-cherry products are increasingly traded and consumed. This bears potential for retaining more value in origin countries and among farmers. However, how farming families can better profit from specialty coffee and its by-products, such as dried coffee cherries (also known as cascara or sultana), remains poorly understood" (Jacobi, et al. 2024).

During roasting, the grains undergo significant transformations due to the gradually reached temperatures. At 100°C, they double in size, and it is then that the grain loses its moisture and changes color to a deep yellow tone. Progressively between 150 and 180°C the grains get tones ranging from light brown to brown. When the temperature inside reaches around 200°C, the oils come out of the grains. Generally, higher oil results in changes in taste (Severin & Lindemann, 2024).

The chemical composition of green coffee beans is not only determined by species and variety, but also influenced by a few different factors including the terroir, harvesting methods (handpicked or mechanical), seed processing (wet, dry, or semi dry) and storage (Kath, et al, 2021).

Supply Chain Management (SCM) is the key unit of action for the implementation and success of the analysis of the algorithm (Hernández-Marquina, et al., 2024).

Traditional literature on linear SCM extensively discusses collaboration and its impact on performance, along with strategies to improve collaboration and enhance Supply Chain (SC) performance (Boughzala & De Vreede, 2015).

For example, there are studies that describe the measurement of supply chain performance using the Supply Chain Operations Reference (SCOR) method with the Key Performance Indicator (KPI) validation phase, the calculation of the actual KPI values and the weighting of the metrics for each level using the Analytical Hierarchy Process (AHP) method. (Suryaningrat, et al., 2024).

Also, with research exploring the significant growth in Honduran coffee production and productivity, while contrasting these achievements with growing concerns about environmental and social sustainability. (Ceballos-Sierra, et al., 2024).

Methodology

Study area

The selected suppliers are from Farm Monte Azul (FMA), farm Coffee-Tal Apan, and farm Xico. For the study, the arabica type green coffee grain with 5% defects, 12.5% moisture, harvested at 1100 meters above sea level is used.

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Box 2

Figure 2
Arabica coffee
Source: Farm Monte Azul

Farm Monte Azul, a company originally from Huatusco, Veracruz, Mexico. Located in the mountainous area and mesophilic forest, harvesting its coffee at more than 1,200 m above sea level and dedicated to marketing green, roasted, ground and soluble coffee (Finca Monte Azul, 2024).

Equipment

The areas and machinery in the faculty industrial workshop are distributed according to the following figure 3.

In other studies, a drum coffee roaster is a basic type of roasting machine that consists of a horizontal drum rotating over a heat source which could be supplied by fuels or electricity. The most common employs indirectly heated drums, where the heat source is under the drum (Klaidaeng, et al., 2023).

Where the following equipment is found, first, toaster machine for coffee beans, cereals such as peanuts and cocoa. It has the largest load capacity of 3 kg per roasting cycle and a minimum of 1.5 kg.

The duration of each cycle varies according to the type of grain, but ranges between 15 and 25 minutes.

The product is fed into the top hopper, the mixing or beating takes place inside the cylinder and the toasted product is discharged through the central gate directly to the cooling tank. Process smoke is distributed through the chimneys to the outside.

Box 3

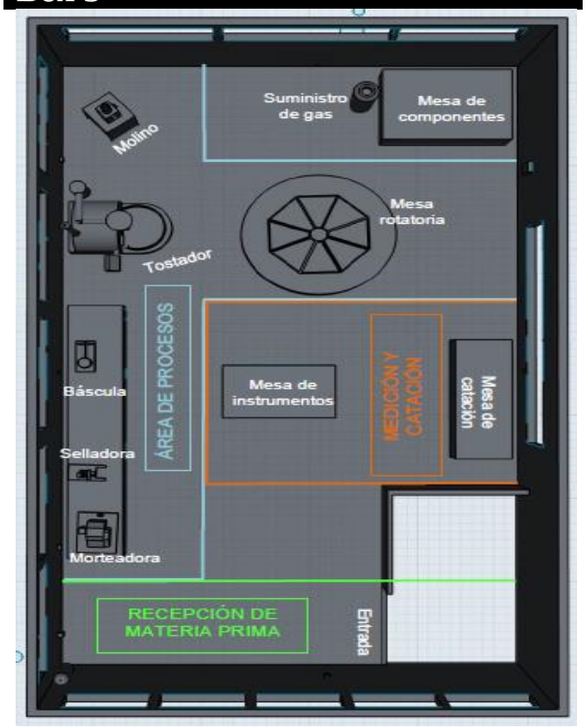

Figure 3
Distribution of the working area (Lay out)
Source: Industrial workshop of the faculty

Box 4

Figure 4
Toaster machine
Source: Industrial workshop of the faculty

Coffee grinder for roasted grain, "Use Rough" classification. It has a grinding capacity of 1.2 kg/min, just like those deposited in the transparent hopper. Once the grain is in the hopper, the side door is released to pass through the body where the blades are found, with the Swiss discs. It has 9 levels of coffee granulation adjustable to the operator's taste. The ground coffee leaves the front nozzle into the pre-placed container, the waste falls into the waste tray.

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Box 5

Figure 5
Machine for grinding
Source: Industrial workshop of the faculty

Morteadora machine, which consists in removing the grain husk that covers the coffee bean washed and dried.

Consists of a horizontal screw that rotates inside an adjusted cover, the bottom of the cover is perforated, through the perforations and by means of a fan a suction force is applied, originating friction and pressure between the grains, the husk is torn off and passes through the holes, a fan produces air flow in the discharge to remove the husks not removed by suction.

Box 6

Figure 6
Mortero machine for grain
Source: Industrial workshop of the faculty

Analysis of information

Travel times and distances to suppliers via sedan type transport.

Box 7

Table 1
Travel times and distances

Destino	Total distance (round trip)	Total travel time
Company Don Coffee	266 km	4 hours
Farm Monte Azul	251 km	4 hours and 25 minutes
Farm Coffee-tal Apan	231 km	3 hours and 45 minutes
Farm Xico Inn	248 km	4 hours and 15 minutes

Source: Own elaboration

The distances proved can be ratified as the shortest from point A to point B with a Dijkstra algorithm, it is this same algorithm that uses the Google Maps™ platform to calculate its travel routes. To check this, the algorithm is then used considering alternate routes to those used, comparing them with the original to corroborate or find the shortest route. Where, as point A is the destination, and point B is the workshop of the faculty.

Application of the Dijkstra algorithm

The analysis of current routes to the workshop suppliers is applied the smallest path algorithm or Dijkstra algorithm, which allows showing the smallest paths to be used.

If you analyze the available routes reported by Google Maps™, by default the platform points to the fastest route considering factors that can only be evaluated through satellite technology, such as traffic, tolls and other variables.

The algorithm finds the shortest route in terms of distance and distance travelled, each supplier will be contacted to compare both results, The necessary analysis is then made with the inclusion of the factors mentioned above for the selection of the best route.

Results

Dijkstra chart for the Apan Coffee

Towns or intermediate towns on the routes are represented by nodes from A to H, is shown in figure 7:

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Box 8

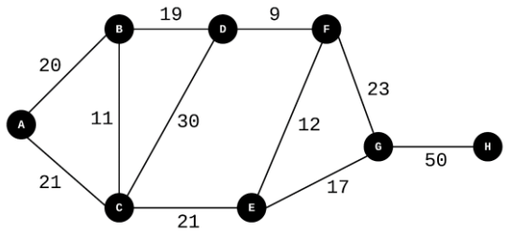

Figure 7

Dijkstra chart for the Apan Coffee

Source: Own elaboration

Interpreting nodes

- Node A: Workshop, Boca del Río, Ver.
- Node B: San Julian, Ver.
- Node C: Santa Fe, Ver.
- Node D: La Antigua, Ver.
- Node E: Tolome, Ver.
- Node F: Salmoral, Ver.
- Node G: National Bridge, Ver.
- Node H: Coffee-tal Apan, Coatepec, Ver.

Therefore, the distances between them are set in kilometers and specified with numbers on the edges. The resolution of the algorithm is described in the following table.

Box 9

Table 2

Iterations of the algorithm Coffee-tal Apan.

Node	Iter. 1	Iter. 2	Iter. 3	Iter. 4	Iter. 5	Iter. 6	Iter. 7	Iter. 8
A	**(0, -)**	*	*	*	*	*	*	*
B		**(20, A)**	*	*	*	*	*	*
C		(21, A)	(31, B)	*	*	*	*	*
D			**(39, B)**	(51, C)	*	*	*	*
E				(42, C)	(90, D)	(60, F)	*	*
F					**(48, D)**	*	*	*
G						**(71, F)**	(77, E)	*
H							(127, E)	**(121, F)**

Source: Own elaboration

Then, the shortest path found by the Dijkstra algorithm is shown in figure 8:

Box 10

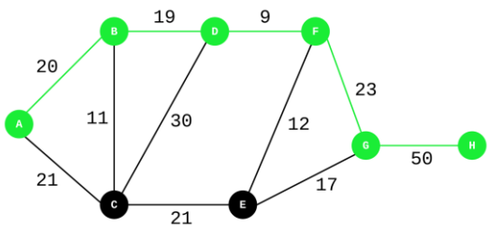

Figure 8

Route found by Dijkstra

Source: Own elaboration

Dijkstra chart for the Xico Inn

Finding then the Dijkstra graph is similar the route of the Coffee-tal Apan. Changing only the destination node "H", is shown in figure 9:

Box 11

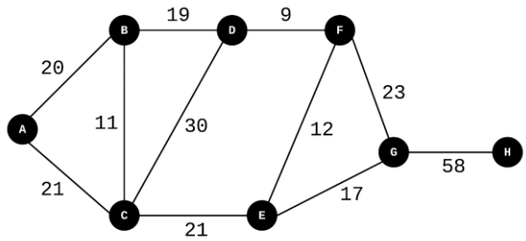

Figure 9

Dijkstra chart for the Xico inn.

Source: Own elaboration

Applying the same procedure as table 2, a similar close result of the routes is obtained.

Box 12

Table 3

Iterations of the algorithm Xico Inn

Node	Iter. 1	Iter. 2	Iter. 3	Iter. 4	Iter. 5	Iter. 6	Iter. 7	Iter. 8
A	**(0, -)**	*	*	*	*	*	*	*
B		**(20, A)**	*	*	*	*	*	*
C		(21, A)	(31, B)	*	*	*	*	*
D			**(39, B)**	(51, C)	*	*	*	*
E				(42, C)	(90, D)	(60, F)	*	*
F					**(48, D)**	*	*	*
G						**(71, F)**	(77, E)	*
H							(135, E)	**(129, F)**

Source: Own elaboration

Then, shortest route found by Dijkstra algorithm is shown in figure 10:

Box 13

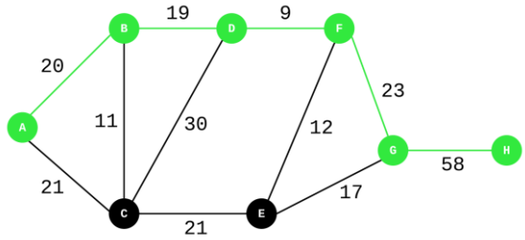

Figure 10

Route found by Dijkstra

Source: Own elaboration

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Dijkstra chart for the Monte Azul

The nodes correspond to the following cities, is shown in Figure 11:

Box 14

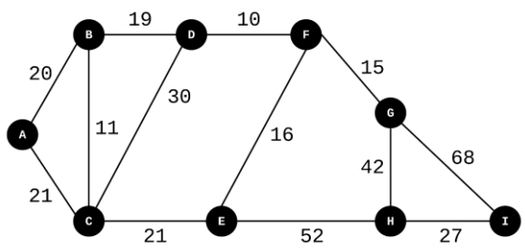

Figure 11
Dijkstra chart for the Monte Azul
Source: Own elaboration

Interpreting nodes,

- Node A: Workshop, Boca del Rio, Ver.
- Node B: San Julian, Ver.
- Node C: Santa Fe, Ver.
- Node D: La Antigua, Ver.
- Node E: Tolome, Ver.
- Node F: Jose Cardel, Ver.
- Node G: National Bridge, Ver.
- Node H: El Encinal, Ver.
- Node I: Finca Monte Azul, Huatusco, Ver.

Then, solving the algorithm at figure 12.

Box 15

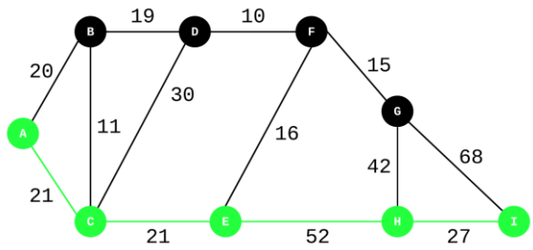

Figure 12
Route proven by Dijkstra
Source: Own elaboration

A vehicle is a motor vehicle for the transport of the raw material. The numbers of inputs are 50 kg of green grain with up to four passengers. This data is important in proven fuel expenditure, which is a principal factor when considering costs.

Comparison of transport costs between separate route and unified routes, is shown in figure 13:

Box 16

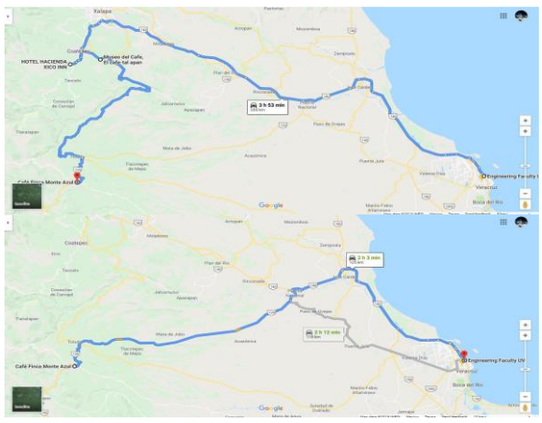

Figure 13
Unified route for suppliers found
Source: Own elaboration

Box 17

Table 4
Transports costs. National currency

Coffee-tal Apan + Xico Inn + Monte Azul	Unified route
Fuel consumption (litres)	
47.11	21.71
Distance (km) Total	
716	330
Fuel cost	
$857.32	$395.13
Cost of stands	
$392.00	$160.00
Total cost	
$1,249.32	$555.13

Source: Own elaboration

As a process description, the flow diagram of the workshop supply chain is found, is shown in figure 14.

Box 18

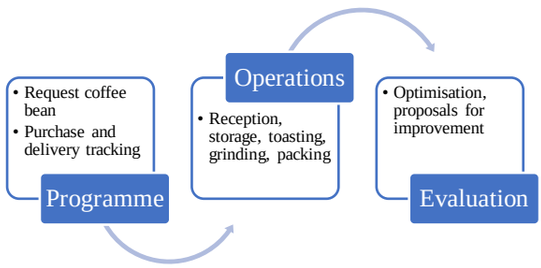

Figure 14
Flow diagram
Source: Own elaboration

Discussion of results

Combining the routes of Coatepec and Xico, also noting the proximity of the city of Huatusco, generates unified route for suppliers found in the region, is shown in figure 13.

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As a short road is the route formed by I, H, E, C, A with 121 km, is shown in table 2.

Generating the minimum distance H, G, F, D, B, A with 129 km from the point of origin is shown in table 3.

Then, the route determined is a 55.6% saving by improving time and resources.

Although, consumers demand assurance in their consumed products, starting from their composition and safety.

Also, categorize actors or stakeholders in the coffee industry supply chain into 6 groups. They are farmers, processors, manufacturers, national government agencies, markets/retailers/cafes, and the end consumer. Each stake holder has a specific role, either to write and read data or only to read the information. There are 3 functions in the system; input data, which acts as process information, transaction or process confirmation, and tracing information (Alamsyah, et al., 2023).

Conclusions

The information from the workshop field work, supply chain indicators are decided.

Visits to farms are important to define the processes used in cultivation, wet or dry profit process, storage and distribution of this important product for the economy of the state of Veracruz.

However, coffee is one of the most consumed beverages worldwide. Like other agricultural products, coffee is susceptible of colonization by mycotoxin-producing fungi and therefore, the presence of mycotoxins. These chemical hazards can pose a risk for consumers, as them are potentially carcinogenic, neurotoxic, or immunosuppressive (Rubio-Lopez, et al., 2023).

Supply chain management (SCM) practitioners currently face multiple challenges, ranging from eradicating supply chain disruptions to improving the flow of goods, and from increasing the need for supply chain flexibility to mitigating bullwhip effects. To address these growing challenges, firms are developing novel capabilities in digitalization or Industry 4.0, sustainability, servitization, and e-commerce, among others (Sandberg, et al., 2022).

Box 19

Figure 9

Project academic and students on visits

Source: Own elaboration

The tools applied in the project helped demonstration of results, showing operations that generate a positive assessment of supply.

Production and buying indicators were proposed for resource management and supply planning. The indicators are savings in transport costs of up to 60% compared with first expenditure and ensure the availability of raw material for internships during the academic semester.

Future work includes the possibility of marketing the product as roasted or ground coffee, proving a business register for the support of the entrepreneur.

Box 20

Figure 10

Project academic and students on visits

Source: Own elaboration

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Box 21

Figure 11
Academics and researchers from the University of Veracruz

Source: Own elaboration

Conflict of interest

The authors declare no interest conflict. They have no known competing commercial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

Ramírez-Roman, Adolfo: Contributed to the project idea, research method and technique. Supported the development of the visit to coffee farms. He analysed the data and systematized the results; he worked the article.

Rodríguez-Rodríguez, Luis Alberto: worked on the development of graphs and diagrams, coffee bean roasting tests and systematization of results; also worked on the drafting of the document.

Suárez-Álvarez, Ángel: Contributed to research design, type of research, approach, use of equipment and writing of article.

Chabat-Uranga, Jacqueline: Done the systematization of the background for the state of the method. Supported the field study. Also contributed to the writing of the article.

Availability of data and materials

The map images for the sign of routes were obtained from the free platform google maps. Data from associations and museums related to coffee.

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The research did not receive any funding.

Abbreviations

FMA	Farm Monte Azul
SC	Supply Chain
SCM	Supply Chain Management

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Article

Global port supply chain management

Gestión de la cadena de suministro global portuaria

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Abstract

90% of trade obeys port route logistics that involve the five global communication channels. The aim of this research was to analyze the evolution of global logistics and management of the global port supply chain with the aim of transforming it into a single window. On the other hand, global port success depends on geopolitics, infrastructure, adhesion to clusters, continuous investment, services, quality, costs and time. However, ports that do not have these parameters will be trunks or failures. A mixed analysis was carried out on the management of the global port supply chain based on the quantification and estimation of statistical control variables, decision making, geopolitics and modernization. The characterization of data obtained from port logistics determined transportation systems of sustainable, sustainable and circular development. The identification of critical routes for the conversion of a port to a single window will be the future work subject.

Global port supply chain management		
Objectives	**Methodology**	**Contribution**
The aim of this research was to analyze the evolution of global logistics and management of the global port supply chain with the aim of transforming it into a single window.	A mixed analysis was carried out on the management of the global port supply chain based on the quantification and estimation of statistical control variables, decision making, geopolitics and modernization.	The characterization of data obtained from port logistics determined transportation systems of sustainable, sustainable and circular development.

Port logistics, Supply chain management, Maritime routes.

Resumen

El 90% del comercio obedece una logística de rutas portuarias que involucran los cinco canales de comunicación global. El objetivo de esta investigación fue analizar la evolución logística global a gestión de la cadena global portuaria de suministro con fines transformacion a ventanilla única. Por otro lado, El éxito portuario global depende de la geopolítica, infraestructura, adhesión a clústeres, inversión continua, servicios, calidad, costos y tiempo. Sin embargo, los puertos que no cuenten con estos parámetros serán troncales o fracasos. Un análisis mixto fue realizado en la gestión de la cadena de suministro global portuario basado en la cuantificación y estimación de variables de control estadísticas, toma de decisiones, geopolíticas y modernización. La caracterización de datos obtenidos de la logística portuaria determinaron sistemas de transporte de desarrollo sustentable, sostenible y circular. La identificación de rutas críticas para la conversión de un puerto a ventanilla única será motivo de trabajos futuros.

Global port supply chain management		
Objectives	**Methodology**	**Contribution**
El objetivo de esta investigación fue analizar la evolución logística global a gestión de la cadena global portuaria de suministro con fines transformación a ventanilla única.	Un análisis mixto fue realizado en la gestión de la cadena de suministro global portuario basado en la cuantificación y estimación de variables de control estadísticas, toma de decisiones, geopolíticas y modernización.	La caracterización de datos obtenidos de la logística portuaria determinaron sistemas de transporte de desarrollo sustentable, sostenible y circular.

Logística portuaria, Gestión de la cadena de suministro, Rutas marítimas

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Introduction

Global maritime trade obeys the logistics of tracing critical routes that involve the five global communication channels: English Channel, Strait of Malacca, Strait of Hormuz, Suez Canal and Panama Canal. Fluid logistics problems in the supply chain on maritime routes have become increasingly frequent in recent years, generating bottlenecks. Because 90% of the goods traded in the world use these routes in an upward evolutionary trade (Ksciuk, et. al. 2023 and Sun, et. al. 2024).

The International Maritime Organization in its 2023 report indicated that disruptions to global trade waterways have affected industry supply chains and the global economy. The fracture of the logistics chain is due to different circumstances, highlighting; COVID-19 pandemic, Ever Given jam in the Suez Canal, drought in the Panama Canal, Russian blockade of Ukrainian ports on the Black Sea and continuous attacks on ships in the Red Sea among others (Hou, et. al. 2022 and Sun, et. al. 2024).

The English Channel is the world's busiest shipping lane with more than 500 ships daily from the North Sea to the Atlantic and from the United Kingdom to continental Europe, and vice versa. Every year more than 16 million people and five million trucks pass through nearly 170 English Channel ports. The main ones are Portsmouth, Le Havre, Cherbourg and Brest (Zelenkov, et. al. 2022).

Strait of Malacca; Located between the island of Sumatra (Indonesia) and the Malay Peninsula, they interconnect the Indian and Pacific oceans. It extends from the Andaman Sea to the South China Sea, passing through the Singapore Strait. Every year around 94,000 ships cross the Strait of Malacca through more than 40 ports. On the other hand, to maintain fluidity, Thailand has proposed a 100 km "land bridge" in the narrowest part of the Malay Peninsula, where goods could be unloaded and transported by rail and road, avoiding the Strait of Malacca.

The Strait of Hormuz, between Iran and Oman, links the Persian Gulf with the Gulf of Oman and the Arabian Sea.

This maritime route covers the transfer of liquefied natural gas and oil from the Middle East, representing 20% of global consumption, which is equivalent to around 21 million barrels of oil. The strait operates with a two-lane traffic system in opposite directions. However, a concern for shipping companies is the security and geopolitical tensions that truncate the fluidity of the canal.

The Suez Canal, in Egypt, connects the Mediterranean with the Red Sea, it is a dividing line between Africa and Asia, it is the shortest maritime route from Europe to Asia, with 200 km in length it receives more than 20,000 ship crossings al anus. This has been affected by attacks on ships in the Red Sea, causing a drop in income to the canal, global effects on the economy and shortages.

The Panama Canal connects the Atlantic and Pacific oceans, it works through locks to raise and lower ships that cross the isthmus of Panama. It connects almost 2000 ports in 170 countries. Lately the drought has affected the lakes that supply the canal locks with more than 100,000 cubic meters of water. This has meant that the passage of ships has decreased, increasing waiting times from hours to weeks or even months, generating reservations and auctions for permits to pass through the Panama Canal.

Although the modernization of the lock system was launched with water-saving measures, ships have had to reduce their draft, stand in physical and virtual waiting lines to access the canal (Bedoya, et. al. 2024 and Ksciuk, et. al. 2023).

At the World Economic Forum, the congestion of ports and airports in global freight transport was analyzed. Transit delays, natural disasters and socioeconomic disruptions affect supply chains facing transportation challenges that involve; waterways, climate crisis, geopolitical instability and congestion that combine with social factors, such as labor conflicts and the increase in the cost of living. International trade is a system that evolves unpredictably, which is why freight transport companies consider it crucial to boost economic growth through global connectivity.

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The efficiency of the movement of goods has been possible thanks to supply chain logistics applied to the network of global maritime routes. An analysis of the global trade logistics of the five busiest maritime routes in the world will help understand and propose applicable strategies in the short, medium and long term (Ji, 2024).

The aim of this research was to analyze the evolution of global logistics and the management of the global port supply chain with the aim of transforming it into a one-stop shop. The characterization of data obtained from port logistics determined transportation systems of sustainable, sustainable and circular development.

The Trans-Pacific maritime trade route is one of the world's busiest and most crucial maritime corridors, spanning the Pacific Ocean. This links the manufacturing centers of East Asia, where China as a power covers the consumption markets of the west coast of North America, highlighting the United States, which had commercial activity of approximately 28 million TEU container units in 2022.

Transpacific route is paramount in global trade, a wide range of goods and manufactured products in Chinese ports such as Shanghai, Shenzhen and Hong Kong are the main exporters, while US ports such as Los Angeles, Long Beach and Seattle are import destinations. The route covers waterways such as the Taiwan Strait, the South China Sea and the Pacific Ocean. The Panama Canal represents the main link of trade between Asia and the United States. Therefore, the Asia-East Coast of the United States route is considered the busiest trade route (Liu, et. al. 2023, Nicolet, et. al. 2023 and Yin, et. al. 2020).

The Asia-Europe maritime route extends throughout the Eurasian continent, being the main route of global trade, connecting the manufacturing centers of Asia, led by China, South Korea and Japan, covering the main markets of Europe, and economic powers. such as Germany, France and the Netherlands.

The Suez Canal, providing fluidity to an annual load volume of one billion tons in 2019, between the Mediterranean Sea and the Red Sea, with an extension of 193 kilometers, connects the north of Port Said with the south of Suez.

The Asia-Europe maritime route faces a series of challenges such as the blockage of the Suez Canal by the Ever Given in 2021, in addition to geopolitical conflicts in the Middle East, which disrupt the flow of maritime traffic, making the Suez Canal an impassable route. Due to this, ships are forced to navigate around the southern tip of Africa through the Cape of Good Hope, generating delays and million-dollar losses (Farah, et. al. 2024).

The Transatlantic maritime route crosses the Atlantic Ocean, linking North America with Europe. It connects ports such as New York, Norfolk and Miami in North America with European port centers such as Rotterdam, Hamburg and Liverpool.

This route interacts with the North Atlantic Ocean and the English Channel, which separates the United Kingdom from continental Europe and connects the North Sea with the Atlantic Ocean. The English Channel serves as a passage for more than 500 ships per day, with an extension of 560 kilometers. The Dover Strait is the narrowest part of the English Channel and is used daily by more than 400 ships (Zelenkov, et. al. 2022).

The Intra-Asian maritime transport trade route covers the Asia-Pacific region, linking ports in East Asia that include countries such as China, Japan and South Korea, with Southeast Asia, covering countries such as Singapore, Malaysia and Vietnam, as well as ports in South Asia, belonging to India, Sri Lanka, and those of Oceania, including Australia and New Zealand.

The intra-Asian route drives economic growth throughout Asia, the waterways of the South China Sea, the East China Sea, the Indian Ocean and the Strait of Malacca, with around 50,000 ships per year. However, it faces challenges such as port congestion, trade disparities and disruptions (Farah, et. al. 2024).

South America-Europe maritime trade route is the maritime trade corridor that spans the Atlantic Ocean, uniting ports in South America, including countries such as Brazil, Argentina and Chile, with European ports in countries such as Spain, Portugal, the United Kingdom and the Netherlands.

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The route is the South Atlantic Ocean and the North Atlantic Ocean, they have efficient logistics and infrastructure for reliable load flow. Challenges include variable weather, large distances and precise supply chain management, bottlenecks, among others (Ji, 2024 and Ksciuk, et. al. 2023).

The global logistics evolution to global port supply chain management as a one-stop shop is a source of desire for many ports as sustainable, sustainable and circular development systems, due to the avant-garde importance that this represents, but how to achieve port success?

This depends on geopolitical factors, infrastructure, adhesion to clusters, quality of service in a continuous reduction of costs and delivery times, for this reason port systems are increasingly opening their range of opportunities to a line of business with private investors. as majority capitalists while the investment and dependence of countries and governments are reduced to compliance with regulations and payment of partner taxes, reducing the impact on the GDP (Gross Domestic Product) of the host country.

The identification of critical routes for the conversion of a port to a single window will be the subject of future work.

Sea Route Layout Logistics with Global Underpowered Iteration

An infinite number of shipping routes can be laid out making the system complex and busy, but the configuration of the global shipping system is simple. The central axis of the globe (Ecuador) is a circum-equatorial corridor that links North America, Europe and Asia-Pacific through the Suez Canal, the Strait of Malacca and the Panama Canal.

These routes support most of the global port traffic, but there are other routes for cabotage maritime transport (which is a sub-feeder maritime transport between two ports for the transfer of goods), the transatlantic and transpacific route covers a wide variety of ports. with a route along the circum-equatorial corridor.

Trans-Indian traffic is predominantly between the Asia Pacific and Europe, involving a series of clearly defined routes between the Strait of Malacca and Bab el-Mandeb. However, when these main routes are affected, alternative routes emerge to complement marine transportation and prevail as sub-feeder routes, complementing the system in an emergent way.

Maritime routes are determined by mandatory passage points, which are strategic locations that act as bottlenecks. The physical limitations (coasts, winds, ocean currents, depth, reefs, ice, among others) and political borders that influence the configuration of maritime routes with customs clearances.

Primary routes support major commercial shipping flows serving major markets, and secondary routes are connectors between smaller markets.

Bottlenecks in maritime routes

Geography, geopolitics and trade flows play a strategic role in the global maritime network labeled as bottlenecks of global trade. These include the 2021 Suez Canal blockage, delays in the Panama Canal due to drought recently, and geopolitical conflicts in the Strait of Malacca and Bab el-Mandeb.

A second type of bottlenecks are those that connect to maritime dead ends such as the Strait of Hormuz, which provides access to the Persian Gulf, and the Bosphorus Strait, which provides access to the Black Sea. The Oresund Strait is the only access to the Baltic Sea and Russia's main ports.

The closure of these bottlenecks forces the use of alternative land routes that are unlikely to have the capacity to handle port load volumes. Other secondary choke points are the Magellan Passage, Dover Strait, Sunda Strait and Taiwan Strait. The most notable bottlenecks are the Yangtze, the Rhine, the Mississippi, the Danube and the St. Petersburg. Lawrence (Dong, et. al. 2020 and Liu, et. al. 2023).

Investigation methodology

This research had a mixed approach, applying both quantitative and qualitative technologies, using systematic processes, as well as records and estimated data.

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The aim of this research was to analyze the evolution of global logistics and management of the global port supply chain with the aim of transforming it into a single window.

For this, the application of the quantitative method was relevant in the identification of control variables involved in previous studies such as; statistics, decision making, geopolitics and port modernization. The characterization of data obtained from port logistics determined transportation systems of sustainable, sustainable and circular development.

The records of results obtained by different port companies, governments of different countries and previous studies of logistics experiences in port systems that formulate analysis of global supply chain management, were considered as the application of the qualitative method that allowed the possibility of obtaining results of the estimation of variables, which played an important role in decision making to understand the evolution and trends of a global port culture.

The operational data resulting from this research determined special adjacent requirements such as an uncertainty in the way each port adapts port conditions depending on its geopolitics, infrastructure, adhesion to clusters, quality of service in a continuous reduction of costs and delivery times, among others.

Finally, through the mixed method, an analysis of the control variables that allow involvement in; management, logistics, scale, offshoring, nearshoring and farshoring in the global logistics evolution management of the global port supply chain as a single window is a source of desire for many ports as sustainable, sustainable and circular development systems.

Port systems are increasingly opening their range of opportunities to a line of business with private investors as majority capitalist partners, while investment and dependence on countries and governments is reduced to compliance with regulations and payment of taxes, reducing the impact on GDP. (Gross Domestic Product) of the host country.

Port typology

A seaport is a logistical and industrial node in global supply chains with a strong maritime character and a functional and spatial grouping of port-related activities. This is a transit zone, a gateway through which goods and people circulate to and from the sea. It is a node where maritime and land transportation systems interact.

This is considered a place of convergence of different modes of transportation, because maritime and land transportation modes have different capacities, the port assumes the role of a load breakpoint where load is consolidated or deconsolidated. Sea Ports can be classified based on many dimensions that are related to the logistics of services they can provide.

"Scale" is an assessment of the size of the port in terms of its area, it is associated with its economic and commercial importance, annual load performance, size of its interior, number of shipping services to which it is connected or number of customers. "Geographic attributes" are the characteristics of the site and port location, coastal and inland geographical conditions (bay, coast, river or estuary). Many sites have natural advantages, while others need to be improved with dredging and landfilling.

Although the port site is fixed in space, its location is relative to the main maritime routes and the interior, or to its proximity and interactions with cities or urban conurbations. "Governance and institutional environments" are property conditions, Treaties, agreements, laws, norms, institutional, between the public and private sectors at different levels (Sun, et. al. 2024).

Port functions are the range of services offered by the port, load handling, logistics and distribution, industry and maritime services.

They are subject to competitive pressures. Port logistics is one of the port functions classified within the dimensions of the port typology. Specialization in handled load, containers, conventional general, liquid bulk, dry bulk or rolling load, passenger traffic. Another subclassification refers to industries focused on ports, steel plants, energy, automotive, and chemical industries.

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Logistics activities contribute significantly to port specialization. Port logistics must obey the typology of ports based on the dimensions of their scale, geographical attributes, governance - institutional environments, port functions and specialization. The latter being the one that determines the changing port capacities in the continuous optimization of maritime routes in a productive market in constant evolution (Liu, et. al. 2023 and Nicolet, et. al. 2023).

Evolution of port systems

Port functions have evolved, responding to technical, economic and social advances, giving rise to generations of port development. Traffic in seaports generates functions such as trade, distribution, industry, containerization, type diversification, load equipment, intermodal transportation and information technologies. Some ports have grown to become global manufacturing industrial complexes due to the strategic use of their port typology.

The 20 ports with the largest container movement represented 44% of total traffic, reflecting a well-established global hierarchy of ports with the greatest impact on GDP (Gross Domestic Product) in the economy of their countries of origin and in the global economy according to Global Transportation Practice; the container port, Performance Index 2022.

The Global Ranking of Container Ports designates 348 ports that in descending order of the first 20 ports globally were Yangshan, Salalah, Port Khalifa, Tangier-Mediterranean, Cartagena (Colombia), Tanjung Pelepas, Ningbo, Hamad, Guangzhou, Port Said, Hong Kong, Cai Mep, Shekou, Mawan, Yokohama, Algeciras, Port King Abdullah, Singapore, Posorja, Tianjin (Liu, et. al. 2023 and Oliveira, et. al. 2022).

This does not imply that small ports have limited importance for the economies they serve, because although they are not a means of generating economic resources for the passage of container ships that greatly impact the Gross Domestic Product of a Nation, however, it can present advantages such as having a means of access to global markets with its port infrastructure that allows them to import and export to satisfy the economies of the nation, transferring them to a port system with national or local competition.

From a supply chain perspective, seaports increasingly function not as individual locations handling ships but as revolving platforms of global supply chains and transportation networks.

The contemporary fourth-generation port is characterized by being a platform that controls load flows and requires knowledge-intensive coordination activities through specialized logistics.

A seaport is not autonomous, since port activities contribute to industrial and logistical development in port areas and their interior. Thus, ports act as service centers and logistics platforms for international trade and transportation (Noto, et. al. 2023).

In recent decades, ports have undergone a wave of reforms with a market-oriented business approach to port management. Ports have become independent commercial organizations whose focus is profitability, cost recovery and customer service.

These are part of a system with spatial and functional characteristics that support global logistics and transportation networks. They interact with other nodes, such as neighboring and overseas seaports, intermodal terminals and inland logistics platforms, being subject to three types of functional interdependencies with other nodes; “chain networks” ports are nodes that are part of a sequence of flows, the output of one is the input of another.

“Hierarchical networks” ports are nodes that are part of different levels of connectivity, which implies that they can be reached directly and indirectly.

“Transactional networks” ports are nodes in a system of commercial relationships where they can be competitive or complementary. They use advantages such as location, cost, and productivity to attract or retain shipping services and traffic (Noto, et. al. 2023).

Ports rarely operate in isolation from other ports, they are part of complex networks of interactions, grouping together adjacent container ports in the same region competing for the same port calls and inland multi-port gateways.

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Interior nodes and feeder ports are considered part of the port system.

They are competing to attract economic activities associated with seaports, which leads to functional changes in the port system. These nodes can also cooperate and coordinate their development by pooling transport flows and offering land and infrastructure for development.

This provides economic activities such as manufacturing and logistics with a range of node location options suitable for operational and market access needs.

Maritime transport evolves "global maritime space" profile of continental masses, global shipping routes and choke points the logistics performance index is a combination of a country's rating according to seven criteria: customs clearance, logistics infrastructure, ease of shipping international logistics competency/internal skill sets and service providers, track and trace capabilities, domestic logistics costs and timeliness/consistency (Dong, et. al. 2020).

Cluster in global supply chains

Seaport logistics and its importance of integrating ports and terminals into supply chains has increased the value-added focus. Major seaports offer opportunities to improve value-added logistics services by integrating the production and distribution chain. Modern seaports logistics system centers called cluster in global supply chains

Port and route selection criteria are related to the entire network in which the port is only one node. The ports selected are those that will help minimize the sum of ocean, port and land costs, including inventory and carrier quality considerations.

Port choice becomes more a function of cost and overall network performance. A well-coordinated logistics and distribution function of seaports, with the cooperation of various service providers, facilitates the integration of ports into high-quality value-added advanced logistics and distribution networks.

Port clusters generate scale and scope advantages linked to physical load flows, "ecologies of scale" due to their spatial concentration, but they could also face challenges, mainly accessibility (congestion) and higher land costs. On the other hand, the concentration of activities opens more opportunities to group load flows through intermodal transport (short sea shipping, barge or rail) (Dong, et. al. 2020).

External logistics company with global management

Logistics operators are classified according to the logistics tasks they perform in the company. Party Logistics or PL is subclassified as; 1PL, 2PL, 3PL, 4PL, 5PL.

1PL (First Party Logistics); fleet agencies and drivers for freight transportation. Companies maintain control of warehouses. 2PL (Second Party Logistics); In addition to transportation, the logistics operator is also responsible for storage tasks and material flows. 3PL (Third Party Logistics); External logistics operators are responsible for transportation, storage, management and organization of activities. 4PL (Fourth Party Logistics).

They are logistics operators that act as consultants and auditors of 3PLs, to validate and optimize the activity.

They do not have a logistics infrastructure, they only advise. 5PL (Fifth Party Logistics); They carry out a total integration of the services offered by 3PLs and 4PLs, thanks to their size and experience (Chen, et. al. 2022 and Sheikh, et. al. 2023).

International trade in port centers is dependent on the growth of carriers, load owners, terminal operators, external 3PL (Third Party Logistics) logistics service providers, freight forwarders and insurers.

This is also known as third-party logistics and can entail some disadvantages associated with the limited control that companies exercise over logistics functions such as; price, rate (subject to the type of merchandise), shipping method (urgent or not) and its destination, scalability.

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The ability of a logistics operator to efficiently respond to an increase in activity is key to sustainable business growth; Technology: logistics operators who, supported by technology and automation, carry out their processes; Reputation:; Your operator's references have to be excellent. Management in a 3PL warehouse requires the functionalities associated with traceability, stock management or location assignment, exhaustive logistics control, capable of working with different transportation agencies integrated into the software (Bernacki, et. al. 2024, Chen, et. al. 2022 and Sheikh, et. al. 2023).

Ship fleet transport logistics

TEU (twenty-foot equivalent unit) containerization of maritime trade is the name of a ship's container. The 20 most important categories of the Standard International Trade Classification indicate that maritime transport represents 70% of total trade and 66% of world trade in containers, which represented about $54,000 per TEU in 2020.

Global trade takes place predominantly within Europe, North America and East Asia called the triad. The energy, minerals and agricultural trade has specialized transport networks and port facilities designed to handle bulk loades with hopper type (Tramp) ships, as well as oil, gas, chemicals and special fluids on tankers. On the other hand, for various products that can be packaged, they are transported in container ships (Dong, et. al. 2020).

Imbalances in trade flows are a topic of interest in port logistics due to everything it implies. China exports more than it import with partners such as the United States and the European Union.

This generates an imbalance in maritime flows for bulk and container trade that involves repositioning, representing around 20% of global movements, this makes the return trip of the hopper or container ship empty. In the case of tankers, these are specialized in the fluid or gas they transport and cannot have any other use, because they become contaminated, therefore their return empty is a given (Castrellon, et. al. 2023 and Farah, et. al. 2024).

Transatlantic trade flows are considered the most frequent, they occur between Asia and North America (especially the United States), between Europe and North America and between Europe and Asia. The sea routes pass critical points such as the Strait of Malacca (30%), the Suez Canal (15%), the Strait of Gibraltar and the Panama Canal (5%). These routes can represent the largest number of bottlenecks in transatlantic trade so shipping lines tend to organize their services to connect the dominant trade flows directly and the less dominant trade flows indirectly through transshipments.

Very large Capesize ships will first call at a deep-water island port to unload part of the load and then proceed to the second port of call with lesser nautical access to unload the remainder.

Another practice consists of lightening deep-water ships in the current, whereby floating cranes unload part of the load onto barges, given the ship's increasingly shallow draft, but there will never be talk of total unloading of the ship to a means of transport. trunk. Bulk ships are smaller, so operators have a wider range of potential ports of call. They follow patterns determined by factors such as proximity to the market, specificities of the distribution network in the number of load lots and the need for silo-type infrastructure (Wang, et. al. 2023).

The characteristics of intraregional maritime services in the segment RORO (Roll On-Roll Off), ropax (ferries), Lo-Lo (Lift On-Lift Off) and Ro-Lo (a hybrid of Ro-Ro and container ships) are ships that They transport rolled load i.e. vehicles via ramps or cranes, combined with container ships, passengers, these are typical of the end-to-end type with shipping services following fixed schedules with medium to high frequencies.

Ferry capacity tends to vary depending on load density on the route and distance. Deepwater and short sea vehicle transportation is another submarket of the RORO market. On intercontinental routes, operators use Pure Car and Truck Carriers (PCTC) with capacities of up to 8,000 TEU, cost savings shipping lines aim for short port time and face a shortfall in the number of ports that have the infrastructure to accommodate large quantities of new cars.

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Rail and barges play an increasingly important role in ensuring inland access to automobile ports as safe trunk transportation. On the other hand, the Dynamar typology is based on services of a specific frequency operated with exclusive ships for that task, implementing charter trips, within a defined commercial route "Parcelization", such as vagabondage, a process in which a ship (Witte, et. al. 2020).

Reefer ships primarily transport high-value food and pharmaceutical products that require refrigeration and atmospheric control in an end-to-end service. Refrigerated shipping is a one-way business.

The refrigerated transport sector is increasingly under pressure from container transport.

Therefore, shipping lines design the networks that they consider convenient to offer, but they are obliged to provide the services that their customers want in terms of frequency, direct accessibility and transit times.

Shipping productivity has improved using larger post-Panamax ships with lower fuel consumption and the design of new operating patterns and cooperation between shipping lines, resulting in a reduction in the cost per TEU of capacity provided.

Supply chains are highly dynamic as they react to patterns in global trade and information technology. The coordination and management of a complex network of activities that deliver a finished product to end users or customers.

The process includes supply of raw materials, parts, manufacturing and assembly of products, storage, entry and tracking of orders, distribution through the different channels and, finally, delivery to the customer.

Logistics services that still offer value can suffer degradation and become basic services called physical value added. Average product life cycles and global supply chain cycles, such as delivery time, have decreased. A series of indicators can be evaluated, such as the Logistics Performance Index developed by the World Bank (Dong, et. al. 2020).

Global logistics in one-stop shops

Intellectual property intensive activities focus on developing a brand, key in the business model of multinational companies with a focus on customers and product innovation, while production and logistics providers are outsourced to a network of suppliers, adopting flexible multi-company organizational structures on a global scale.

However, very few of the world's largest multinational companies operate globally, they rely regionally on the breadth and depth of their market coverage on a sustainable basis and their sales are situated within their local branch of the “triad”.

Global logistics expenses represent around 10 to 15% of GDP and 20 to 50% of its total finished product costs. Logistics costs reveal that transportation costs are increasing relative to inventory holding costs, indicative of more inventory in circulation rather than held in distribution centers (Bernacki, et. al. 2024).

Technological innovation. of supply chains through customization and standardization using advances in data analysis and visibility “plug-and-play supply chains” (Agile Supply Chains). Logistics service providers external to the company control the supply chain supported by ICT (Information and Communications Technologies) systems; they are increasingly more efficient, sustainable, profitable, circular and establish Green Supply Chain Management strategies.

This involves reducing environmental impacts by focusing on supply chain strategies known as the five “Rs”; Reduce, Reuse, Recycle, Remanufacture and Reverse Logistics. Supply chain visibility results in efficient planning and lower operating costs. Logistics service providers could use low-cost outsourcing to reduce their cost base versus vertical integration.

This strategy is not free of risks and could subcontract activities that are not recognized as generating value. The use of real-time digital tools update data automatically, providing supply chain managers with updated and relevant information in decision-making for regulation, automation and optimization as a niche opportunity.

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However, a low-price advantage is a challenge and cost leadership is very difficult to achieve, but it generates competitiveness and sustainable differentiation (through I+D, marketing and competitions), among companies of maritime-port logistics throughout the value chain (Bernacki, et. al. 2024, Yang, et. al. 2024, and Zhang, et. al. 2024).

Manufacturers are looking for global logistics packages rather than just shipping or reshipping. Global logistics (megacarrier) is the dominant paradigm to which most transportation chains have responded by providing new value-added services in an integrated package along supply chains. Global logistics companies in intermodal integration and synchro modality share the ambition of becoming "one-stop shops" in overlapping distribution networks.

Point-to-point logistics with online sales channels

The rise of 4PL the electronic commerce environment at the company-company, company-consumer levels. The quality of the information system, the quality of the service and the satisfaction of users offers more opportunities to reach customers around the world and eliminate unnecessary intermediate links, reducing the cost price.

This is particularly the case for the spot business and basic port-to-port transportation, which are entry points for electronic forwarding, shippers gain better information using Big Data and electronic markets, greater rate transparency and visibility into shipping schedules. line services. Intermediary freight forwarders are most at risk from new technology providers or business models unless they adapt, offering supply chain visibility.

Carriers are challenged to opt for technology-driven collaborative networks, they must recruit new talent from outside the logistics sector with new perspectives and continually feedback their logistics flexibly with cutting-edge perspectives.

Customer profiling and market segmentation will be the core of the business model of these online sales channels. This practice will be available to many at a lower transaction cost and with more flexibility using customized electronic tools.

The use of larger ships (threshold of 12,000 TEU) generates great advantages such as the design of new operating patterns, cooperation between shipping lines of larger ships (post-Panamax) with lower fuel consumption, improvement of the container fleet , reduction of unit costs, access to more loops or services with relatively low cost implications, sharing of terminals, cooperating in areas at sea and on land, operating on multiport itineraries, calling at a limited number of ports, circulation of traffic through a network of specific nodes and lower costs of time slots.

The effort to prepare ports and terminals for increasingly larger ships is growing disproportionately. Supply chain risks with larger container ships could increase. Therefore, it is becoming increasingly difficult to generate profits for shipping lines, ports/terminals and carriers.

The digitalization of smart containers makes it possible to make additional information available to carriers, terminal operators and load owners. This information is related to container identification, location, geofences, and physical characteristics throughout the transportation chain. Information on temperature, humidity and pressure are relevant for reefer containers and cold chain logistics. Refrigerated containers require more detailed monitoring such as impact detection, disconnection of the cold chain, etc.

This allows for clearer identification of liability in the event of theft, damage or breach of container integrity. In 2018, 2.9 million reefer TEUs were used, approximately 5% of global container capacity. A normal 40-foot container costs around $5,000, while a reefer container of the same size costs around $30,000. The logistics of relocating empty refrigerated container ships is a need that worries the maritime transport sector, due to their exclusive use or disinfection as appropriate for new use (Castrellon, et. al. 2023 and Yang, et. al. 2024).

Container offloading logistics covers the container market chassis fleets required to transport containers by road within terminals. to store containers in terminals and distribution centers. It is called wheeled operations. For road transport of a refrigerator, a clip-on generator (called a Genset; it is attached to the upper front end of a refrigerator) or a suspended generator (it is attached under the chassis of a container) is used.

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For maritime and rail transport, the capacity of the energy system determines the number of refrigerated containers that can be transported. Some ships have up to 25% of their spaces dedicated to refrigerated load. Power is provided by the ship's generator.

For rail movements, diesel generators are used to provide power to about 8 reefer containers. It is important to emphasize that refrigeration units are designed to maintain the temperature within a preset range, not to cool it.

Means that the shipment must reach the required temperature before being loaded into a reefer container. Refrigerated terminal facilities The growth of cold chain logistics has required transportation terminals and ports to dedicate a portion of their storage yards to refrigerated containers. represents between 1% and 5% of the total capacity.

Results Discussion

Continuous investment in infrastructure in a race against the requirements of the modernization of port areas is a crucial logistics factor that will allow the competitiveness of port customs at an international level in a critical supply network that under the concept of logistics, quality and delivery time will always look for port areas that offer lower costs, times and port tariffs, with monitored logistics of the passage of products that ensure their protection at all times in the event of any situation that puts the integrity of the container ship transfer service at risk.

For the export supply network through shipping companies to be profitable, the load on container ships must be mixed, that is, standard containers for the transfer of non-perishable products and refrigerated TEUs for perishable products.

The transfer of goods via port can occur within the same country, but many times it occurs in an external country, which is defined as offshoring. The term can be further qualified with the concepts of nearshoring and farshoring which imply a level of proximity. Types of corporations by multinational expansion strategy (Silva, et. al. 2024 and Xie, et. al. 2022).

"Platform companies" actively took advantage of the "China effect" manufacturing industry activities. This underlines that location decisions are continually re-evaluated, considering changes in global input costs, regulations and geopolitics. Furthermore, public policy attention is shifting from promoting competitiveness to developing capabilities. The main reason is that competitiveness tends to focus on decreasing input costs, while capabilities focus on increasing the added value provided by the manufacturing sector.

Results

Value chains are therefore a sequential process used by corporations within a production system to gather resources, transform them into parts and products, and finally distribute manufactured goods to markets. Backward participation. When one stage of a value chain produces products created by previous stages. This usually takes place in the later stages of a value chain. Forward participation. When one stage of a value chain produces products that will be used in later stages to create a final good. This usually takes place in the early stages of a value.

An environment in which just-in-time (JIT) and synchronized flows have become the norm in production and distribution systems. International transportation is changing to meet the growing needs to organize and manage its flows through logistics. Containerization is adaptable enough to address a variety of time and load constraints (Ji, 2024 and Lai, et. al. 2024).

Conclusions

The layout of critical routes around the circum-equatorial belt and the passage that involves the main global communication channels; English Channel, Strait of Malacca, Strait of Hormuz, Suez Canal and Panama Canal have generated bottlenecks in the maritime transport of goods, impacting the global economy (offshoring, nearshoring and farshoring). However, the evolution of global logistics to management of the global port supply chain as a single window has involved global logistics management specialized in technical characteristics of means of transport, port infrastructure that depend on geopolitical factors, adhesion to clusters, quality in the service in a continuous reduction of costs and delivery times.

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Online commerce and customs processes as a sustainable, sustainable and circular development system, use as a preferential transport system the services of interconnected avant-garde port networks that have single window shipments whose services cover offshore and onshore areas. with trunk or internal ports.

Port systems are increasingly opening their range of opportunities to a line of business with private investors as majority capitalist partners while investment and dependence on countries and governments is reduced (due to the large magnitude of continuous investment that they require to be competitive by committing the public finances of the country) to compliance with regulations and payment of taxes, reducing the impact on the GDP (Gross Domestic Product) of the host country.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Cruz-Ramirez, Christian: Contributed to the project idea, research method and technique, for develop the project.

Cruz-Gómez, Marco Antonio: Contributed to analyze the evolution of global logistics.

Espinosa-Carrasco, María del Rosario: Apported investigation about geopolitics and infrestructure.

Mejía-Perez, José Alfredo: Researched papers and references about the topic.

Availability of data and materials

The data obtained focus on the analysis of global logistics and port supply chain management. This includes statistical control, decisions related to geopolitics, and aspects of modernization and sustainability in port logistics.

The materials used in this research comprise experimental protocols and analytical models employed to evaluate the evolution of port logistics and the transformation of ports into single windows.

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Abbreviations

COVID-19	Coronavirus disease 2019
GDP	Gross Domestic Product
ICT	Information and Communications Technologies
JIT	just-in-time
Lo-Lo	Litf On-Lift Off
PCTC	Pure Car and Truck Carriers
PL	Party Logistics
Ro-Lo	hybrid of Ro-Ro and container ships
RORO	Roll On-Roll Off
St.	Street
TEU	Twenty-foot Equivalent Unit
US	United States

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Article

Diagnostic, analysis and management of the routes of a Distribution Center of a dairy producer in the State of Mexico

Diagnóstico, análisis y gestión de las rutas de un Centro de Distribución de una productora de lácteos en el Estado de México

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Abstract

Distribution Centers are an important part of an organization, since the goal of this area is to ensure that products reach their destination in a timely manner. In the case of the dairy producing company, one of its distribution programs was diagnosed, analyzed and managed due to the decrease in efficiency. The status of the project was diagnosed as a priority, and the strengths and areas of opportunity were identified. Subsequently, an analysis of the first ten critical paths with the lowest indicator was carried out. The implementation of quality tools and methodologies continued to identify the main causes and the root cause of low effectiveness. Likewise, efforts were made to increase the indicator and reach its minimum standard. In addition to a final evaluation of the results obtained after the implementation of the pre-established countermeasure plan.

Diagnosis analysis and management of the routes of a Distribution Center of a dairy producer in the State of Mexico		
Objectives	**Methodology**	**Contribution**
Increase the degree of effectiveness of the distribution route project to 90%	The research type is basic and explanatory level.	The degree of effectiveness increased by 4.1%, achieving 90.3%, on average; applying quality techniques.

Distribution Center Management, Quality, Effectiveness

Resumen

Los Centros de Distribución son parte importante de una organización, ya que esta área tiene como meta lograr que los productos lleguen a su destino en tiempo y forma. En el caso de la empresa productora de lácteos se diagnosticó, analizó y gestionó uno de sus programas de distribución debido a la disminución en la eficiencia. Se diagnosticó de forma prioritaria el estado en el que se encontraba el proyecto, se identificaron las fortalezas y las áreas de oportunidad. Posteriormente, se realizó un análisis de las primeras diez rutas críticas con el menor indicador. Se prosiguió con la implementación de herramientas y metodologías de calidad para identificar las causas principales y la causa raíz de la baja efectividad. Asimismo, se realizó una gestión para aumentar el indicador y alcanzar su estándar mínimo. Además, se realizó una evaluación final de los resultados obtenidos después de la implementación del plan de contramedida preestablecido.

Diagnóstico, análisis y gestión de las rutas de un Centro de Distribución de una productora de lácteos en el Estado de México		
Objetivos	**Metodología**	**Contribución**
Incrementar el grado de efectividad del proyecto de rutas de distribución a un 90%.	El tipo investigación es básica y de nivel explicativo.	Se incrementó el grado de efectividad en un 4.1%, logrando un 90.3%, en promedio; aplicando técnicas de calidad.

Centro de distribución, Calidad, Efectividad

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Introduction

Distribution centres (CEDIS) are another element of study for the optimisation of supply chains. In this sense, the logistics area in an organisation requires its distribution process to be efficient in each of its stages. In the case of the company under study, whose activity is the production of dairy products, a drop in productivity was detected in one of the projects implemented for the distribution of goods.

Therefore, it was necessary to carry out a diagnosis where problems such as downtime, delays in the entry of some operators, lack of constant monitoring and evaluation, among others, were detected. The analysis was carried out by applying quality tools, then improvement strategies were determined, implemented and the results were evaluated, improving the programme's productivity.

Framework of Reference

Efficient management in the operation of a CEDIS is the key to customer satisfaction and optimisation of the resources required for this task. Therefore, it is not enough to deliver the product; it is also necessary to continuously detect areas of opportunity to improve the operation of the storage, delivery and service process. Nowadays, companies around the world are currently managing their stocks as a valuable aspect of logistics and they are considered to be the fundamental asset of the company. In this way Giovana Toro expresses the importance of quality management in distribution centres.

It should not be forgotten that even if the production, marketing, finance and human resources areas have carried out their activities according to the organisational manual, if the logistics part does not function properly, the success of the company is put at risk. For this reason, administrative and technological strategies have been implemented for the proper functioning of this area.

Distribution centres are places where goods are stored and orders are processed. More and more technological resources are used to manage them, to the extent that there are fully automated technologies that make material handling equipment, personnel and controls less necessary.

However, adopting new technologies requires a significant investment, which micro, small and medium-sized enterprises (MSMEs) cannot afford in the short term. Therefore, it is important to generate an internal and external analysis of the department that carries out such an important storage and distribution activity.

Hence the relevance of having personnel with the right profile who are able to develop a methodology that achieves the objective of analysis for monitoring the logistics system of the organisation.

Distribution centres have an infrastructure designed to perform operations efficiently, with high speed. [...] they group infrastructures that provide an adequate environment to temporarily store goods and materials [...].

The design of a CEDIS must be in accordance with the needs of each company, it is necessary to observe the flow of activities from the moment the product is in the warehouse until it reaches the customer's hands. It is necessary to assess the elements that must be integrated in the CEDIS infrastructure in order for it to function optimally.

The distribution centre is an area equipped for the development of logistics activities. For Antún, the CEDI is a logistics centre, which must have at least: a layout for the transit of vehicles, logistics warehouses with platforms, areas for the parking of transport vehicles, areas for logistics operators, areas for complementary services for vehicles, and in some cases, areas for complementary services (training, meeting rooms, banking services, customs services and health controls, among others).

These elements enable an organisation to geographically concentrate its distribution operations and have an efficient flow of cargo.

A distribution centre (DC) can be defined as a planned space for locating, holding, handling and transporting goods and materials.

There are two dominant elements: warehousing and materials handling.

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The main goals of a CEDI are to minimise the total cost of operation, provide adequate levels of service to the end users, take care of the maintenance of the stored products, provide the necessary infrastructure for its operation and develop traceability of the products handled to validate their effective flow.

It has been shown that 90% of the total cycle time of the chain corresponds to movement and/or waiting times, so reducing this time is the most important challenge for the logistics function of each company within the supply chain, with the consequent reduction of inventories and costs.

Considering the above statistics, it is necessary to propose a productive management in the distribution process towards customers, focused mainly, as Galindo describes, on the adequate use of transport and storage resources such as the transport fleet, the number of platforms, the number of visits or stops per transport unit, storage capacity, and transport capacity, among others.

It is essential to assess the human, material, technological and logistical resources, among others, that are required to operate a CEDI; otherwise, there will be economic consequences for not delivering the goods in time and form, bottlenecks will form, there will be expired products and products that are mishandled due to mishandling, etc.

In this sense, there are methodologies that can help in the proper design of a CEDI. The company Portal Logístico proposes a methodology called IPISI, whose components are, according to its abbreviation: Infrastructure, Processes, Inventories, Work Safety and Indicators. The methodology is interesting because it includes safety at work, a legal and regulatory aspect that is mandatory in Mexico within the framework of the Mexican Official Standards.

The phases of the IPISI methodology include: analysis of infrastructure and areas, analysis of processes, analysis of inventories, implementation of labour and occupational safety, and implementation of logistical indicators.

There are a variety of tools that can be used to carry out an organisational diagnosis. For the purpose of this research, only the following will be described: PEST diagnosis, which is a technique that consists of studying the environment through political, economic, socio-cultural and technological aspects. And the most widely used, which is the SWOT Analysis.

Some of the quality tools that can be applied in the analysis of any organisation are shown in Table 1. Each author establishes the techniques that from their point of view are appropriate.

Box 1

Table 1

Quality Tools

Author	Quality Tools
(López, 2016)	Cause-effect diagram, Pareto diagram, scatter diagram, check sheet, control charts, histogram.
(Chang, 2019)	Tree diagram, Pareto diagram, sequence flow diagram, process flow diagram, scatter diagram, operation diagram, control chart, histogram.
(Vargas, 2014)	Cause-effect diagram, histogram, Pareto diagram, dispersion diagram, control charts, stratification diagram, check sheet
(Vilar, 2018)	Affinity diagram, relationship diagram, tree diagram, prioritization matrices, matrix diagram, decision process diagram, arrow diagram.

Source: Own elaboration

The techniques used in the project are described below, starting with the Ishikawa diagram, followed by the Pareto diagram and ending with the Gantt chart.

The Ishikawa or fishbone diagram is a technique used to identify the possible causes of a central problem, also used to improve processes and resources in an organisation.

The aim of this quality tool is to identify the effects and their respective causes. It is suggested to start with the opinions or ideas of the people involved in the problem. Then the main problem is sought in order to list the causes with the analysis of the structure of the Ishikawa diagram, which consists of five variables: work method, machinery, materials, labour and environment.

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A Pareto diagram is a graph that represents in order, in terms of importance or magnitude, the frequency of occurrence of the different causes of a problem.

The Pareto principle, also known as the 80-20 principle, dictates that few problems are more important than the many that can be observed, but are of no significant importance. 20% of the problems cause 80% of the consequences.

The Pareto diagram is practical and simple to construct. First, the problems that exist in the area being monitored must be located, then the information that causes the problem and its consequences must be collected. Then, they are ordered in descending order, from most to least frequency of occurrence.

It is suggested to quantify them in order to better appreciate the impact of each of the problems. This is how this tool is used to make decisions.

Another important tool is the Gantt chart, which according to (Terrazas, 2011) is a graphic system that is executed in two dimensions; on the abscissa axis the time is placed and on the ordinate axis the activities to be developed are placed.

This diagram is very useful to show the sequence of execution of operations of an entire work package and has the virtue that it can be used both as a planning tool as well as a monitoring and control tool.

Problem statement

The company currently has 37 delivery routes, each with its own driver, 4 operations supervisors and 13 assistants. The distribution process starts when the delivery operators arrive at the CEDIS at 6:30 a.m. to receive a daily talk and training from the supervisors to the collaborators, in which the operators are given new updates so that they can carry out their activities better.

They are reminded of the safety measures they must execute at all times, to prevent accidents, in terms of using their personal protective equipment, among other activities.

The operators then count the product that the warehouse workers have loaded into their units in the early hours of the morning.

The delivery drivers must accurately count the goods to be delivered, as they are only provided with the exact product to be delivered and the warehouse managers are not exempt from errors, and often make mistakes with the quantities of product they load onto the trucks.

When the operators finish counting their merchandise, they continue by filling out a checklist, which is used for operators to indicate the condition of their unit, so that if the unit is damaged, it can be reported and corrected as soon as possible.

Finally, workers should clean their units before leaving on route, check that they contain the necessary documentation to be able to circulate without problems, and lock their refrigeration boxes.

Once the operators are on the road, each one must record and scan each visit through an application, i.e. each time an order is delivered to a customer. When a visit is recorded, the number of records generated by each route driver is displayed in real time.

This data is updated hourly and the visit report is provided to supervisors so they can identify critical routes and take action to speed up their deliveries and finish on time.

At the end of their visits, the delivery drivers proceed to return to the CEDI; if they return to the CEDI before 7:30 pm, it would be established that they have complied. It is worth mentioning that the project called Project 7 X 7, refers to the fact that operators should not spend more than 12 hours to deliver their merchandise.

Regardless of the time they leave and arrive, they must do so in less than 12 hours, and if they do so, they receive an economic bonus.

The next day, they receive a file by mail with the database generated the previous day, which is used to visualise that the routes have been completed.

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According to the reports, there is a percentage of effectiveness lower than its standard, which is 90% compliance, generating repercussions, such as: a decrease in the delivery of the product to the clients, impossibility of reaching the maximum effectiveness in the report of daily visits, a reduction in the company's profits, and an affectation in the performance and commitment of the delivery collaborators.

Based on these reports, it has been detected that some of the indicators are not favourable to the expected results, generating a lower effectiveness than established, in terms of compliance with the standard.

Likewise, it has been detected that the performance of delivery employees has been decreasing or lacks good practices since months ago, when several changes of supervisors and managers were managed.

For example, the number of accidents at work has increased, the number of delivery vacancies has increased, and the efficiency of product delivery has decreased, among others. In the process of delivering products to retail customers, it has been identified that there is a lot of downtime generated by the operators, where some of this downtime is due to the lack of standardised processes that prevent employees from wasting time, from the moment the delivery drivers arrive at the distribution centre until they return from their routes.

For the aforementioned reasons, the objective of the research was to increase the degree of effectiveness of the distribution routes project to 90%.

Methodology

In order to achieve the proposed 90% effectiveness target, the present work comprises 3 stages: diagnosis, analysis, management and evaluation of the project to improve the effectiveness of the distribution centre's deliveries to retailers.

Diagnosis: This stage involves the process of recognition and evaluation of the phenomenon under study, in which the trends, the general context, as well as the historical data of the problem are determined.

Among the tools that allow for the diagnosis of specific events, problems or situations is the SWOT analysis.

According to , SWOT analysis is a strategic planning tool. The acronym SWOT stands for the study of the Strengths, Weaknesses, Opportunities, Opportunities and Threats of a company or an individual. The SWOT analysis can be applied to any situation in which an analysis or study is needed, which is why it was decided to use it in this research.

In order to carry out the SWOT analysis, it is imperative to gather information that shows the real situation of the problem, so the following steps were taken:

a) Information was collected on the effectiveness of delivery to retailers, by route, by delivery driver and by supervisor for the last 3 months.
b) A comparative analysis was carried out with the information collected using bar graphs.
c) Routes with the highest delivery effectiveness rates and routes with the lowest levels were identified.
d) Routes were identified as critical, i.e. routes with delivery effectiveness rates below 90%, which is the company's target.
e) Supervisors of routes with critical effectiveness rates were identified.
f) A comparative analysis was carried out by route and supervisor of the routes with effectiveness rates above and below 90%.

Based on the above information and with the support of the supervisors, a SWOT matrix was drawn up, which shows a complete picture of the current situation of the improvement project.

Analysis: This stage involves a thorough process, which is based on determining and detecting the main causes - potential causes that generate problems or areas of opportunity within an organisation. It is important to mention that for this stage, several meetings were held with the operations team, as well as with the supervisors of the retail distribution routes.

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The analysis tools used were the Ishikawa diagram or cause-effect diagram and the Pareto diagram.

In the first instance, the Ishikawa diagram was used to show the possible causes of the low effectiveness of the distribution routes to retailers.

a) Ishikawa diagram. The cause-effect diagram was developed by brainstorming with operational staff and supervisors, who concluded that the main cause of low effectiveness is due to downtime and the number of customers assigned to the different routes.

Downtime includes the following factors: driver absence, poorly planned routes, closed customers, use of alternative routes and customer delays.

b) Pareto diagram. According to , the Pareto diagram is a graph where various rankings of data are arranged in descending order from left to right by means of bars after data have been collected to rank the causes so that priorities can be assigned.

With the information from the cause-effect diagram and the opinion of those involved in the project, the importance of the potential causes affecting the effectiveness of retail distribution was evaluated.

For this purpose, during the month of October, when the delivery person did not meet the established target, he was asked to fill in a form in which he had to specify the cause of non-compliance.

With the data obtained, a Pareto diagram was drawn up to determine the relative importance of each of the potential causes and to focus the company's efforts on reducing and/or eliminating the vital causes.

Management and evaluation of the retailer distribution improvement project. Once the main causes (vital causes) of the low effectiveness of distribution to retailers had been identified, corrective or management actions were designed to tackle the current problem.

For this stage, it was decided to use different tools to visually identify the activities to be carried out, the people in charge, the time in which these activities will be carried out, among other aspects, in order to standardise the operating procedures and the activities to be carried out.

A Gantt chart was drawn up establishing the improvement activities (countermeasure plan) that were carried out over a period of 2 months.

These activities focus on supervision and standardisation of procedures. The Gantt chart shows the activities, the description, the responsible persons and the time period in which they were carried out.

To support the improvement activities, formats were developed to serve as control: delay format, critical route supervision format and critical route audit format.

The activities proposed and approved by management were implemented starting in November and December.

The evaluation of the impact of the improvement project (countermeasures plan) on the effectiveness of the delivery routes was carried out based on the results obtained in November and December, comparing them with the indicators obtained in the months taken as historical data (August, September and October).

Results

In order to comply with the objective of the research, which was to increase the degree of effectiveness of the distribution routes project to 90%, the results are presented starting with the diagnosis stage, in this stage the trends, the general context, as well as the historical data of the problem are determined using the SWOT analysis.

To carry out this analysis, information was collected to show the real situation of the project, starting with the effectiveness of distribution to retailers, by route, by delivery person and by supervisor for the last 3 months.

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Box 2

Table 2

Effectiveness of delivery to retailers, by route and by supervisor in the last 3 months

ROUTE	SUPERVISOR	AUGUST	SEPTEMBER	OCTOBER
1	SUPERVISOR W	96%	92%	100%
2	SUPERVISOR W	100%	92%	85%
3	SUPERVISOR W	100%	85%	100%
4	SUPERVISOR X	81%	62%	50%
5	SUPERVISOR W	100%	88%	96%
6	SUPERVISOR X	88%	81%	65%
8	SUPERVISOR X	100%	100%	85%
9	SUPERVISOR X	85%	77%	92%
10	SUPERVISOR X	100%	100%	92%
11	SUPERVISOR Z	100%	96%	85%
13	SUPERVISOR Z	88%	77%	69%
14	SUPERVISOR Z	96%	100%	96%
15	SUPERVISOR Z	73%	88%	81%
18	SUPERVISOR Y	96%	100%	100%
20	SUPERVISOR Y	62%	81%	85%
21	SUPERVISOR Y	88%	92%	77%
22	SUPERVISOR Y	96%	100%	100%
23	SUPERVISOR Y	81%	85%	69%
24	SUPERVISOR Y	96%	100%	69%
25	SUPERVISOR Y	69%	69%	54%
26	SUPERVISOR Y	81%	73%	81%
27	SUPERVISOR Y	92%	81%	88%
28	SUPERVISOR X	62%	69%	46%
30	SUPERVISOR Y	38%	62%	46%
32	SUPERVISOR W	100%	92%	100%
33	SUPERVISOR X	100%	96%	92%
34	SUPERVISOR Y	96%	96%	100%
35	SUPERVISOR W	100%	100%	100%
36	SUPERVISOR Y	81%	73%	65%
38	SUPERVISOR X	81%	85%	85%
39	SUPERVISOR X	81%	58%	73%
40	SUPERVISOR Z	96%	88%	100%
41	SUPERVISOR X	100%	100%	96%
42	SUPERVISOR Z	100%	100%	100%
45	SUPERVISOR Z	92%	92%	96%
46	SUPERVISOR W	73%	85%	85%
47	SUPERVISOR X	96%	92%	92%

Source: Own elaboration

According to the effectiveness of distribution by route and supervisor, a comparative analysis is presented in table 2, which contains the percentage of effectiveness by supervisor for the three months of August, September and October of the diagnostic analysis to represent it in a bar graph.

Box 3

Table 3

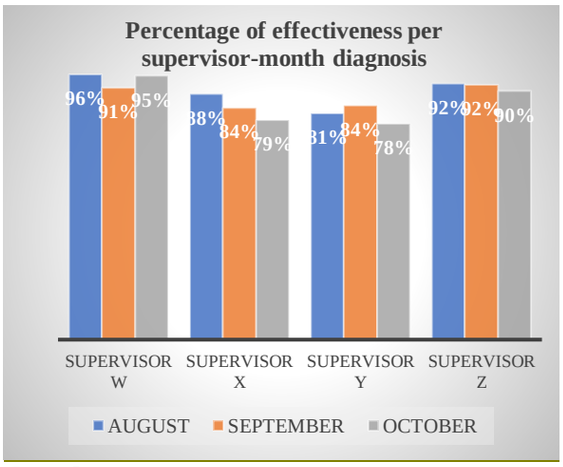
Percentage of effectiveness per supervisor months diagnosis

SUPERVISOR	AUGUST	SEPTEMBER	OCTOBER
SUPERVISOR W	96%	91%	95%
SUPERVISOR X	88%	84%	79%
SUPERVISOR Y	81%	84%	78%
SUPERVISOR Z	92%	92%	90%

Source: Own elaboration

Table 3 shows that supervisor W has the highest route effectiveness and supervisor Y remains in the lowest effectiveness position with respect to the other three supervisors (graph 1).

Box 4



Graph 1

Percentage of effectiveness per supervisor-month diagnosis

Source: Own elaboration

The routes with the highest delivery efficiency rates and the routes with the lowest levels per month in the last three months of the diagnostic analysis were identified.

In the month of August, of the 11 efficient routes, five correspond to supervisor W, while supervisor Z has only one efficient route. In September, nine routes show the highest efficiency, of which three are from supervisor X, three from supervisor Y, two from supervisor Z and only one from supervisor W.

The last month of diagnosis is October in which nine routes are efficient, four from supervisor W, three from supervisor Y, and only two from supervisor Z. Supervisor X has no efficient routes (see table 4).

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Box 5

Table 4

Routes with the highest effectiveness rates in August, September and October

RUTA	SUPERVISOR	AUGUST	SEPTEMBER	OCTOBER
1	SUPERVISOR W	96%	92%	100%
2	SUPERVISOR W	100%	92%	
3	SUPERVISOR W	100%		100%
5	SUPERVISOR W	100%		96%
32	SUPERVISOR W	100%	92%	100%
35	SUPERVISOR W	100%	100%	100%
8	SUPERVISOR X	100%	100%	
9	SUPERVISOR X			92%
10	SUPERVISOR X	100%	100%	92%
33	SUPERVISOR X	100%	96%	92%
41	SUPERVISOR X	100%	100%	96%
47	SUPERVISOR X	96%	92%	92%
18	SUPERVISOR Y	96%	100%	100%
21	SUPERVISOR Y		92%	
22	SUPERVISOR Y	96%	100%	100%
24	SUPERVISOR Y	96%	100%	
27	SUPERVISOR Y	92%		
34	SUPERVISOR Y	96%	96%	100%
11	SUPERVISOR Z	100%	96%	
14	SUPERVISOR Z	96%	100%	96%
40	SUPERVISOR Z	96%		100%
42	SUPERVISOR Z	100%	100%	100%
45	SUPERVISOR Z	92%	92%	96%

Source: Own elaboration

The routes that were considered critical, as they have delivery effectiveness rates of less than 90%, which is the company's goal, are shown in table 5 and are grouped by supervisor in order to identify those routes with lower efficiency (graph 2)

Box 6

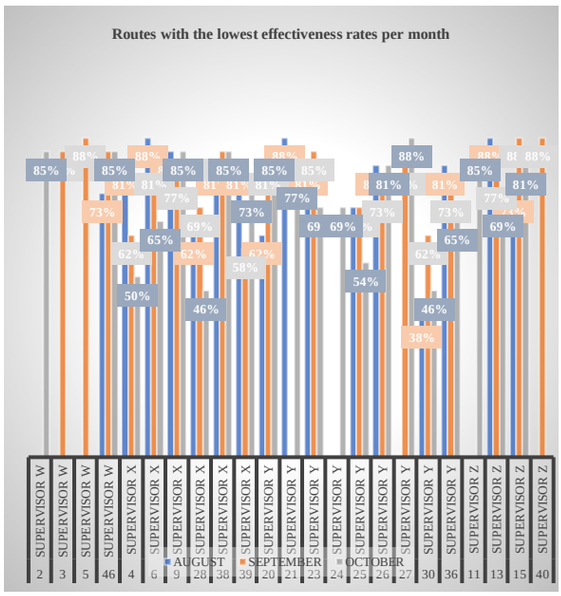
Table 5

Routes with the lowest effectiveness rates per month

ROUTER	SUPERVISOR	AUGUST	SEPTEMBER	OCTOBER
2	SUPERVISOR W			85%
3	SUPERVISOR W		85%	
5	SUPERVISOR W		88%	
46	SUPERVISOR W	73%	85%	85%
4	SUPERVISOR X	81%	62%	50%
6	SUPERVISOR X	88%	81%	65%
9	SUPERVISOR X	85%	77%	85%
28	SUPERVISOR X	62%	69%	46%
38	SUPERVISOR X	81%	85%	85%
39	SUPERVISOR X	81%	58%	73%
20	SUPERVISOR Y	62%	81%	85%
21	SUPERVISOR Y	88%		77%
23	SUPERVISOR Y	81%	85%	69%
24	SUPERVISOR Y			69%
25	SUPERVISOR Y	69%	69%	54%
26	SUPERVISOR Y	81%	73%	81%
27	SUPERVISOR Y		81%	88%
30	SUPERVISOR Y	38%	62%	46%
36	SUPERVISOR Y	81%	73%	65%
11	SUPERVISOR Z			85%
13	SUPERVISOR Z	88%	77%	69%
15	SUPERVISOR Z	73%	88%	81%
40	SUPERVISOR Z		88%	

Source: Own elaboration

Box 7

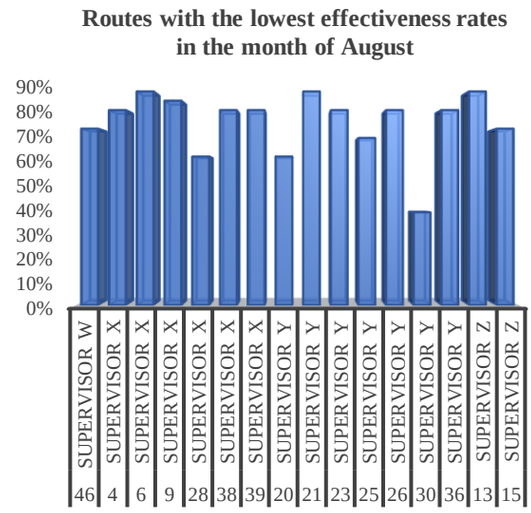


Graph 2

Routes with the lowest effectiveness rates per month

En la gráfica 3 se muestran las 16 rutas con eficiencia por debajo del 90%, en agosto.

Box 8



Graph 3

Percentage of effectiveness by supervisor and route in August

Graph 4 shows the 19 routes with the lowest efficiency in the month of September, seven from supervisor Y, six from supervisor X, both representing 68%, three from supervisor W and three from supervisor Z

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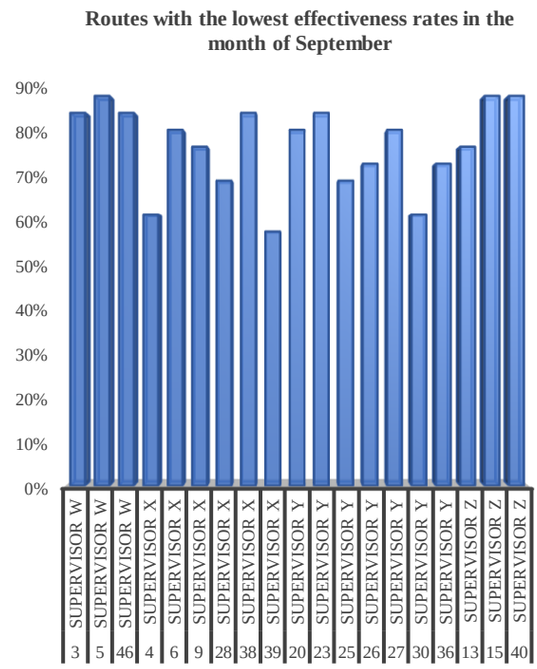
Box 9



Graph 4

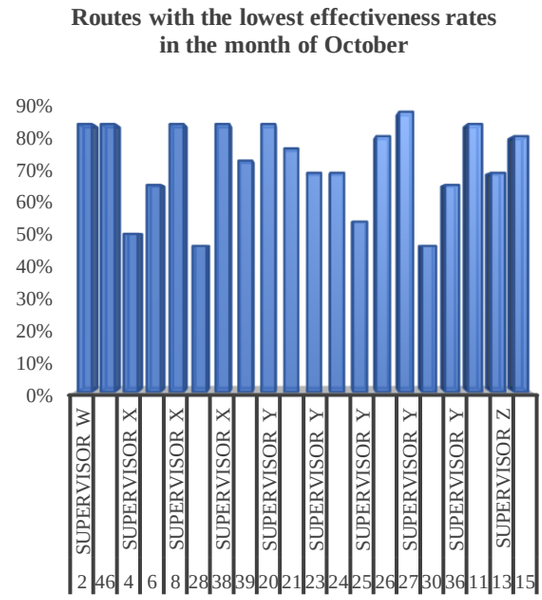
Routes with the lowest effectiveness rates in September

In October, the number of routes with efficiency below 90% increased to 20, of which eight belonged to supervisor Y, six to supervisor X, two to supervisor W and the last two to supervisor Z (Figure 5).

As part of the diagnostic stage, a SWOT matrix was drawn up (Table 6), where the constant monitoring of delivery operators by supervisors and the record of visits made by delivery operators during the course of their day were identified as strengths, as well as the company's ability to award an economic bonus for compliance with the schedule on their route. In terms of weaknesses, the main one is the low effectiveness of the programme, as it is below standard.

In relation to the opportunities, the use of technology is important and the threats are reflected in the fact that the effectiveness can be affected by people or events external to the organisation.

Box 10



Graph 5

Routes with the lowest effectiveness rates in October

Box 11

Table 6

SWOT MATRIX

SWOT MATRIX OF THE 7X7 PROJECT	Strengths (S)	Weaknesses (W)
	S1. Provide a financial bonus if 7X7 is met. S2. Constant monitoring of delivery operators through supervisors. S3. Constant monitoring of the record of visits that delivery operators carry out throughout their day.	W1. 7X7 effectiveness below its minimum standard. W2. Existence of quite a few dead times. W3. Effectiveness subject to the performance and effectiveness of delivery collaborators.
Opportunities (O)	**Strategies SO**	**Strategies WO**
O1. Technology to carry out more accurate monitoring of the performance of delivery operators. O2. Technology to visualize the fastest and most viable routes for each operator. O3. Technology to forecast future events.	S2, O2. Design an incentive plan to provide an economic bonus to the operator who complies with their deliveries. S3, O2. Implement adequate technology in delivery units so that operators can detect the fastest and most viable routes to follow.	W1, O1. Generate feedback to delivery drivers so that they can increase their standards from supervisors using advanced technology. W2, O3. Develop a route program that includes possible contingencies that may occur with the support of technology.
Threats (T)	**Strategies ST**	**Strategies WT**
T1. Project effectiveness may be affected by natural events. T2. Project effectiveness can be affected by people outside the organization. T3. The effectiveness of the project can be affected by situations external to the organization.	S3, T2: Design a control format to corroborate deliveries with clients to generate greater effectiveness. S2, T2. Have a communication system that allows monitoring by supervisors and by operators, the reporting of any external contingency that influences the visit is achieved.	W2, T2. Prepare weekly planning involving delivery drivers to reduce downtime and avoid losing effectiveness on delivery routes. W1, T1. Provide a training course regarding the actions of delivery drivers in case of risk situations.

Source: Own elaboration

For the analysis, we first used the Ishikawa diagram or cause-effect diagram as a tool to show the possible causes of the low effectiveness of the delivery routes to retailers (table 6).

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Subsequently, experts from the operations team were interviewed and several potential causes were identified, such as downtime, the absence of drivers, the number of customers, long routes, among others.

Members of the operations area recognise that they pay attention to downtime. Delivery drivers tend to waste time at different points in their working day from their arrival at the distribution centre to their return after delivering products to customers.

The causes and main effect are shown in the Ishikawa diagram in figure 1

Box 12

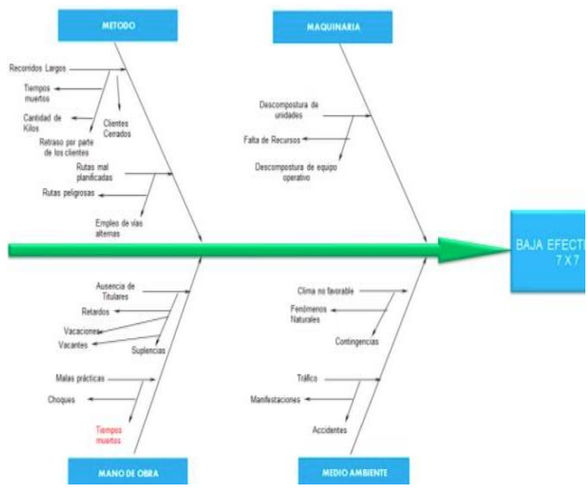


Figure 1

Ishikawa diagram

Source: Own elaboration

With the information from the cause-effect diagram and the opinion of those involved, the importance of the potential causes that do not allow the standard of distribution to retailers to be achieved is evaluated, specifying the cause of non-compliance.

With this information, a Pareto diagram was drawn up to determine the relative importance of each of the potential causes and to focus the company's efforts on reducing and/or eliminating the vital causes: Number of customers, climate, lack of drivers, route and closed customers account for 79% of the causes of non-compliance with the established standard, which can be seen in table 6 and in the Pareto graph (graph 6)

Box 13

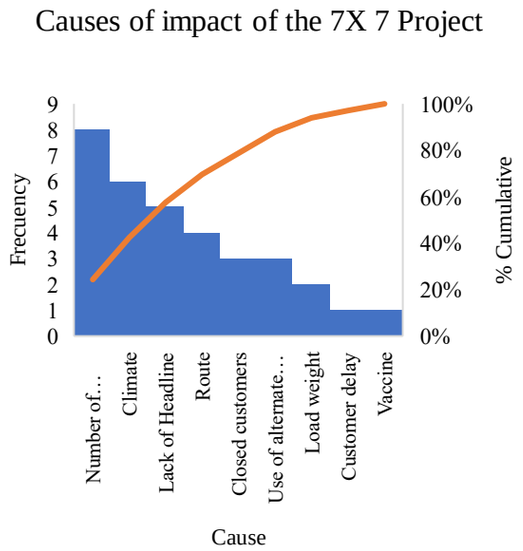
Table 7

Main causes and their frequencies

NUMBER	CAUSE	FREQUENCY	% INDIVIDUAL	CUMULATIVE	% INDIVIDUAL COMULATIVE
1	Number of customers	8	24.24%	8	24.24%
4	Climate	6	18.18%	14	42.42%
6	Lack of headline	5	15.15%	19	57.58%
7	Route	4	12.12%	23	69.70%
3	Closed customers	3	9.09%	26	78.79%
5	Use of alternate routes	3	9.09%	29	87.88%
2	Load weight	2	6.06%	31	93.94%
8	Customer delay	1	3.03%	32	96.97%
9	Vaccine	1	3.03%	33	100.00%
		33	100.00%		

Source: Own elaboration

Box 14



Graph 6

Main causes and their degree of frequency

Once the main root cause of the low effectiveness of the 7 X 7 project was identified, and in order to improve the effectiveness of the project, the management and evaluation of the retailer distribution improvement project was carried out with the planning and development of a countermeasure plan to address the problem of downtime, as well as the development of actions to improve effectiveness. To this end, a Gantt chart (figure 2) was drawn up, as shown below, with the programming of the following activities:

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Delay format, Critical route supervision format, Management of registration machine applications, Standardisation of arrival, Load Counting, Priority review filter at departure, constant monitoring of visitor registration, Assignment of assistants to critical routes and, finally, Route audits.

Box 15

7 x 7 countermeasure plan				Month 1 November semana					Month 2 December semana				
				1	2	3	4	5	1	2	3	4	5
Number	Activity	Description	Responsible										
1	Delay format	A delay form will be created so that delivery people who arrive late can sign it so that there is evidence of it.	Resident										
2	Critical path monitoring format	A supervision form will be created which the supervisor will fill out in their audits of the critical routes.	Resident										
3	Application management of registration machines	Of the operators who have been identified as wasting a lot of time using the phone and not for work matters, applications that could distract them such as WhatsApp, Facebook, among others, will be removed.	Supervisors										
4	Arrival standardization	The keys to the units and the registration machines will be placed in the operations area so that the delivery people do not waste time searching and thus go directly to their trucks.	Supervisors and Resident										
5	Load count	As the delivery assistants arrive, they will be assigned a unit to count the load or assist the owners in filling the pulpomatic.	Supervisors										
6	Output a priori review filter	So that the delivery people do not waste time in the exit filter with the police, an a priori review will be carried out to ensure that the delivery people take their transit documents, their licenses, their locks on the boxes, in order. their drums full of water and their outlet cones.	Resident										
7	Constant monitoring of visit logs	An update of the client's visit records will be carried out every hour, and the report will be sent to the supervisors so that they can communicate with their operators and thus take action on the matter with those who have few records.	Resident										
8	Helper assignment to critical routes	From the critical routes detected at work, delivery assistants will be provided on their days with the most clients and volume of products to ensure that they arrive 7 x 7.	Supervisors										
9	Route audits	Surprise audits will be carried out on the identified critical routes to ensure that their performance is as desired.	Supervisors										

Figure 2

Gantt chart

Source: Own elaboration

Once the 7 X 7 project was implemented, the number of routes with efficiency greater than 90% increased to 25 per supervisor during November as shown in table 7 and graph 7.

The following table compares the routes for November and December in order to detect coincidences.

In November, only route 15 of supervisor Z was less than 90% efficient, and in December, routes 3 and 46 of supervisor W, 21 and 25 of supervisor Y, and only route 13 of supervisor Z lost efficiency.

Box 16

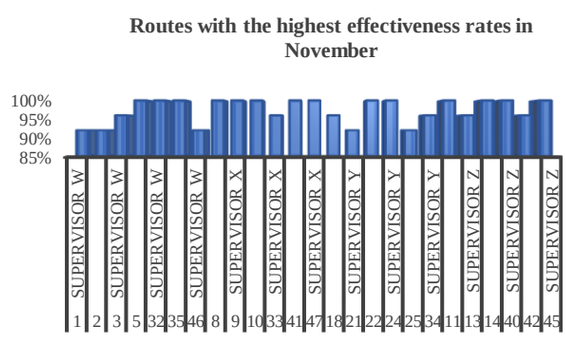
Table 7

Routes with higher effectiveness rates in November and December

ROUTER	SUPERVISOR	NOVEMBER	DECEMBER
1	SUPERVISOR W	92%	100%
2	SUPERVISOR W	92%	92%
3	SUPERVISOR W	96%	
5	SUPERVISOR W	100%	96%
32	SUPERVISOR W	100%	100%
35	SUPERVISOR W	100%	100%
46	SUPERVISOR W	92%	
8	SUPERVISOR X	100%	100%
9	SUPERVISOR X	100%	100%
10	SUPERVISOR X	100%	96%
33	SUPERVISOR X	96%	100%
41	SUPERVISOR X	100%	100%
47	SUPERVISOR X	100%	96%
18	SUPERVISOR Y	96%	100%
21	SUPERVISOR Y	92%	
22	SUPERVISOR Y	100%	100%
24	SUPERVISOR Y	100%	100%
25	SUPERVISOR Y	92%	
34	SUPERVISOR Y	96%	100%
11	SUPERVISOR Z	100%	100%
13	SUPERVISOR Z	96%	
14	SUPERVISOR Z	100%	96%
15	SUPERVISOR Z		96%
40	SUPERVISOR Z	100%	92%
42	SUPERVISOR Z	96%	100%
45	SUPERVISOR Z	100%	96%

Source: Own elaboration

Box 17



Graph 7

Routes with the lowest effectiveness rates in November

As of December, there are 21 routes with an efficiency of more than 90% per supervisor, as shown in table 7, graph 8.

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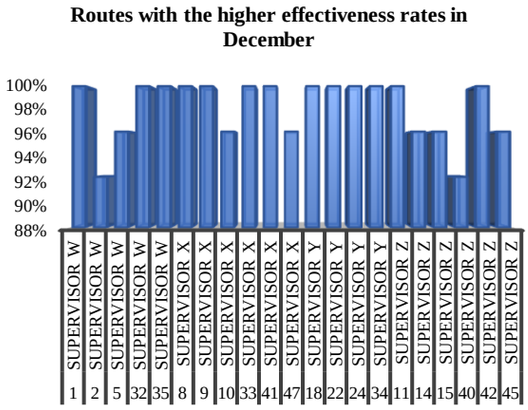
Box 18



Graph 8

Routes with the lowest effectiveness rates in December

Conclusions

At the end of this research it was observed that the main objective of this project was achieved, which was to increase the effectiveness of the distribution routes. The minimum standard was achieved, through the optimisation of times, an adequate general management of the processes and activities that contemplate the delivery of products to the final consumer; in the same way, a standardisation of positive upward trends was developed. In general terms, it can be concluded that the diagnosis, analysis and improvement plan implemented contributed positively to improving the 7 X 7 indicator. This led to a notable improvement in the reduction of substandard routes at a general level and, in particular, in the reduction of the time taken by operators from departure to their route to arrival.

This was possible with the use of basic quality tools and above all with the involvement of operational staff, supervisors and senior management. In addition, there was a reduction in absenteeism and tardiness of employees, greater motivation and commitment, as those involved participated both in the detection of the potential causes of low effectiveness in their activities and in the improvement project. There was a reduction in the number of vacancies, thus generating an operation with a robust team.

As for the areas of opportunity identified in the diagnostic stage, such as the presence of idle times, the high rate of operator delays, the lack of monitoring and constant evaluation, these were eliminated or reduced by a large percentage.

Supervisors were helped to improve their individual indicators, as well as reducing the number of non-compliant routes and increasing the delivery effectiveness of the critical routes analysed.

It is worth highlighting the importance of change in any organisation, as work teams often have a specific way of carrying out their daily activities, but when they become routine, they fail to identify areas for improvement, which is why the application of quality tools is recommended on an ongoing basis.

In operations, a lack of camaraderie was identified because in certain situations supervisors are only interested in the operation of the routes they are in charge of, when colleagues need support. It was also noted that certain supervisors team up and manage route departure planning and the allocation of helpers according to their needs.

Best practices in the work routines of supervisors and delivery drivers were identified for the design of standardised work procedures, thus drawing on the experience and skills of supervisors and operators.

In the internal context of the company, some areas lead to non-compliance with the effectiveness indicator. Such is the example of the financial department, which should streamline processes to provide it with the tools required by the operations area to achieve more effective deliveries, such as: having the invoices to be delivered on time, delivering the corresponding TAG for the payment of toll booths, resources for the payment of parking, among others.

Similarly, the commercial area, because on several occasions it causes deliveries to be less effective due to the way in which they manage customer orders, i.e., for a delivery to be convenient, customers need to be as close as possible or be in the path of the delivery person. However, pre-sales staff sometimes enter orders with customers who are outside the delivery driver's area and this causes the project indicator to be affected.

In this sense, it is necessary for the commercial department to take into account the delivery route so that the sales work is generated in the established areas.

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Conflict of interest

The authors declare that they have no conflicts of interest. They have no competing financial interests or known personal relationships that could have influenced the information in this article.

Authors' contribution.

Zenteno-Bonola, Ana Luisa: contributed with the idea of the project, development of the introduction and frame of reference, statement of the problem and formulation of the conclusions.

Calderón-Ríos, Norma Otilia: contributed to the development of the methodology, the formulation of the conclusions and the general revision of the article.

Palomar-Fuentes, María del Pilar: contributed to the elaboration and interpretation of graphs, tables and figures, and the calculation of statistical measures.

Benitez-Vallejo, Juan Carlos: contributed with the project idea, the collection and processing of information and the proposal of the countermeasure plan.

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Abbreviations

CEDIS	Center of Distribution
IPISI	Analysis methodology for distribution centers
MIPyMES	Micro, Small and Medium Enterprises

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Article

Optimization of production processes through the Kaizen philosophy to reduce time

Optimización de procesos productivos mediante la filosofía Kaizen para la reducción de tiempos

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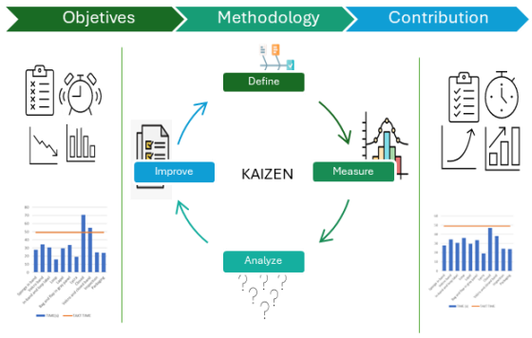
Abstract

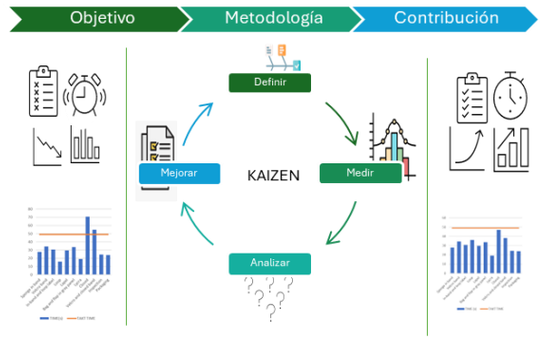
This work presents the results obtained from the design and implementation of the Kaizen philosophy in a maquiladora company, where downtime in the production line, machine failures and low production levels have been detected. The philosophy was implemented where the production line was analyzed through the implementation of continuous improvement tools that managed to eliminate downtime and thereby improve the company's productivity.



Kaizen, Continuous Improvement, Productivity

Resumen

Este trabajo presenta los resultados obtenidos del diseño e implementación de la filosofía Kaizen en una empresa maquiladora, en donde se ha detectado tiempos muertos en la línea de producción, fallas en las máquinas y bajos niveles de producción. Se implemento la filosofía en donde se analizó la línea de producción mediante la implementación de herramientas de mejora continua que lograron eliminar los tiempos muertos y con ello mejorar la productividad de la empresa.



Kaizen, Mejora Continua, Productividad.

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Introduction

Competitiveness plays a fundamental role in industrial and service companies because they seek to gain new customers or retain the customers they have.

One way to increase companies' competitiveness is through management strategies in which they seek to constantly improve their processes, thus becoming more efficient and having a higher performance.

This is thanks to the simplification and optimization of methods, which helps reduce or eliminate waste that the production system presents and thus increases the productivity of companies.

These management strategies are based on continuous improvement such as Lean Manufacturing, also known as world-class manufacturing, and Toyota production system. According to Ibarra-Balderas (2017), it consists of a continuous and systematic process that seeks to eliminate waste or activity that does not add value to the product, service, and processes and thereby increases efficiency increasing productivity, as reflected by Marmolejo et al (2016) the implementation for the reduction of downtime.

Arrieta Posada et al. (2010) in their study show that companies in the textile industry do not have great benefit in the implementation of Lean Manufacturing because they have not been able to develop the culture nor have, they implemented the philosophy consciously and comprehensively due to its complexity.

On the other hand, the Six Sigma philosophy, also of continuous improvement, seeks to increase quality and decrease variety in production processes to obtain zero defects. Tello Capa, J. R. T., & Aguirre, M. (2019) mention that the success of this depends on the dissemination of knowledge in statistical methods and above all on the willingness of its workgroup to promote change in the culture of the company.

Another philosophy for improvement is Total Quality Management (TQM), this philosophy focuses on the production of quality products and services to meet the needs of customers helping to improve employee productivity and thereby increase customer satisfaction to achieve a competitive advantage. Fuentes, M. D. M. F., & Torres, N. E. H. (2002), in their study, establish that the greatest problem presented by organizations that have TQM is the measurement of performance because subjective measurement predominates over objective measurement.

The Kaizen philosophy, like the philosophies, promotes continuous improvement in organizations according to Pin et al (2022), and is based on the improvement of the initial design by involving all personnel and training them to identify areas of opportunity, developing action plans for future improvements. In Moreno et al (2020), thanks to the implementation of Kaizen, there were savings in monthly investment and a reduction in manufacturing time.

This philosophy is not only implemented in production areas, in the study carried out by Gallegos (2007) it was implemented in administrative areas, and with it, a cost reduction was achieved thanks to the action plan that solves the areas of opportunity found. These philosophies bring with them many benefits since they help analyze the current situation of the company and measure and implement actions that reduce costs, time, and efforts to increase productivity and thus have greater competitiveness.

This work proposes the implementation of the Kaizen philosophy in a manufacturing company in the medical area, where there have been downtimes in the production line, machine failures, and low production levels. This implementation will help detect and analyse the production system. With this, implement improvement tools that allow eliminating downtime and problems that arise, optimizing the production line and increasing the productivity of the company.

Kaizen

Kaizen is a business management strategy that describes the improvement of organizational processes at all levels of hierarchy.

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Its objective is to implement improvements and reduce inefficiencies to build an efficient and productive environment that increases the competitiveness of companies. (Kasuga, 2021).

This strategy is implemented within companies where they seek to obtain profit through the motivation of ingenuity, and the creativity of the staff to identify the areas of opportunity that could be improved in the company, as well as find a way for them to have a better functioning and be more effective.

To guarantee the success of this philosophy, it is necessary to involve all the company's personnel, as well as to keep them motivated, always looking for possible improvements in all areas of the company. That is why it has as its pillars the commitment, perseverance, and discipline of both line operators up to the highest rank of the company.

This philosophy is immersed in a series of principles that guide the behavior of the personnel who apply the tools to improve their processes. Many authors describe different principles such as Boluda, M. Á. V., & Soler, V. G. (2016) who establish 10 such as:

- *Customer focus:* Ensuring that your products and/or services meet customer needs.
- *Make continuous improvements*: Constantly improve, once a task is completed, focus on improving that same task.
- *Openly recognize problems*: Promote a culture of communication to recognize problems and thus be able to solve them to improve, without looking for those responsible.
- *Promote openness:* Sharing, inter-functional communication, and visible leadership.
- *Create teams:* Teamwork promotes the creation of quality circles where we seek to solve detected problems.
- *Team project management:* Setting up projects within departments engages all employees to gain different points of view.
- *Encourage appropriate relationship processes:* Intervene in the relationship of your employees, managers, and leaders for the harmony of the company.
- *Develop self-discipline: Allow employees to adapt to situations that arise.*
- *Constant information to employees: Establishes understanding and acceptance of the company's vision, mission, values, practices, and plans.*
- *Promote the development of employees:* Train the members of the company to acquire knowledge and skills for decision-making.

With these principles, Kaizen allows reducing waste and consequently improving work performance, leading the organization in constant innovation according to Suárez-Barraza (2007). This optimization of the company is possible through the implementation of Kaizen tools.

Kaizen Tools

Quality Tools

These tools are common tools due to the simplicity of being able to implement them without having great statistical knowledge, apply at any level of the organization, and are very useful due to the collection and organization of useful information. According to Lemos, P. L. (2016) these tools are:

- *Control Sheet:* Also known as a checklist, this is designed to obtain information related to a process or project.
- *Control Chart:* A chart implemented to control and improve a process by analyzing its variation over time.
- *Cause and Effect Diagram:* Also known as the Ishikawa Diagram, this tool allows you to identify, know, and classify the information related to the causes of the problem.
- *Histogram:* A bar graph that shows the rate of data that a given category counts.
- *Pareto Chart:* It is an analysis method that allows discriminating and establishing priorities between the causes of the problem by defining categories, based on the Pareto principle where 80% of defects are caused by 20% of the causes.
- *Scatter Plot:* This graph allows you to identify the relationship between two variables.

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Box 1

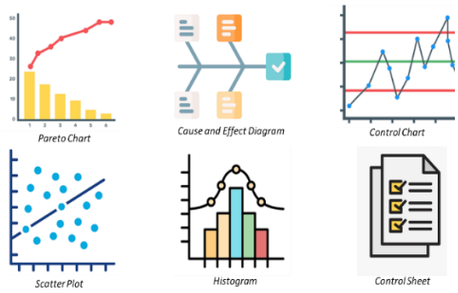

Figure 1

Basic quality tools

Source: Own elaboration

Deming Cycle

This philosophy uses the Deming circle, also called PDCA, as a tool to detect problems and optimize processes. Walter A. Shewhart is the creator of the PHVA Cycle, which was later renamed the Deming Cycle by the Japanese due to William Edwards Deming.

He was the one who taught the methodology in Japan in the 1950s. It should be noted that Shewhart was a friend and mentor of Deming. (Cuggia-Jiménez et al, 2020).

The Deming cycle is a method that companies use to continuously improve their processes, making them more efficient and of higher quality, in addition to solving problems and executing continuous improvement systems since its application helps companies to increase their productivity and constantly improve.

If implemented correctly, it allows the quality standards of a process to improve. But the most interesting thing is that, since it is a circle, it is possible to start the improvement system once again, as many times as necessary. (Costa et al, 2024)

This cycle is made up of 4 steps:

- *Planning:* an analysis of the problem is carried out and the action plan is decided. (improvement)
- *Execution:* The improvement is made, and a record is kept.
- *Verification:* After some time after the improvement has been applied, the results obtained are analyzed.
- *Action:* If necessary, another modification is made to achieve the expected results.

PDCA stands for Plan, Do, Check, Act. Benefits of the Deming Cycle:

- Reduces process times
- Increases productivity
- Decreases and prevents failures and errors.
- Optimize the use of the company's resources (materials, people, money, etc.)

The 5s

This is an activity that depends on the joint participation of all the company's personnel. Workers must be made aware that they will be able to improve their daily work environment. The 5s method consists of the following:

- *1st S – Classification (Seiri):* It is based on identifying and classifying the materials essential for the process, while the rest is considered unnecessary material and therefore will be removed or separated from the workplace. From that moment on, an inventory of each job will be made to have the essentials so that there are no longer elements that can hinder the work.

- *2nd S – Organization (Seiton):* The next thing is to organize the essential materials, for their easy location, use, and availability, as well as to replace these tools to eliminate non-productive times due to the search for materials and unnecessary displacements. To achieve this, the location of each material or tool must be marked with the help of labels, molds, drawings, signs, etc.

- *3rd S – Cleaning (Seiso):* It is very important to locate and remove dirt from the work area, as well as its correct maintenance of cleanliness and organization, as this has a direct impact on the motivation of the staff, in addition to considerably reducing accidents and work injuries.

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- *4th S – Standardize (Seiketsu):* The standard process simply tries to distinguish between "normal" and "abnormal" situations, i.e., personnel must be able to distinguish when the previous three S's are used correctly and when they are not. All plant personnel must have the appropriate training to identify this type of situation. With this, the staff feels more valued and increases their motivation to work, which in turn, operators are better able to detect small failures in their workplace that could trigger more serious problems in the future in the process.

- *5th S – Keep Improving (Shitsuke):* The 5S do not have a defined end. It is a cycle that repeats itself continuously and in which discipline must be maintained to achieve an orderly and clean workplace. The success in the implementation of the 5S provides a much more pleasant workspace with a good work environment where accidents are also reduced and the productivity and satisfaction of the company's personnel when working is increased. (Carreras, 2021) (Tomal Das, 2024).

5 Whys

The 5 Whys is a very simple continuous improvement tool, but at the same time very effective, because it shows the direct path to the root cause of the problem you have so that it can be implemented it is convenient to make a quality circle, that is, a group of people who are directly familiar with the problem and with the process to improve it.

The 5 whys consist of clearly defining the problem to be solved and questioning why it is generated and obtaining an answer from it, followed by another 4 whys that give an answer to why that situation is being carried out and in this way guide to the true root. (Oliveira 2021).

Methodology

According to the steps to be followed to apply continuous improvement based on the Kaizen methodology, it includes the use of statistical tools within a structured methodology increasing the necessary knowledge to achieve in a better way, faster, and at the lowest cost, products and services than the competition.

This methodology can be carried out through the phases as shown in Figure 2. (Tapias, Y. A. A., & Correa, J. H. R., 2010).

Box 2

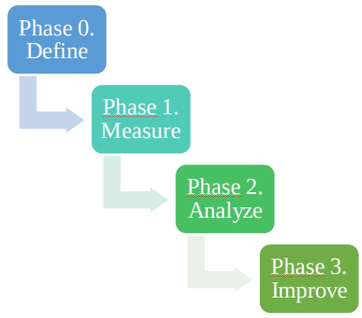

Figure 2
Methodology
Source: Own elaboration

Phase 0: Definition

In the Definition phase, the starting point is established, and the objective to be achieved is defined, where the reduction of downtime and line balancing due to the excess of downtime in certain process operations is proposed, which generates bottlenecks and affects the achievement of the production goal.

Phase 1: Measurement

In this phase, time was taken for each of the operations that make up the production system as shown in Table 1. This table shows how many traders each trade has, and the Takt Time it has.

Box 3

Table 1
Cycle time measurement

Operation	Description	Operators	Tim E(s)	Takt time	Difference
1	Sponge in band	1	27.82	48.96	21.14
2	Velcro band	1	34.49	48.96	14.47
3	In-band and loop label	1	30.74	48.96	18.22
4	Loop	3	15.85	48.96	33.11
5	Lapel	1	29.69	48.96	19.27
6	Bag and flap in gray panel	1	33.73	48.96	15.23
7	Lycra	2	19.08	48.96	29.88
8	Closed	1	70.7	48.96	-21.74
9	Velcro and closed band	1	54.7	48.96	-5.74
10	Inspection	1	24.37	48.96	24.59
11	Packaging	3	24	48.96	24.96
	Total	**16**	**365.17**		

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With these measurements, it can be seen that the closing velcro and banding operations in closed are those that exceed the Takt Time shown in Figure 3, being the operations that generate the bottleneck in the line.

Box 4

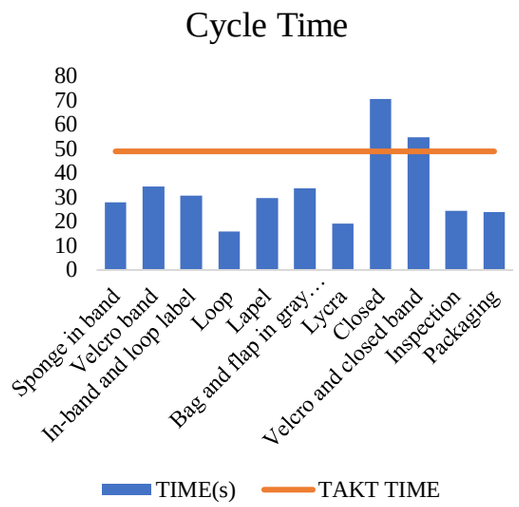

Figure 3
Cycle Time

Phase 2: Analysis

In this phase, the activities that occur within the operations that generate downtime and that in turn cause it to be the bottleneck of the line are analyzed.

The analysis is carried out using the tool of the 5 Why? To carry out this tool, a quality circle was made, made up of the workers of the area to find the root cause of the delay in each of the activities. Table 2-5 shows the causes and responses to each Why?

Box 5

Table 2
Answers of the 5 Why? of thread cutting

Cause	Thread cutting 
Why 1	Excessive wire tension
Why 2	Knots in the thread or damaged part where the thread passes
Why 3	Incorrect threading on the machine
Why 4	Lack of knowledge of the personnel to thread
Why 5	Lack of training

Source: Own elaboration

Box 6

Table 3
Answers of the 5 Why? of stitch mismatch

Cause	Stitch mismatch 
Why 1	Mismatched tension on the bobbin spool
Why 2	Reel failing on the spool
Why 3	Accumulation of dust or lint on the machine
Why 4	Lack of machine cleaning
Why 5	Lack of training

Source: Own elaboration

Box 7

Table 4
Answers of the 5 Why? of dirty machine

Cause	Dirty machine 
Why 1	Accumulation of dust and lint in the machine
Why 2	Lack of knowledge of the staff about the cleaning of the machine
Why 3	Lack of staff training
Why 4	Lack of cleanliness during the shift
Why 5	Lack of cleaning utensils

Source: Own elaboration

Box 8

Table 5
Answers of the 5 Why? of online operator imbalance

Cause	Online Operator Imbalance
Why 1	Poor organization of workstations
Why 2	Poor organization of operations
Why 3	Ignorance of the process
Why 4	Erroneous cycle times
Why 5	Non-continuous workflow

Source: Own elaboration

Phase 3: Improvement

In the improvement phase, proposals are established that eliminate or reduce the root causes found in the analysis phase, by the circle of quality. The proposals reached are the following:

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1. Training operators on the basic operation and adjustment of the tension in the machine's wire, thus eliminating the problem of automatic wire cutting.
2. Training of personnel on cleaning utensils for stitch misalignment.
3. Implementation of cleaning checklist TPM for the machine as shown in Figure 4.
4. Study of times and balancing of the line with the changes of the Takt Time, based on the client's demand.

Box 9

TPM/SEWING CHECKLIST

	Activity	Date									
		1	2	3	4	5	6	7	8	9	10
1	Verify that the machine has guards										
2	Verify that the machine has its accessories										
3	Clean the sewing area										
4	Check that there are no air leaks										
5	Check that the thread holder is clean and in good condition										
6	Check that there are no loose or disconnected electrical cables.										
7	Verify that the pedal chair and bench are in good condition										
8	Check that the lamp is working correctly										
9	Check that the machine does not present any strange noise										
10	Check that the ignition box is in good condition										
11	Carry out general cleaning of the machine										
12	Turn off the machine when not in use (change bobbin, or needle at rest)										

Mark with ✓ if the activity was carried out and no anomalies were found.

Mark with **X** if the activity was carried out and anomalies were found. Any anomalies detected should be repaired and reported to the department.

Mark **N/A** if the activity does not apply to your team

Figure 4

Cleaning checklist

Source: Own elaboration

Results

As a result of the training carried out, delays at the workstations were eliminated. Table 3 shows the times obtained and the line balancing. A rearrangement of operators was made since there were operations that required less time and had more operators than necessary (Green cells in Table 6).

On the other hand, operators were included in critical operations to reduce the workload and cycle time, so that it would adjust to the calculated takt time (Yellow cells in Table 6).

Finally, an operator was eliminated in the lycra operation, as it was not necessary, and the operation involved a minimum time (blue). The results shall be by section of the article.

Box 10

Table 6

Cycle time measurement

Operation	Description	Operators	TIME(s)	Takt time	Difference
1	Sponge in band	1	27.82	48.96	21.14
2	Velcro band	1	34.49	48.96	14.47
3	In-band and loop label	1	30.74	48.96	18.22
4	Loop	2	36	48.96	12.96
5	Lapel	1	29.69	48.96	19.27
6	Bag and flap in gray panel	1	33.73	48.96	15.23
7	Lycra	1	19.08	48.96	29.88
8	Closed	2	47	48.96	1.96
9	Velcro and closed band	2	38.04	48.96	10.92
10	Inspection	1	24.37	48.96	24.59
11	Packaging	2	24	48.96	24.96
	Total	**15**	**344.96**		

Figure 5 shows the times for each operation and how, thanks to the improvements, they are within the Takt Time and thus eliminate the bottlenecks that the line presented.

Box 11

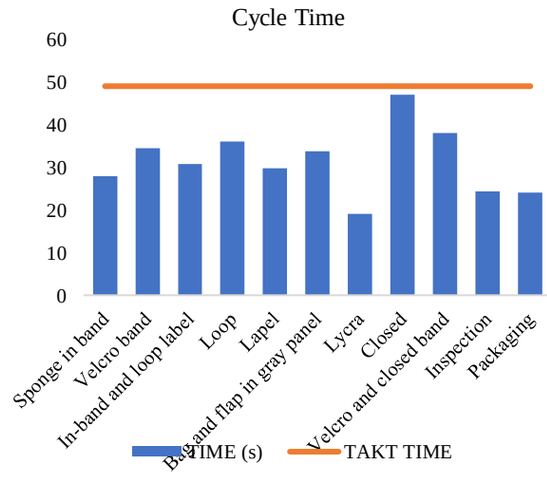

Figure 5

New cycle times

Source: Own elaboration

Conclusions

With the implementation of the Kaizen project in the production line, it was found that there was not good flow in the operations and excess cycle times, so it was necessary to make an analysis of operations and follow up on the balancing of the line (Figure 6).

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Box 13

Table 7

Comparison of the results obtained

	BEFORE KAIZEN	AFTER KAIZEN	
Cycle Time (Max)	70.7	47	itself
Pz x hour	50.9	76.60	Pcs
Available time	36720	36720	itself
Efficiency	85	85	%
Daily demand	750	750	Pcs
Pz produced	519.4	781	Pcs
Production efficiency	69.25	104.17	%
Goal	100	100	%
Time-out	33.5	4	%

Source: Own elaboration

Box 12

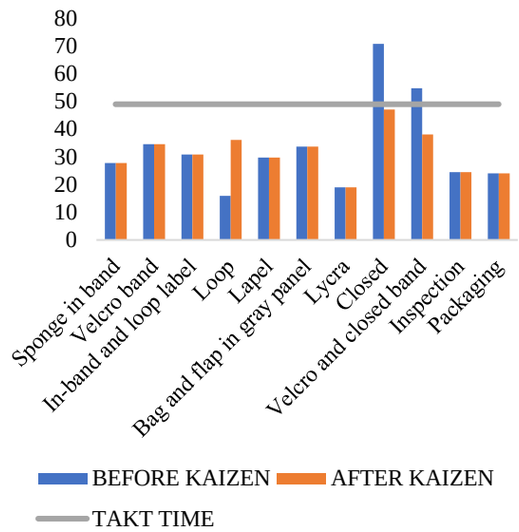

Figure 6

Comparison of cycle times

As a result of the analysis and improvements, the number of operators in certain stations was reduced, and with it the reduction of downtime, achieving a more efficient and optimized line that allows the established production goals to be achieved.

With this, it can be said that the Kaizen philosophy and the continuous improvement project obtained great benefits and good results for the company and its objective of customer satisfaction since the delivery times were met due to the increase in production obtained, the benefits obtained thanks to Kaizen can be reflected in Table 7 and Figure 6.

These results are a clear example of the great benefits of the implementation of the Kaizen philosophy generated within companies because it allows companies to increase productivity and be more efficient thanks to continuous improvement. Clearly explain the results and possibilities of improvement.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Hernández-Anaya, Luisa Fernanda: contributed with the project idea, research, and implementation.

López-Garza, Esmeralda: Contributed to the idea of the project, research and state of the art. She contributed to the methodology and writing of the article.

Garza-Moreno, Jesús Cruz: Contributed to the idea of the project, the methodology, analysis of results and writing of the article.

Espíndola-Álvarez, Jorge Antonio: Contributed to conceptualization, analysis of results and writing of the article.

Availability of data and materials

The data presented for this research is available according to the sources consulted.

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The project was carried out with its own financing.

Abbreviations

List abbreviations in alphabetical order.

PDCA	Plan, Do, Check, Act
PHVA	Planear, Hacer, Verificar, Actuar
TPM	Total Productive Maintenance

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Article

Optimization of photovoltaic panels through machine learning algorithms linked to predictive maintenance

Optimización de paneles fotovoltaicos mediante algoritmos de aprendizaje automático vinculándolo con el área de mantenimiento predictivo

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Abstract

Zitácuaro, Michoacán, faces the challenge of maximizing the performance of photovoltaic systems. This study addresses this challenge through the development and implementation of advanced predictive models based on machine learning and predictive maintenance strategies. Historical and real-time data from photovoltaic systems are collected, including meteorological variables, panel performance, and energy consumption. Advanced analysis techniques, such as linear regression, decision trees, and neural networks, are applied to forecast energy production and detect patterns of suboptimal performance. The methodology is divided into two stages: comprehensive data collection from sources like the National Meteorological Service and OpenWeatherMap, and detailed analysis through preprocessing techniques and predictive modeling. The results demonstrate significant improvements in prediction accuracy and failure reduction, optimizing energy efficiency and contributing to the sustainability of photovoltaic systems in the region.

Enhancing Photovoltaic System Performance in Zitácuaro, Michoacán		
Objectives	Methodology	Contribution
* Develop Predictive Models * Implement predictive maintenance strategies *Improve Energy Efficiency *Enhance Data Utilization	*Data Collection *Predictive Modeling *Performance Optimization	*Enhanced Prediction Accuracy *Reduced System Failures *Increased Energy Efficiency *Methodological Framework

Predictive, Optimization, Neural

Resumen

La creciente adopción de tecnologías solares en Zitácuaro, Michoacán, presenta el desafío de maximizar el rendimiento de los sistemas fotovoltaicos. Este estudio aborda este reto mediante el desarrollo e implementación de modelos predictivos avanzados basados en aprendizaje automático y estrategias de mantenimiento predictivo. Se recopilan datos históricos y en tiempo real de sistemas fotovoltaicos, que incluyen variables meteorológicas, rendimiento de paneles y consumo energético. Se aplican técnicas avanzadas de análisis, como regresión lineal, árboles de decisión y redes neuronales, para prever la producción energética y detectar patrones de rendimiento sub óptimo. La metodología se divide en dos etapas: la recolección exhaustiva de datos de fuentes como el Servicio Meteorológico Nacional y OpenWeatherMap, y el análisis detallado mediante técnicas de pre procesamiento y modelado predictivo. Los resultados demuestran mejoras significativas en la precisión de predicciones y reducción de fallos, optimizando la eficiencia energética y contribuyendo a la sostenibilidad de los sistemas fotovoltaicos en la región.

Mejorando el Rendimiento de los Sistemas Fotovoltaicos en Zitácuaro, Michoacán		
Objetivos	Metodología	Contribución
*Desarrollar Modelos Predictivos *Implementar Estrategias de Mantenimiento Predictivo *Mejorar la Eficiencia Energética *Potenciar la Utilización de Datos	*Recolección de Datos *Modelado Predictivo *Optimización del Rendimiento	*Precisión Mejorada en las Predicciones *Reducción de Fallos en el Sistema *Aumento de la Eficiencia Energética *Framework Metodológico

Predictivo, Optimización, Neural

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Introduction

The growing demand for sustainable energy solutions has driven interest in optimizing photovoltaic systems, especially in regions like Zitácuaro, Michoacán, where the implementation of solar panels has become a priority to reduce dependency on non-renewable sources.

However, despite significant efforts in the installation of these systems, it has been observed that the performance of solar panels does not always reach the expected optimal levels. This underperformance can largely be attributed to the lack of effective optimization and predictive maintenance strategies.

In this context, the present research proposes an integrated approach that combines machine learning algorithms with predictive maintenance strategies to improve the efficiency of photovoltaic systems. The methodology employed in this study combines descriptive and applied methods, based on a thorough documentary review and experimental research. Historical and real-time data are collected from a photovoltaic system located in Zitácuaro, and predictive models are developed using advanced techniques such as linear regression, decision trees, and neural networks.

Previous studies have demonstrated the importance of using historical and real-time data to improve the efficiency of photovoltaic systems. The Solar Comet Project – CS, led by Cecilia E. Sandoval-Ruiz, uses meteorological data analysis and advanced mathematical models to optimize solar energy production.

Similarly, Guillermo García Dávila and Miguel Ángel Hernández Flores have addressed the optimization of photovoltaic systems through simulations and computer tools to maximize efficiency and reduce operational costs. These approaches highlight the need to integrate environmental data and maintenance strategies to achieve optimal operation of solar panels.

The research also faces significant challenges in Zitácuaro, such as the variability of environmental conditions and the accumulation of dirt on the panels.

Traditional maintenance methods are often reactive and based on predefined time intervals, which can result in ineffective interventions. The use of machine learning algorithms allows for the analysis of large volumes of data to predict the behavior of solar panels and optimize maintenance routines, ensuring optimal performance for as long as possible.

This study aims to address these challenges by developing a predictive model and a maintenance system based on machine learning, with the goal of improving energy efficiency and reducing the operational costs of solar panels in Zitácuaro. The integration of meteorological data and predictive analysis is fundamental to achieving these objectives and contributing to the region's energy sustainability

Methodology

The research proposes an integrated approach to optimize photovoltaic systems through the use of machine learning algorithms and predictive maintenance strategies.

The methodology employed combines descriptive and applied methods, with a solid foundation in document review and experimental research. Historical and real-time data from a photovoltaic system located in Zitácuaro, Michoacán, are collected, and predictive models are developed using machine learning techniques such as linear regression, decision trees, and neural networks.

The review of previous studies highlighted the importance of using historical and real-time data to improve the efficiency of photovoltaic systems.

In Zitácuaro, Michoacán, the search for sustainable and efficient energy generation solutions, optimizing photovoltaic systems emerges as a critical necessity.

Various studies have explored innovative approaches to maximize solar panel efficiency and reduce operating costs through the use of machine learning algorithms and predictive maintenance strategies.

The optimization of photovoltaic systems is a field that has significantly evolved in recent years.

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Neama et al. (2023) emphasize the importance of renewable energy in sustainable development, highlighting how the optimization of these systems can maximize energy efficiency. David et al. (2022) point out that the implementation of optimized energy systems in rural areas not only improves electrification but also promotes economic and social development.

Artificial neural networks (ANN) and other machine learning algorithms have proven to be effective tools for predicting and optimizing the performance of photovoltaic systems. Cardil et al. (2015) implemented prediction models based on neural networks for the spread of forest fires, demonstrating their potential in renewable energy applications. Pereira et al. (2022) used neural networks for solar resource assessment, showing significant improvements in prediction accuracy. Predictive maintenance is a crucial strategy to ensure the efficiency and longevity of photovoltaic systems. Rosado et al. (2022) demonstrated how neural networks can predict the mass of peach fruits using non-destructive methods, a technique applicable to the monitoring and maintenance of solar panels.

Abbass (2023) proposed a framework based on Bayesian optimization and neural network connections to predict the energy performance of buildings, highlighting its application in photovoltaic systems.

Several studies have used simulation models to evaluate and improve the efficiency of photovoltaic systems. Osman et al. (2023) conducted sub-seasonal to decadal predictions to support climate services, providing a solid foundation for energy system planning and optimization. Beccali et al. (2017) developed a decision support tool based on ANN to assess energy performance and rehabilitation actions in non-residential buildings.

The practical application of these methodologies has been explored in various contexts. Báez Coronado (2024) designed an artificial intelligence model to predict solar energy production, applying it in the context of Antioquia, Colombia. Sandoval-Ruiz (2020) and Davila (2023) examined the optimization of photovoltaic systems in specific projects, highlighting the importance of integrating advanced technologies to improve efficiency and sustainability.

The accumulation of dirt on solar panels can significantly reduce their efficiency. González (2022) and Cobian Lufin (2023) investigated optimization models for cleaning planning in solar parks, proposing strategies that combine simulation techniques and machine learning models to keep panels in optimal condition.

The implementation of digital twins for the optimization of self-sufficient energy systems is an emerging trend. Rodríguez de Lope López et al. (2023) developed a digital twin for a residential self-sufficient energy system, demonstrating how these technologies can improve the management and efficiency of energy resources.

The state of the art in the optimization of photovoltaic panels using machine learning algorithms and predictive maintenance strategies reveals a dynamic and constantly evolving landscape. Advances in neural networks, simulation methods, and practical applications highlight the potential of these technologies to transform solar energy management, promoting greater efficiency and sustainability in the use of renewable resources.

Problem Description

In Zitácuaro, Michoacán, the implementation of photovoltaic solar panels has been a key initiative to promote the use of renewable energy and reduce dependence on non-sustainable energy sources. However, despite advances in the installation of these systems, their performance has not always reached the optimal levels expected.

This underperformance is largely due to the lack of effective optimization and predictive maintenance strategies. Solar panels are highly dependent on environmental conditions such as solar irradiation, temperature, humidity, and wind speed.

These factors can vary significantly over time, affecting the efficiency of converting solar energy into electricity. Additionally, the accumulation of dirt and other physical obstructions can further reduce the panels' ability to generate electricity.

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Without adequate maintenance, these problems can lead to a considerable decrease in energy production, resulting in higher operating costs and a shorter lifespan for the panels. However, most traditional maintenance methods are reactive and based on predefined time intervals, which can result in unnecessary or late interventions.

On the other hand, optimizing panel configuration to maximize their energy efficiency is not always carried out systematically and data-driven, limiting the energy generation potential. The implementation of machine learning algorithms offers a promising solution to these problems.

These algorithms can analyze large volumes of historical and real-time data to identify patterns and predict the behavior of solar panels under various conditions. Valverde, L. et al (2023).

By applying machine learning techniques, it is possible to develop predictive models that anticipate maintenance needs before failures occur, thereby optimizing maintenance routines and ensuring that panels operate at their maximum capacity for as long as possible.

Despite the potential of these technologies, their practical application in Zitácuaro still faces several challenges (social, economic, geographical). The collection of accurate and real-time data, the selection and training of appropriate algorithms, and the implementation of an effective early warning system are critical aspects that require careful research and development.

This study aims to address these challenges by developing a predictive model and a maintenance system based on machine learning, with the objective of improving energy efficiency and reducing the operating costs of solar panels in Zitácuaro, Michoacán.

Data Collection from Local and National Sources:

- National Meteorological Service (SMN)
- National Forestry Commission (CONAFOR)
- National Water Commission (CONAGUA)

The reports provided by these organizations contain historical data related to meteorological conditions, such as radiation, temperature, and humidity, as these factors are relevant.

Determination of Energy Needs

First, the devices requiring electrical power were identified, including in our case study of a building: 25 LED lamps, 17 computers, and 6 printers. The energy consumption of each type of device was calculated based on its nominal power and daily operating time.

Real-time Data

- Solar Energy Information System (SIES): Provides real-time data on solar radiation and weather conditions in various regions of Mexico.
- Meteorological Data Platforms

- OpenWeatherMap: Provides current weather data and forecasts for any location.
- Weather Underground: Provides real-time weather data as well as forecasts for Zitácuaro.

Optimizing the Performance of a Photovoltaic System in Zitácuaro by Analyzing Historical and Real-time Data

Data Sources

- National Meteorological Service (SMN): Provides historical solar radiation and meteorological data in Mexico, can provide specific data for Zitácuaro.
- NASA's Surface Meteorology and Solar Energy (SSE): Offers historical data on solar irradiation and meteorological conditions. The SSE portal can filter data on solar irradiation and temperature for Zitácuaro.

Process

Collected Data

- Historical Solar Radiation: Monthly average solar irradiation in kWh/m² for the last 5 years.
- Historical Temperature: Monthly average temperature in °c during the same period.

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- Humidity and Wind Speed: Monthly average data.

Real-time Data Collection

- OpenWeatherMap API: Provides current weather data and forecasts (solar radiation, temperature, humidity, and wind speed) for Zitácuaro.
- Solar Energy Information System (SIES): Offers real-time data on solar conditions in Mexico.

Collected Data

- Real-time Energy Generation: Data on energy generation from polycrystalline panels.
- Current Solar Radiation: Real-time measurements of solar irradiation in W/m².
- Current Environmental Conditions: Real-time temperature, humidity, and wind speed.

Data Integration and Analysis

Tools and Methods

- Database: SQL (like MySQL) or NoSQL (like MongoDB) to store historical and real-time data.
- Analysis Software: PVsyst to analyze and simulate the performance of polycrystalline solar panels.
- Visualization Tools: Tableau or Power BI to create dashboards and charts to visualize panel efficiency and correlate weather data with energy production.

Analysis Process

- Comparison of Historical vs. Real-time Data: Compare current energy production of polycrystalline panels with historical solar irradiation data to identify patterns or discrepancies.
- Environmental Conditions: Analyze how current environmental conditions affect panel performance compared to historical data.

Optimization

Operational Adjustments: Based on the analysis, make adjustments to the orientation or tilt of the panels or maintenance scheduling.

Predictive Models: Machine learning models to predict energy production and adjust the system according to forecasted conditions.

Database Creation for Research

Steps

1. Define Requirements: Identify the types of data needed, such as solar irradiation, temperature, humidity, wind speed, and panel performance. Organize data in the database (tables, relationships, etc.).

2. Select Database Technology: Use relational databases like MySQL or PostgreSQL for highly structured data and complex relationships. Use NoSQL databases like MongoDB for flexibility in the data schema or unstructured data.

3. Collect Data: Gather data from mentioned sources (Sistema Meteorológico Nacional (SMN), Administración Nacional de Aeronáutica y del Espacio(NASA), etc.) and store in the database. Consider automating real-time data collection using APIs or monitoring systems.

4. Design and Configure Database: Design a data model including tables for solar irradiation, temperature, humidity, wind speed, and panel performance. Configure indices to improve query performance and create SQL queries or scripts for data extraction.

5. Implement and Maintain Database: Develop the database and enter historical and real-time Conduct Periodic Maintenance to Ensure Data Integrity and Accuracy

Data Analysis

- Utilize data analysis tools such as Excel, Tableau, Power BI, or programming languages like Python to extract and analyze stored data.
- Implement a predictive model and machine learning algorithms to optimize the performance of solar panels.

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For this database process, a variety of key data must be collected:

Meteorological Data

Solar Radiation:

- Daily/Monthly/Annual Average: Measured in kWh/m² or W/m².
- Specific Data: Direct, diffuse, and global irradiation.

Ambient Temperature:

- Daily/Monthly/Annual Average: Measured in °C.
- Range: Maximum and minimum daily temperature.

Relative Humidity:

- Daily/Monthly/Annual Average: Measured in %.
- Additional Data: Minimum and maximum humidity.

Wind Speed:

- Daily/Monthly/Annual Average: Measured in m/s or km/h.
- Additional Data: Maximum and minimum speed.

Atmospheric Pressure:

- Daily/Monthly/Annual Average: Measured in hPa or mmHg.
- Additional Data: Pressure variations that may affect production.

Weather Conditions:

- Precipitation: Measured in mm or liters per square meter.
- Cloud Cover: Percentage of sky covered or type of cloudiness.

Solar Panel Performance Data

Energy Generation:

- Daily/Monthly/Annual Production: Measured in kWh.
- Additional Data: Total and per panel production.

Conversion Efficiency:

- Instantaneous and Average Efficiency: Measured in %.

Panel Condition:

- Panel Temperature: Measured in °C.
- Shade and Obstruction: Data on shaded or dirty areas.

Tilt and Orientation Angle:

- Specific Data: Tilt angle and orientation with respect to north.

Maintenance and Failures:

- Maintenance History: Dates and types of maintenance performed.
- Incidents and Failures: Record of failures and downtime.

Installation System Data

Installation Characteristics:

- Panel Type: Polycrystalline, monocrystalline, etc.
- Inverter Specifications: Type and capacity.
- System Configuration: Series/parallel and panel arrangement.

Installation Conditions:

- Location: Exact geographic coordinates.
- Surrounding Areas: Description of possible obstructions or reflections.

Operational Data

Energy Consumption Data:

- Daily/Monthly/Annual Consumption: Measured in kWh.
- Consumption Profile: Hours of highest and lowest demand.

Economic Data:

- Maintenance Cost: Costs associated with maintenance and repairs.
- Energy Cost: Cost per kWh produced and savings generated.

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Comparison and Validation Data

Benchmarking Data:

- Comparison with Similar Systems: Performance data of photovoltaic systems in similar conditions.

Historical Project Data:

- Previous Projects: Historical data from similar projects for model and technique validation.

Selection of Machine Learning Algorithms

The following machine learning algorithms are evaluated and selected for modeling:

- Linear Regression: Used to predict energy production based on environmental variables. Suitable for establishing simple linear relationships between variables.
- Decision Trees: Applied to model decisions based on multiple variables. Ideal for capturing non-linear relationships and providing clear interpretations of factors affecting energy production.
- Neural Networks: Employed to capture complex, non-linear relationships between variables. Useful when relationships between variables are highly complex.

Model Training

For each selected algorithm, training is performed using the training data set:

Linear Regression:

- Fit the model to historical energy production and environmental conditions.
- Evaluate the model's ability to predict energy production based on environmental data.

Decision Trees:

- Construct the decision tree using the training data set.
- Adjust tree parameters to improve accuracy and avoid overfitting.

Neural Networks:

- Design the neural network architecture, including the number of layers and neurons.
- Train the model using optimization algorithms like gradient descent.
- Adjust hyperparameters to improve model performance.

Model Validation and Evaluation

After training, each model is validated and evaluated using the test data set. The evaluation metrics considered are:

- Mean Squared Error (MSE): Measures the average squared difference between the model's predictions and actual values.
- Coefficient of Determination (R^2): Evaluates the proportion of variability in the dependent variable explained by the model.
- Precision and Recall: Especially relevant for classification if a classification approach is used instead of regression.

Selection of the Best Model

The performance metrics of all evaluated models are compared. The model with the best combination of accuracy, lowest error, and generalization ability is selected for final implementation.

Model Implementation

The selected model is implemented in the photovoltaic system for real-time prediction and optimization. Monitoring mechanisms are established to evaluate model performance and adjust the model as necessary based on new data.
Optimization of a Photovoltaic System's Performance

- Objective: Predict energy production and optimize the configuration of solar panels using machine learning.
- Data: Energy production (kWh/day), solar radiation (kWh/m²), temperature (°C), humidity (%), wind speed (m/s).

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Algorithm Selection:

- Linear Regression to establish a basic relationship between solar radiation and energy production.
- Decision Trees to model complex interactions between multiple environmental variables.
- Neural Networks to capture complex patterns in energy production and optimize system configuration.

Training and Evaluation:

- Models are trained with historical data over a 5-year period.
- Model performance is validated with a recent data set.

Implementation:

- The best-performing model is used to adjust panel angles and improve real-time efficiency.

Results

Development and Evaluation of Predictive Models

1. Data Collection:
- Dependent Variables: Energy production (kWh/day).
- Independent Variables: Solar radiation, temperature, humidity, wind speed.

2. Data Preprocessing:
- Data Cleaning: Remove or impute missing values and handle outliers.
- Normalization/Standardization: Scale variables to improve model efficiency, especially for neural networks.

3. Data Splitting:
- Training Set: Use approximately 70-80% of the data.
- Test Set: Use the remaining 20-30% to evaluate model accuracy.

4. Development of Predictive Models:
- Linear Regression:

```
from sklearn.linear_model import
LinearRegression
from sklearn.metrics import
mean_squared_error, r2_score
# Definir el modelo
modelo_lineal = LinearRegression()
 # Entrenar el modelo
modelo_lineal.fit(X_train, y_train)
# Hacer predicciones
y_pred_lineal =
modelo_lineal.predict(X_test)
# Evaluar el modelo
mse_lineal =
mean_squared_error(y_test,
y_pred_lineal) r2_lineal =
r2_score(y_test, y_pred_lineal)
print(f"Regresión Lineal - MSE:
{mse_lineal}, R²: {r2_lineal}”)
```

Decision Trees

```
from sklearn.tree import
DecisionTreeRegressor
# Definir el modelo
modelo_decision =
DecisionTreeRegressor()
# Entrenar el modelo
modelo_decision.fit(X_train, y_train)
# Hacer predicciones
y_pred_decision =
modelo_decision.predict(X_test)
# Evaluar el modelo
mse_decision =
mean_squared_error(y_test,
y_pred_decision)
r2_decision = r2_score(y_test,
y_pred_decision)
print(f"Árboles de Decisión - MSE:
{mse_decision}, R²: {r2_decision}")
```

Neural Networks

```
from sklearn.neural_network import
MLPRegressor
# Definir el modelo
modelo_nn =
MLPRegressor(hidden_layer_sizes=(100,),
max_iter=1000)
# Entrenar el modelo
modelo_nn.fit(X_train, y_train)
# Hacer predicciones
y_pred_nn = modelo_nn.predict(X_test)
# Evaluar el modelo
mse_nn = mean_squared_error(y_test,
y_pred_nn)
r2_nn = r2_score(y_test, y_pred_nn)
print(f"Redes Neuronales - MSE: {mse_nn}, R²:
{r2_nn}")
```

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Mean Squared Error (MSE):

Description

Measures the average of the squares of the errors, i.e., the average difference between actual values and predictions.

Formula: $MSE=1 \sum^{n}_{i=1} n(yi-yi^)2$

A lower MSE value indicates better model performance.

Coefficient of Determination (R^2):

Measures the proportion of variance in the dependent variable that is explained by the independent variables in the model.

Formula: $R2=1-\sum_{i=1}n\ (yi\ -y^{-}\ )2$
$\sum_{i=1}n\ (yi\ -yi\ ^\ )2$

An R^2 value close to 1 indicates that the model explains the variability of the data well. A value close to 0 indicates that the model does not explain the variability well.d

Predictive Maintenance

Prevent failures in photovoltaic panels and reduce operational costs by implementing an early warning system that detects and predicts maintenance needs.

Data Collection

Data to Collect:

- Historical and Real-Time Data of Photovoltaic Panels:
- Energy Production: kWh/day.
- Solar Radiation: kWh/m²/day.
- Temperature: °C.
- Humidity: %.
- Wind Speed: m/s.
- Previous Maintenance Data:
- Failure History: Type of failure, date, and time.
- Maintenance Interventions: Type of intervention, date, and time.

Additional Sensor Data:

- Light Tracking Sensors: Data on panel orientation and alignment.
- Panel Status Sensors: Temperature and voltage of each panel.

Development of the Predictive Model

Data Preprocessing:

- Data Cleaning: Impute missing values, remove outliers.
- Normalization/Standardization: Scale variables to improve model performance.

Algorithm Selection:

- Logistic Regression: To predict the probability of failure based on panel characteristics.
- Decision Trees: To identify patterns and conditions that precede failures.
- Neural Networks: To capture complex and nonlinear relationships between variables.

Example

```
from sklearn.model_selection import
train_test_split
from sklearn.ensemble import
RandomForestClassifier
from sklearn.metrics import
classification_report, confusion_matrix

# Preparar los datos
X = data[['radiacion', 'temperatura', 'humedad',
'velocidad_viento', 'estado_panel']]
y = data['fallo']

# Dividir datos
X_train, X_test, y_train, y_test =
train_test_split(X, y, test_size=0.3,
random_state=42)

# Definir y entrenar el modelo
modelo_rf =
RandomForestClassifier(n_estimators=100,
max_depth=10, random_state=42)
modelo_rf.fit(X_train, y_train)

# Hacer predicciones
y_pred = modelo_rf.predict(X_test)

# Evaluar el modelo
print(confusion_matrix(y_test, y_pred))
print(classification_report(y_test, y_pred))
```

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Predicción de producción de energía con lineal

```
# Importar las librerías
import numpy as np
import pandas as pd
from sklearn.model_selection import
train_test_split
from sklearn.linear_model import
LinearRegression
from sklearn.metrics import
mean_squared_error, r2_score
import matplotlib.pyplot as plt

# Generar datos
np.random.seed(42)
n_samples = 100
X = np.random.rand(n_samples, 4) * 100
# Datos de entrada: irradiación solar,
temperatura, humedad y velocidad del viento
estado_panel = np.random.randint(0, 2,
size=(n_samples, 1))  # Estado del panel: 0
(bueno) o 1 (necesita mantenimiento)
y = 3.5 * X[:, 0] + 1.5 * X[:, 1] - 2 * X[:, 2] +
X[:, 3] + estado_panel[:, 0] * 5 +
np.random.randn(n_samples) * 10
 # Datos de salida: producción de energía en
kWh

# Combinar X y estado_panel en una sola matriz
de entrada
X = np.hstack((X, estado_panel))

# Dividir el conjunto de datos en entrenamiento
y prueba
X_train, X_test, y_train, y_test =
train_test_split(X, y, test_size=0.2,
random_state=42)

# Entrenar el modelo de regresión lineal
model = LinearRegression()
model.fit(X_train, y_train)

# Predecir los valores de producción de energía
para los datos de prueba
y_pred = model.predict(X_test)

# Evaluar el modelo
mse = mean_squared_error(y_test, y_pred)
r2 = r2_score(y_test, y_pred)
print(f"Mean Squared Error: {mse}")
print(f"R² Score: {r2}")
# Verificar formas
print(f"Shape of X_test[:, 0]: {X_test[:,
0].shape}")
print(f"Shape of y_test: {y_test.shape}")
print(f"Shape of y_pred: {y_pred.shape}")

# Visualizar los resultados
plt.figure(figsize=(10, 6))
plt.scatter(X_test[:, 0], y_test, color='blue',
label='Datos reales')  # Usar irradiación solar
para el eje x
plt.scatter(X_test[:, 0], y_pred, color='red',
label='Predicciones', alpha=0.5)  # Usar
irradiación solar para el eje x
plt.xlabel('Irradiación Solar (kWh/m²)')
plt.ylabel('Producción de Energía (kWh)')
plt.title('Predicción de Producción de Energía
con Regresión Lineal')
plt.legend()
plt.show()

# Datos en tiempo real
radiacion_actual = 80  # kWh/m²
temperatura_actual = 25  # °C
humedad_actual = 60  # %
velocidad_viento_actual = 5  # m/s
estado_panel_actual = 0  # 0 (bueno) o 1
(necesita mantenimiento)

# Crear un array con los datos en tiempo real

datos_en_tiempo_real =
np.array([radiacion_actual, temperatura_actual,
humedad_actual, velocidad_viento_actual,
estado_panel_actual]).reshape(1, -1)

# Predecir la producción de energía con los
datos en tiempo real
prediccion_energia =
model.predict(datos_en_tiempo_real)
print(f"Predicción de Producción de Energía
(kWh): {prediccion_energia[0]}")
```

Box 1

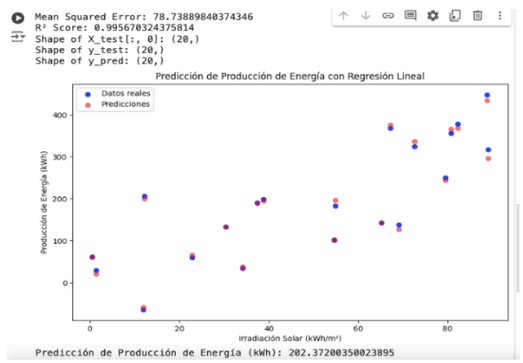

Figure 1

Production Prediction with Linear Regression Source: Data analysis and visualization performed using

Google Colab (https://colab.research.google.com/)

Box 2

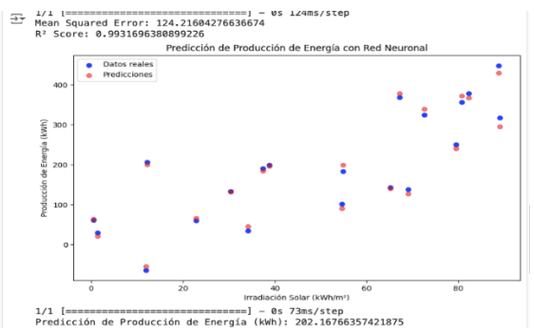

Figure 2

Production Prediction with Neural Network

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Evaluation Metrics

The MSE and R^2 were calculated for both models (Neural Network and Linear Regression). We printed the evaluation metrics to compare the performance of both models.

Neural Network: Tends to be more powerful and capable of capturing complex patterns in the data, but may require more data and training time.

Linear Regression: Is simpler and faster to train but may not adequately capture nonlinear patterns in the data.

Conclusions

This study developed and compared predictive models to optimize photovoltaic panels and perform predictive maintenance using linear regression and neural networks. Both approaches significantly improved the efficiency and sustainability of photovoltaic systems.

Linear regression demonstrated adequate capability for predicting energy production based on environmental variables such as solar radiation, temperature, humidity, and wind speed. It is a simpler and faster model to train but is limited in scenarios with complex nonlinear relationships.

Neural networks, on the other hand, showed greater accuracy in predicting energy production by better capturing complex relationships between variables, although they require more data and training time.

For predictive maintenance, an effective system was developed to predict maintenance needs, detect anomalies, and prevent failures before they occur, reducing operational costs and extending the lifespan of the panels.

Implementation in Zitácuaro, Michoacán, Mexico, showed that it is possible to maximize solar energy production and optimize panel maintenance, contributing to greater sustainability and energy efficiency in the region. The use of machine learning in optimizing photovoltaic systems and predictive maintenance increases efficiency, reduces costs, and promotes sustainable practices, with potential for adaptation to different scales and environments.

Conflict of Interest

The authors declare that they have no conflicts of interest. There are no financial interests or personal relationships that could have influenced the preparation or results of this article.

Author Contributions

Ruiz-Garduño, Jhacer Kharen: Designed the study, performed data analysis, and wrote the final manuscript.

Flores-Serrato, Leonel Alejandro: Contributed to the study design.

Viñas-Álvarez, Samuel Efrén: Contributed to the design and development of the study.

González-Ramírez, Claudia Teresa: Participated in the analysis, design, and development of the study.

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Their contributions were crucial to the development and execution of this research, and their commitment to sustainability and scientific advancement was vital in achieving the proposed objectives. Without their collaboration, this work would not have been possible.

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Their dedication and technical assistance have been fundamental to the success of our research. Their contribution has been essential in achieving the proposed objectives.

Data Availability

The data supporting the findings of this study are available upon request from the corresponding author. For access, please contact Jhacer Kharen Ruiz Garduño at jhacer.rg@zitacuaro.tecnm.mx

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Article

Parallel computing for efficient calculation of multidimensional Bernstein copulas in modeling nonlinear dependence between random variables

Cómputo paralelo para el cálculo eficiente de cópulas de Bernstein multidimensionales en el modelado de dependencia no lineal entre variables aleatorias

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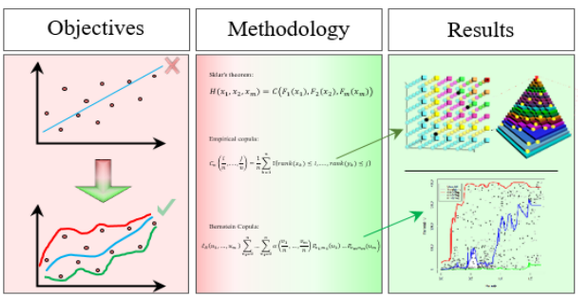
Abstract

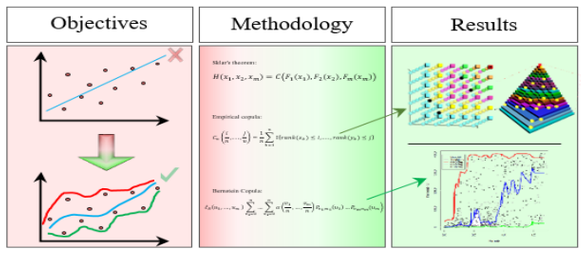
Copulas are a versatile tool for modeling the dependence structure between random variables. By defining marginal distributions, copulas can capture complex joint distributions that are often beyond the scope of traditional statistical methods, which typically rely on linearity and normality assumptions. Unlike these methods, copulas are marginal-free and can effectively model nonlinear dependencies. A Bernstein copula is an empirical, data-driven model capable of reproducing intricate relationships between variables. While highly effective for real-world data, computing Bernstein copulas becomes computationally demanding in higher dimensions. In an $m-dimensional$ case with a sample size of (n), the computation requires evaluating an n^m grid of points, which leads to significant resource demands in terms of processing time and memory as (m) and (n) increase. In this paper, we propose an efficient method for implementing multidimensional Bernstein copulas. We introduce both an optimized algorithm for calculating a multidimensional empirical copula and a parallelized approach for computing the Bernstein copula.



Empirical and Bernstein copula; Multidimensional dependence; parallel computing

Resumen

Las cópulas son una herramienta versátil para modelar la estructura de dependencia entre variables aleatorias. Al definir distribuciones marginales, las cópulas pueden capturar distribuciones conjuntas complejas que a menudo están fuera del alcance de los métodos estadísticos tradicionales, los cuales suelen basarse en suposiciones de linealidad y normalidad. A diferencia de estos métodos, las cópulas no dependen de las marginales y pueden modelar eficazmente dependencias no lineales. Una cópula de Bernstein es un modelo empírico, basado en datos, capaz de reproducir relaciones intrincadas entre variables. Aunque son muy eficaces para datos del mundo real, el cálculo de las cópulas de Bernstein se vuelve computacionalmente exigente en dimensiones más altas. En un caso de $m-dimensiones$ con un tamaño de muestra de (n), el cálculo requiere evaluar una cuadrícula de puntos de n^m, lo que genera una demanda significativa de recursos en términos de tiempo de procesamiento y memoria a medida que (m) y (n) aumentan. En este artículo, proponemos un método eficiente para implementar cópulas de Bernstein multidimensionales. Introducimos tanto un algoritmo optimizado para calcular una cópula empírica multidimensional como un enfoque paralelizado para calcular la cópula de Bernstein.



Cópula empírica y de Bernstein; Dependencia multidimensional; computación paralela

Citation: Hernández-Maldonado, Victor Miguel, Erdely, Arturo and Diaz-Viera, Martin Alberto. [2024]. Parallel computing for efficient calculation of multidimensional Bernstein copulas in modeling nonlinear dependence between random variables. ECORFAN-Journal Republic of Cameroon. 10[18]1-11: e61018111.

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Article

Introduction to multivariate copulas

Linear regression-based dependence models often fail to capture complex dependence structures, which can result in the underestimation of variance and standard deviation.

This limitation compromises their ability to reproduce the inherent variability of the data, which is critical to understanding the nature of many problems. While these models are appropriate when the joint behaviour of variables adheres to linearity assumptions, nonlinear dependencies among random variables are frequently encountered.

As an alternative, copula functions offer a robust method for modelling the joint distribution of random variables. The core principle of the copula approach lies in expressing the joint distribution of random variables as a function of their marginal distributions. This allows copulas to efficiently capture and model complex dependencies among variables [I, II].

According to Sklar's theorem [III], the underlying copula associated to a multivariate random vector $(X_1, X_2, \ldots, X_m)$ represents a functional link between the joint probability distribution and the univariate marginal distributions $(F_1, F_2, \ldots, F_m)$ respectively, Eq.(1):

$$H(x_1, x_2, x_m) = C\big(F_1(x_1), F_2(x_2), F_m(x_m)\big) \quad (1)$$

For all $(X_1, X_2, \ldots, X_m)$ in the extended real numbers system, where $C: [0,1]^m \rightarrow [0,1]$ the underlying copula is unique whenever $(X_1, X_2, \ldots X_m)$ are continuous random variables. Therefore, all the information about the dependence between continuous random variables is contained in their corresponding copula. Several properties may be derived for copulas [II] and among them we have an immediate corollary from Sklar's theorem: $(X_1, X_2, \ldots X_m)$ are independent continuous random variables if and only if their underlying copula is $C(u_1, \ldots, u_n) = (u_1, \ldots, u_n)$.

Let $S = \{(x_{11}, x_{21}, \ldots, x_{m1}), \ldots, (x_{1n}, x_{2n}, x_{mn})$ be n observations of a random vector $(X_1, X_2, \ldots, X_m)$. We may obtain empirical estimates for the marginal distributions $(X_1, X_2, \ldots X_m)$ by means of, [IV]:

$$\widehat{F}_j(x) = \frac{1}{n}\sum_{k=1}^{n} \mathbb{I}_{[-\infty, x_i]}(X_{j,i}) \quad (2)$$

Where $\mathbb{I}$ stands for an indicator function which takes value 1 whenever its argument is true, and 0 otherwise. It is well-known [V] that the empirical distribution $\widehat{F}_j$ is a consistent estimator of $\widehat{F}_j$ that is, $\widehat{F}_j$ converges almost surely to $\widehat{F}_j$ as $n \rightarrow \infty$ for all t.

We address the issue of examining or characterizing the dependence characteristics of multivariate distributions using a series of observed data points. The multivariate empirical copula is formally defined in Equation (3) as referenced by [VI].

$$C_n(\boldsymbol{u}) = \frac{1}{n}\sum_{k=1}^{n}\prod_{j=1}^{d} \mathbb{I}\left\{\frac{R_{i,j}{}^{n}}{n} \leq u_j\right\}, u = (u_1, u_d)\epsilon[0,1]^d \quad (3)$$

where n is the size of the sample, and $\mathbb{I}$ stands for an indicator function which takes value 1 whenever its argument is true, and 0 otherwise.

The empirical copula is a function C_n with domain $\left\{\frac{1}{n}: i = 0,1, \ldots, n\right\}^m$ and its convergence to the true copula C has also been proved by [VII] The empirical copula is not a copula, since it is only defined on a finite grid, not in the whole unit hypercube $[0,1]^m$ but by Sklar's Theorem [III] it may be extended to a copula.

Sklar's theorem is completely general and a joint distribution function can be constructed using a copula function. The copula separates the marginal distributions from correlation, and the copula itself can capture the dependence structure. This is an essential property of copulas.

From Sklar's theorem (1) each random variable X_m is modeled as an absolutely continuous random variable with unknown marginal distribution function F_m.

For simulation of continuous random variables, the use of the empirical distribution function (2) is not appropriate since $\widehat{F}_j$ is a step function, and therefore discontinuous, so a smoothing technique is needed.

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Since the objective of using copulas is to simulate a primary variable using one or more descriptive variables, it is necessary to have a smooth estimation of marginal quantile function $Q(u) = inf\{x: F(x) \geq u\}, 0 \leq u \leq 1$ which is possible by means of Bernstein polynomials as in Muñoz-Pérez and Fernández-Palacín (1987).

$$\hat{Q}_n(u) = \sum_{k=1}^{n} \frac{1}{2}(x_k + x_{k+1}) \binom{n}{k} u^k (1-u)^{n-k} \quad (4)$$

For a smooth estimation of the underlying copula we make use of the Bernstein copula Eq. (5) [VIII], [IX]:

$$\hat{c}_B(u_1, \dots, u_m) \sum_{v_1=0}^{n} \dots \sum_{v_m=0}^{n} \alpha\left(\frac{v_1}{n}, \dots, \frac{v_m}{n}\right) P_{v_1,m_1}(u_1) \dots P_{v_m,n_m}(u_m) \quad (5)$$

where:

$$P_{v_1,m_1}(u_1) = \binom{k_j}{v_j} u_j^{v_j} (1-u_j)^{k_j - v_j} \quad (6)$$

For every $(u_1, \dots, u_m)$ in the unit hypercube $[0,1]^m$ and $\alpha\left(\frac{v_1}{n}, \dots, \frac{v_m}{n}\right)$ is the empirical copula, defined in (3) [VIII].

Bivariate and trivariate sampling algorithms

For a pair of random variables (X_1, X_2) with joint distribution function H and underlying copula C we need to generate an observation of uniform $(0,1)$ random variables (U, V) whose joint distribution function is C and then transform those uniform variables as in step 3 of the sampling bivariate algorithm. For generating such pair (u, v) it is used a conditional distribution method, this method needs the conditional distribution function for V given $U = u$, which we denote as $C_u(v)$

$$C_u(v) = \frac{\partial \tilde{C}_B(u,v)}{\partial u} \quad (7)$$

where $\tilde{C}_B$ is the bivariate Bernstein copula model, obtained by (5).

To simulate replications from the random vector (X_1, X_2) with the dependence structure estimated from the observed data, $S := \{(x_{11}, x_{21}), \dots, (x_{1n}, x_{2n})\}$ it is applied the following algorithm:

Sampling bivariate algorithm

Generate two independent and continuous Uniform $(0,1)$ random variables u and t.

1. Set $v = C_u^{-1}(t)$ where C_u is defined in *(7)*

2. The desired pair is $(x_1, x_2) = \tilde{Q}_n(u), \tilde{R}_n(u)$, where $\tilde{Q}_n$and $\tilde{R}_n$, according to (4), are the estimated and smoothed quantile functions of and , respectively.

For the multivariate case we must solve equations that represent conditional distribution functions for W given $U = u,\ V = v$

To simulate replications from the random vector X_1, X_2, X_3 with dependence structure estimated from data $S := \{(x_{11}, x_{21}, x_{31}), \dots, (x_{1n}, x_{2n}, x_{3n})\}$ it is applied the next algorithm.

Sampling trivariate algorithm

1. Generate three independent and continuous Uniform $(0,1)$ random variables u, t_1 and t_2.

2. Set $v = C_u^{-1}(t_1)$ where C_u is defined in *(7)*.

3. Set $w = C_{uv}^{-1}(t_2)$ where $w = c\_uv(W)$

$$C_{uv}(w) = \frac{\frac{\partial \tilde{C}_B(u,v,w)}{\partial u \partial v}}{\frac{\partial \tilde{C}_B(u,v,1)}{\partial u \partial v}} \quad (8)$$

Where $\tilde{C}_B$ is the trivariate Bernstein copula model *(5)*.

4. The desired vector is $(x_1, x_2, x_3) = \tilde{Q}_n(u), \tilde{R}_n(v), \tilde{H}_n(w)$, where $\tilde{Q}_n(u), \tilde{R}_n(v)$ and $\tilde{H}_n(w)$, according to (4), are the estimated and smoothed quantile functions of X_1 , X_2 and X_3, respectively.

Method

The Bernstein copula is a function based on empirical distributions that can reproduce the underlying dependence structure between random variables in a data-driven way.

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However its computational performance can be very demanding in terms of processing time and storage capacity. In this proposal it is presented a 2-stage algorithm to improve the implementation of its use.

In the first step it is computed a multidimensional empirical copula using an efficient procedure and in the second step they are generated replications of the Bernstein copula using high performance computational techniques.

An efficient procedure to compute a multidimensional empirical copula

Standard calculations of the empirical copula based on equation (3) can end up in an extremely low performance.

In the $m-dimensional$ case with a sample size n, this calculation implies dealing with an m-dimensional grid with a total of n^m points, which for moderate values of m and n it demands an important amount of resources in terms of processing time and storage capacity.

For example, building a *3-dimensional copula* $(m = 3)$ with a sample size $n = 1000$, it would require an efficient management of a data structure which represents a discrete hypercube with 10^9 elements.

For the bivariate case, the compute of the empirical copula C_n basically consist into count the number of bivariate points (x, y) observed in a unitary grid. In Figure 1 (Left), it is observed a scatter plot of 15 observations of two random variables.

The graphical representation of the distribution of these points into an empirical copula is observed in Figure 2 (Right).

To generate this distribution, the observations are sorted by primary variable and then each one is mapped into the unitary grid. It is important to note that in this distribution it is observed one and only one point for each vertical and horizontal line into the grid.

Box 1

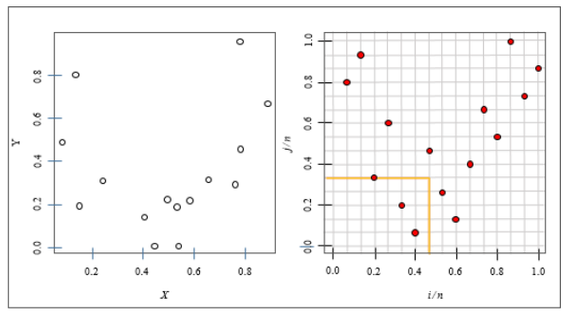

Figure 1

Scatterplot and unitary grid

(Left) Scatter plot of bivariate empirical observations. (Right) Unitary grid of the same observations.

Computing the entire empirical copula consists in calculate the value of each node of the unitary grid of the Figure 1 (Right), using equation (9).

$$C_n\left(\frac{i}{n},\ldots,\frac{j}{n}\right) = \frac{1}{n}\sum_{k=1}^{n}\mathbb{I}\{rank(x_k) \le i,\ldots,rank(y_k) \le j\} \quad (9)$$

Despite (9) represents a systematic calculation, it implies some restrictions, for example, each node always increases its values from 0 to $(observations/n)$ from down to up, from left to right and only it is taken into account the observation that are enclosed into given 'region' of the grid (orange rectangle, Figure 1. (Right).

We are going to take a set of 5 data values of three random variables which are shown in Table 1.

Box 2

Table 1

A set of tree variables and 5 data values. Two secondary variables (SV1, SV2) and one primary variable (PV)

SV_1	SV_2	PV
1.1	2.11	1.111
2.1	1.11	1.111
3.1	4.11	5.111
4.1	3.11	2.111
5.1	5.11	4.111

Source: Microsoft Word.

To construct the Empirical Copula and the Bernstein Copula, we implemented the procedure proposed in [X, XI], which provides a quick and effective method for constructing these copulas, particularly in two dimensions.

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However, in this study, we extend that approach to a multivariate context, specifically to three dimensions. Let's construct the 2D empirical copula, which is exhaustively explained in fragments of code written in ***C++*** which will be found in the section: *"Appendix A"* of this document.

Steps of the first stage of this proposal

1. The computational function that calculates the empirical copula in 2D has the *C++* form shown in (10). It transforms the double data set matrix into integer values, sort the values of the matrix by the main variable and mainly maintain its dependence structure.

The variable 'Rows' is the number of rows of the data set. 'Cols' is the number of variables, in this example we have 3 variables, but it is necessary to say that, for the 2D case only they are considered 2 variables, let us say, 'SV1' and 'SV2'. 'SV1' as secondary variable and SV2 as primary variable, 'VarToSort' is the variable which the sort process will be based on.

2. This matrix is sorted by the SV_2 variable, we do this because we are solving a 2D copula, since the idea that secondary variable is SV_1 and primary variable is *'SV2'*. In fact, it can be any variable but is necessary to think that in the $2D$ case we have only one secondary variable and one primary variable.

As proposed here, the sort function always sorts variables by the primary variable ($VarToSort = SV_2$), see (11). After those process, (IntMaker and SORT) the arrData matrix end up having the form presented in Table 2. Note the array shown in Table 1 now is sorted by $\boldsymbol{SV_2}$ and converted to integer values.

Box 3

Table 2

It is shown the **arrData** Matrix after **IntMakerandSORT** process. Note the array shown in 1 now is sorted by 'SV2' and converted to integer values

SV_1	SV_2	PV
2	1	1
1	2	3
4	3	2
3	4	5
5	5	4

Source: Microsoft Word

3. Next, in (12) it is created the matrix that will contain the 2D empirical copula ("*copemp2D*"). Let us carefully consider the following: equation (10) presents the prototype of the function that calculates the 2D empirical copula, while equation (12) only presents the declaration of the matrix that contains the 2D empirical copula, which is already included within the function in (10). In equation (13), *copemp2D* matrix is populated with zero values.

4. Then in the 2D empirical copula matrix is filled with zero values, see (14). Up to this point, the copemp2D matrix has the appearance of Figure 3. where blue cells indicate a value of *0.0* within them.

Box 4

5	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0
0	0.0	0.0	0.0	0.0	0.0	0.0
	0	1	2	3	4	5

Figure 3

Empirical copula matrix with zero entries
Current state of the 2D empirical copula matrix

5. The calculation of the discrete values of the empirical copula is performed from this point. We know that the primary variable is sorted in ascending mode, so we can take its values and those of the secondary variable given by the current value of 'j' variable of the first 'for' loop (15). Knowing this, we take the value of the secondary variable to locate where the point of the current propagation is (16).

Given this scenario we can set the values of the empirical copula into the copem2D matrix, (17). A propagation must reach the final point of the copem2D Matrix (i.e. When its subscripts are equal to Rows 'copemp2D[Rows][Rows]'), then we have to propagate the influence of the presence of a point in both directions, in 'x' (17) and 'y' direction (18). Schematically all this process be shown in Figure 4.

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Box 5

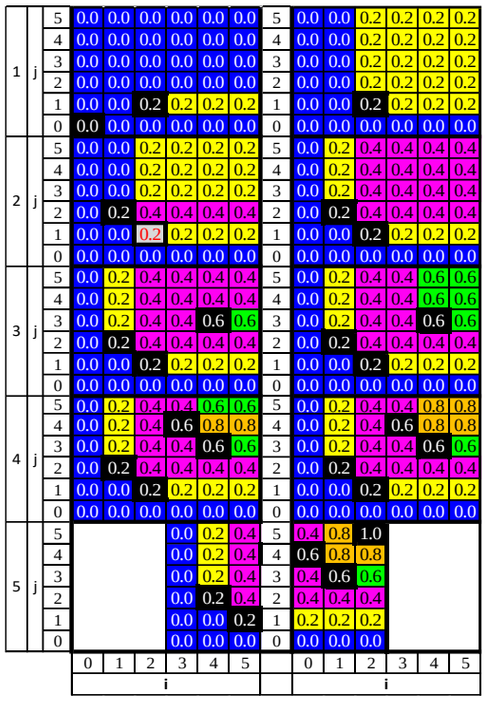

Figure 4

Empirical copula, complete process

Graphical representation of the complete process of the generation of the 2D Empirical Copula proposed in [X]. The propagation points are found in white font colour and black background

For the three-dimensional Empirical Copula generation, it is used the same process, but is augmented one more subscript (k) to the $copemp3d[k][j][i]$ matrix, in order to include the compute of the third dimension, or fourth, fifth, etc.

Figure 5 provides a three-dimensional depiction, where discrete and incrementally ascending steps within the empirical copula are visible for a given dataset, reaching the final value of 1.00.

Box 6

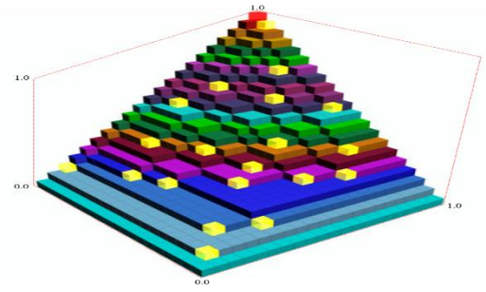

Figure 5

A 3D empirical copula

A three-dimensional depiction of the empirical copula

In Figure 6, the 3D Empirical Copula is displayed in a perspective view, as generated by the proposed process.

The propagation points are represented by black cubes, while the propagated points are shown in cubes of various colors, reflecting different values (observations/n).

Box 7

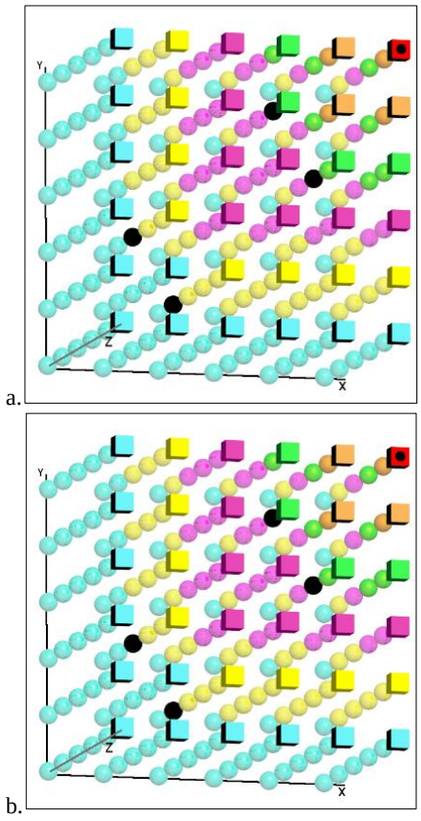

Figure 6

A 3D empirical copula

3D Empirical Copula generated using the proposed process "*a. Perspective view with spheres"; "b. Perspective view with cubes.*" In both views, propagation points are represented by black spheres in (a) and black cubes in (b), while propagated points are shown in spheres and cubes of various colors (a/b)

Parallel computing of a 3D Bernstein copula

Regression and Simulation processes are made in this proposal, a brief explanation of them will be discussed.

It is created a matrix (19) and (20) where results of regression process will be collected. It is a two-sub indexed array where original data set and quantile regressions are collocated.

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It is decided the next calculations will be done in parallel mode, see (21). Immediately it is called a main method to perform regressions of a given quantile, where are passed as argument, the data set, the current value of the quantile regression, the sorted data set, the secondary variable 1, the secondary variable 2, the primary variable, the *2D* empirical copula, the *3D* Empiric Copula, the number of rows and finally the results precision are passed as argument, see (22). Inside this function the Bivariate and trivariate sampling algorithms are solved. Note that (22) must be inside (21).

Finally, it is computed and written an output message to indicate to the user in which step of the process it is, see (23).

Results

In Petrophysics, assessment of formation permeability is a complex and challenging problem that plays a key role in reservoir forecasts and optimal reservoir management[XI]. In heterogeneous carbonate reservoirs, permeability evaluation is commonly performed using permeability-porosity relationships, which often seem to be nonlinear and complex.

Copulas are marginal-free dependence functions that may capture such nonlinear relationships. In the present work we make use of a nonparametric copula approach for bivariate and trivariate modelling of permeability, porosity, and VP Meas real data. A *2D* and *3D* copula function can reproduce complex joint distributions that others statistical techniques cannot, because in many cases these techniques are usually based on linear assumptions [XII].

Next it is presented a set of Petrophysical variables modeled by a *2D* copula model. In Figure 7 are plotted dataset values, *3* quantile Regressions (*0.1*, *0.5* and *0.9*) and *380* simulations. Note that Dataset values and simulated ones are enclosed in the regression bands (*quantile=0.1* and *0.9*), which, preliminary, it is a symptom of good estimation of the *2D* Bernstein Copula.

However, there are some points that are outside of these bands, the question is: How can we improve the estimation bands here?

Answers may appear like change the quantile estimation values or introducing more descriptive variables or take more values in the data set. In this work we will explore the use of more descriptive values and discuss about its convenience and inconvenience of its use.

Box 8

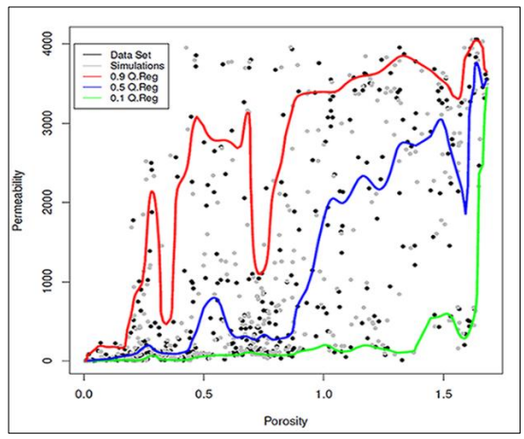

Figure 7

Quantile Regressions by 2D Copula model
Dataset, 3 quantile Regressions (0.1, 0.5 and 0.9) and 380 Simulations by Bernstein Copula 2D
This figure was made in R-project software

Figures 7 and 8 present distinct datasets. Figure 8 plots dataset values along with three quantile regressions (0.1, 0.5, and 0.9) and 380 simulations of the 3D Bernstein Copula. While both figures display similar data, it is evident that the values in Figure 8 are more effectively contained within the quantile regression bands. This indicates that incorporating an additional variable into the Bernstein Copula enhances its capacity to estimate or simulate values.

Box 9

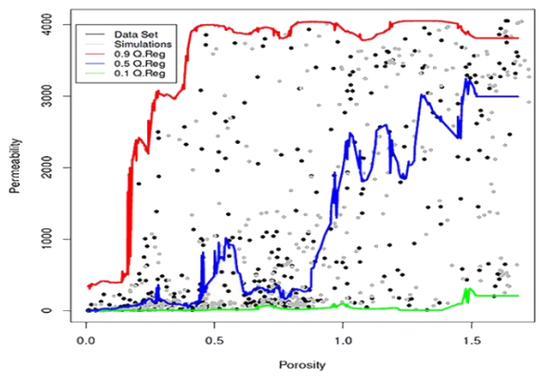

Figure 8

Quantile Regressions by 3D Copula model
Dataset, 3 quantile Regressions (0.1, 0.5 and 0.9) and 380 Simulations by 3D Bernstein Copula
This figure was made in R-project software

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Figure 9 displays 3,800 simulations of the same empirical dataset using a 2D Bernstein Copula. It is notable that many of the simulated values fall outside the regression bands, which is an expected outcome. In contrast, Figure 10 presents 3,800 simulations generated with a 3D Bernstein Copula. Here, the simulations are more effectively contained within the regression bands, consistently surrounding the true data values.

Box 10

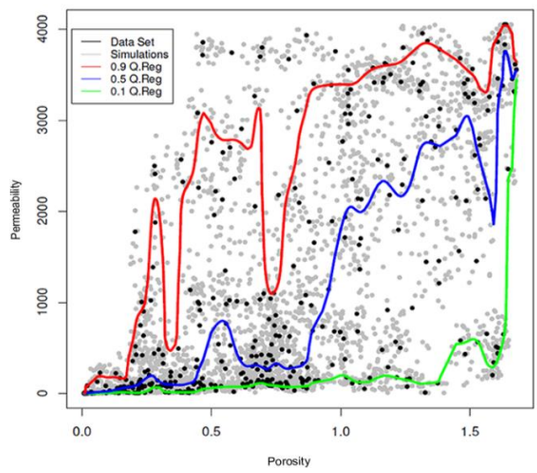

Figure 9

Ten 2D simulations scaled in size by a factor of 10.

Dataset, 3 Quantile Regressions and 3800 simulations by 2D Bernstein Copula. This figure was made in R-project software

This figure was made in R-project software

Box 11

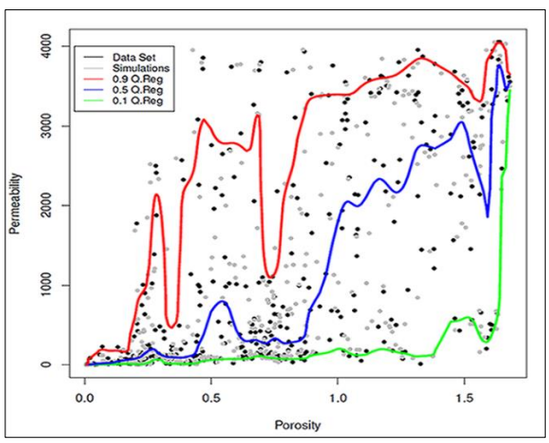

Figure 10

10 times simulation in size

Dataset, 3 Quantile Regressions and 3800 simulations by Bernstein Copula 3D

This figure was made in R-project software

Computing a multidimensional Bernstein Copula can end up in a very demanding task in computational terms, because the empirical copula has to be visited several times to generate a single result inside of the Bernstein copula, Considering the size of these matrices (the empirical copula and Bernstein copula), it is proposed to use parallel techniques. Here we use these techniques to implement more variables into the calculus.

It is used a current personal computer with Windows 10 Pro OS, with 8 processors in hardware and a speed of 2.7 GHz. It is decided to do so, because these kinds of computers are capable to perform this kind of tasks and they are also available for almost every person. In Figure 11 it is presented the performance of the computer when a multidimensional regression process is not run in parallel mode.

Note that it is not reached the full capacity of the computer, in fact, it is just used the 23\% of its capacity. In Figure 12 and Figure 13, things change drastically, it is performed the copula process in parallel mode and the speed and uses of the computer is used almost in its full capacity.

Box 12

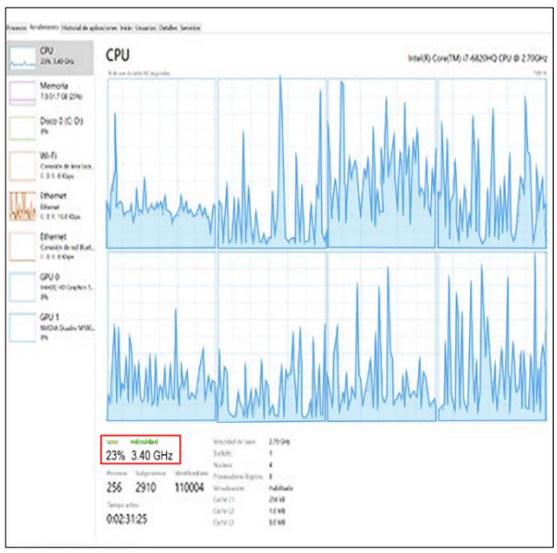

Figure 11

10 times simulation in size

Windows 10 Task Manager when Non Parallel process is performed of Bernstein copula either Regressions or Simulations

This figure is a Windows 10 Pro Task Manager Screenshot

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Box 13

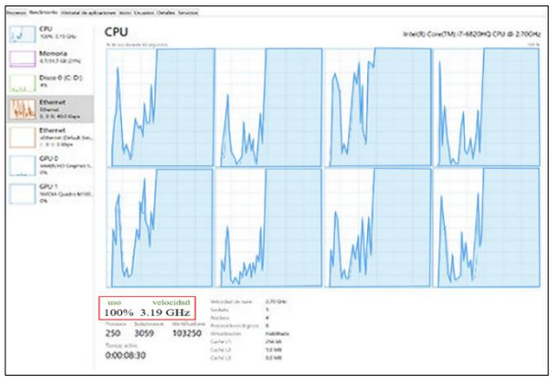

Figure 12

10 times simulation in size
Windows 10 Task Manager when Parallel process is performed of Bernstein copula either Regressions or Simulations.

This figure is a Windows 10 Pro Task Manager Screenshot

Box 14

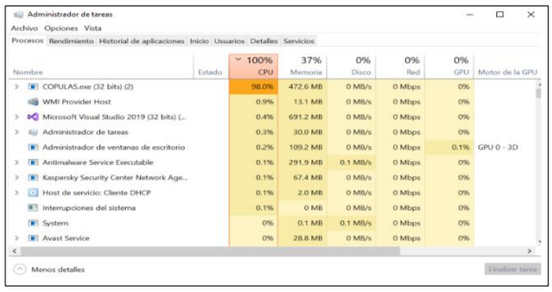

Figure 13

10 times simulation in size
Windows 10 Task Manager (List processes) when Parallel process is performed of Bernstein copula either Regressions or Simulations.

This figure is a Windows 10 Pro Task Manager Screenshot

It was asked a set of three quantile regressions (*0.1*, *0.5* and k) in nonparallel mode, the first one was performed in *1116.12* seconds (*18.60 minutes*), the second one (*quantile regression = 0.5)* was performed in *1842.80* seconds (*30.71 minutes*) and the third one (*quantile regression = 0.9*) was performed in *1862.98 seconds 31 minutes*.

Things changed substantially when parallel computing took place. As before, the total of calculations made for generate *2D* Empirical Copula was *216,410 calculations*, which they took *0.756 milliseconds*. By other side they were performed *73,087,401 calculations* for the *3D* empirical copula, which they took *5 milliseconds*.

The same sets of three quantile regressions (0.1, *0.5* and *0.9*) were performed. The first one was performed in *120* seconds (*2 minutes*), the second one (*quantile regression = 0.5*) was performed in *191* seconds (*~3 minutes*) and the third one (*quantile regression = 0.9*) was performed in *192* seconds (*~3 minutes*) and a final set of *380* simulations where performed it took *193* seconds (*~3 minutes*). In parallel mode, a total computing time was just of *8* minutes for the three regressions.

When comparing performance, the regression process in non-parallel mode required *4,821.9* seconds (*80 minutes, or 1 hour and 20 minutes*) to complete. In contrast, the same task executed in parallel mode took only *8 minutes—10 times faster*. Both tasks were conducted under identical computational conditions, highlighting the substantial efficiency gain achieved through parallel processing.

The difference between waiting *8 minutes* for results versus waiting *80 minutes* is significant, underscoring the practical advantages of parallelization, particularly in scenarios where timely analysis is critical. This performance enhancement not only saves time but also allows for more iterations and refinements within the same time frame, potentially leading to more accurate and robust outcomes.

A total of *3,800* simulations of the dataset were conducted under both conditions, i.e., in parallel and non-parallel modes. The non-parallel mode required *11,757.7* seconds (approximately three and a half hours) to complete the task, whereas the parallel mode completed the same task in *2,260.9* seconds (less than an hour).

Conclusions

The proposed method represents a highly versatile tool for modeling the intricate dependence relationships between petrophysical properties, such as porosity, VS Meas and permeability.

Unlike traditional approaches, such as linear regression, this method does not require the assumption of linear dependencies between variables. This flexibility allows for a more accurate and efficient modeling of multivariate dependencies, capturing the underlying complexities in a manner that linear models fail to achieve.

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In addition to its inherent flexibility, the application of parallel processing techniques in the construction of multidimensional Nonparametric Copulas further enhances the effectiveness of the proposed method. By incorporating empirical data directly into the dependence structure, these parallel techniques not only accelerate computational performance but also enrich the model's ability to capture subtle and complex dependencies among multiple variables.

As a result, the proposed method demonstrates a marked improvement in predictive accuracy and robustness, making it a compelling alternative to conventional modeling techniques in the study of petrophysical properties.

In other scenarios in the petroleum industry, Bernstein copulas have been applied to model nonlinear dependencies between fracture direction and length. Precise fracture network modeling is crucial for reservoir characterization, as fractures either obstruct or facilitate flow, making permeability estimation vital. Traditional linear statistical methods are insufficient for capturing these complex dependencies. [XIII].

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Appendix A

This appendix provides a selection of the most critical lines of C++ computational code that are essential for replicating the results presented in this study.

These code snippets are intended to assist the reader in integrating the methods into their own programs, thereby enabling them to achieve similar outcomes and validate the findings discussed in this paper.

$$double ** db\_copEmp2D = Copula\_2Da1D(Sample, Rows, Cols, 1,0) \quad (10)$$

$$arrData = SORT(arrData, Rows, Cols, VarToSort); \quad (11)$$

$$double^{**} copEmp2D = NULL; \quad (12)$$

$$\text{copemp2D[i]} = (\text{double}^{*})\text{malloc}((\text{Rows} + 1) * \text{sizeof(double)}); \quad (13)$$

$$for(inti = 0; i <= Rows; i + +)for(intj = 0; j <= Rows; j + +)\, copemp2D[i][j] = 0; \quad (14)$$

$$for(int\ j = 1; j <= Rows; j + +) \quad (15)$$

$$x = (int)\, arrData[j - 1][VarSec]; \quad (16)$$

$$\text{copemp2D[j][i]} = \text{copemp2D[j][i]} + (1.0/(\text{Rows})); \quad (17)$$

$$copemp2D[j + 1][i] = copemp2D[j][i]; \quad (18)$$

$$REGS=(double**)malloc((intRegNum)*sizeof(double)); \quad (19)$$

$$REGS[i]=(double*)malloc((Rows)*sizeof(double)); \quad (20)$$

$$parallelfor(size\_t(0),size,[\&](size\_t\ m) \quad (21)$$

$$REGS[i][m]=Regression(Sample[m][VS1\text{-}X], Sample[m][VS2\text{-}Y], quantil, SortedSamp, SV\ 1\text{-}X, SV\ 2\text{-}Y, PV\text{-}Z, dbCopEmp2Da1D, dbCopEmp3D\text{-}1D, Rows, 0.0001); \quad \{(22)\}\ (22)$$

Declarations

Conflict of interest

The authors hereby declare that there are no conflicts of interest associated with this work. They confirm that they have no known competing financial interests, affiliations, or personal relationships that could have influenced the research, interpretation, or conclusions presented in this article. The integrity and objectivity of the findings remain uncompromised by any external factors.

Author contribution

Erdely Arturo: Made a significant contribution to this article, particularly in the development and refinement of its theoretical aspects. His expertise and insights were instrumental in shaping the theoretical framework that underpins the research, and his involvement has greatly enhanced the overall quality and depth of the study

Diaz-Viera, Martin Alberto: Contribution was pivotal to this work, as he brings over 20 years of experience in the petroleum industry and spatial stochastic simulation. His insights carry significant weight and illuminate the path forward for the effective application of the tools proposed herein.

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Hernández-Maldonado Victor: Made a substantial contribution to this work through his complete implementation of the computational aspects. He was responsible for designing and proposing the entire architecture of the computational models used in this study. His expertise in computational modeling played a crucial role in the successful execution of the research.

Availability of data and materials

This article includes a subset of the data used in the study. However, it is important to note that the Petrophysical data referenced are confidential and cannot be fully disclosed.

The available data provided within the article are intended to support the key findings while respecting the confidentiality agreements associated with the Petrophysical data.

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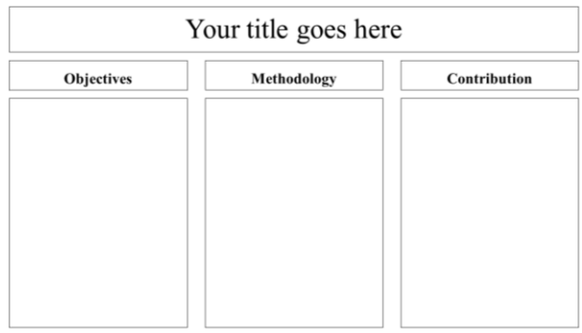

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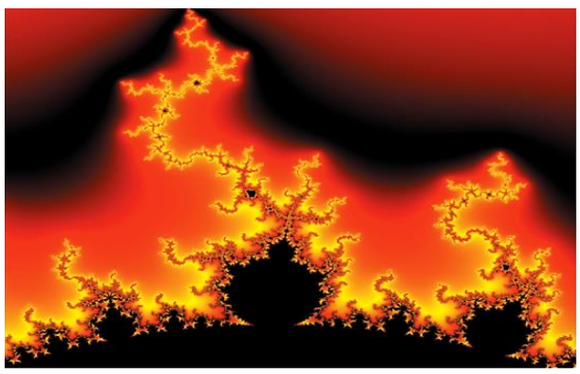

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