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ARTIFICIAL INTELLIGENCE AND ITS IMPACT ON INVENTORY MANAGEMENT IN THE SUPPLY CHAIN

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Tamayo Contreras Porfirio[1], Maldonado Alcaraz Saul[2] and Angel Gutierrez Rodriguez[3]

ABSTRACT
The use of systems and algorithms in a field of great relevance that is the supply chain is becoming more and more frequent, integrating a large amount of data (Big Data) that exists in cyberspace, which operated with artificial intelligence efficiently and effectively manage risks. The objective of this research is to determine how the use of machine learning, advanced optimization and the inclusion of algorithms, positively impacts inventory management, mainly in the reduction of stock and in the savings of internal or external storage within the supply chain. The warehouse management system method known under the acronym WMS (SAP WMS complex mode, 2024; SAP EWM, 2024). In a sample of 130 companies the auto parts industry located in Guanajuato. The results showed that the use of the artificial intelligence clustering algorithm generated a considerable improvement in both warehouse saturation by going from a utilization level of 68% to a maximum average utilization of 93%.

Keywords: Artificial Intelligence. Inventory Management. Supply Chain. SAP WMS.

[1] Department of Business Management and Management of the Division of Economic-Administrative Sciences of the University of Guanajuato
E-mail: aeinegocios1@gmail.com
[2] Universidad Iberoamericana Campus León
E-mail: saul.maldonado@pirelli.com
[3] Department of Business Management and Management of the Division of Economic-Administrative Sciences of the University of Guanajuato
E-mail: angel0@ugto.mx

INTRODUCTION

The evolution of industry and commerce over time has evolved, at its beginnings in a rhythmic way and later at a greater speed it has increased significantly, in the XXI century that began on January 1, 2001 and will end on December 31, 2100, it has reached exciting and unimaginable points. It is possible to note the increasingly frequent presence of systems and algorithms in a field of great relevance that is the supply chain, integrating a large amount of data *(Big Data)* that exists in cyberspace, which operated with artificial intelligence efficiently and effectively manage risks, reducing logistics costs and with extensive control (Chen, Mao, & Liu, 2014; Gandomi , & Haider, 2015; Kitchin, 2014; Manyika, Chui, Brown, Bughin, Dobbs, Roxburgh, & Byers, 2011; Mayer-Schönberger, & Cukier, 2013).

The essential ideas of what we currently know as artificial intelligence go back to the logic and algorithms of the Greeks, and to the mathematics of the Arabs, the concept of obtaining artificial reasoning appears in the fourteenth century and at the end of the nineteenth century sufficiently powerful formal logics are obtained, so that in the middle of the twentieth century, machines capable of solving problems are created through the advanced use of what began with philosophical reasoning of logic and Greek algorithms (Liu, Romera-Paredes, & Lehman, 2024; Mirrashid, & Naderpour, 2023; Vienna Center for Logic and Algorithms, 2024; Yannakakis, & Papadimitriou, 2023).

Artificial intelligence (AI) is defined as the ability of a machine or computer system to perform tasks that normally require human intelligence. This includes skills such as logical reasoning, learning, perception, problem-solving , natural language understanding, and decision-making (IBM, 2023; McKinsey & Company, 2023; Mirrashid, & Naderpour, 2023; SciELO Mexico, 2023). Here are some approaches to better understand AI:

- Technical definition: According to the academic field, AI is the field of computer science that seeks to develop systems capable of performing tasks that mimic human cognitive processes, such as machine learning and natural language processing.
- Functional definition: AI refers to any system that can interpret data, learn from it, and use that learning to achieve specific goals with adaptability. Popular definition: Often described as the ability of machines to "think" or "act" like humans, although in reality, AI works with data and mathematical models that optimize outcomes beyond traditional human reach.

Alan Turing, in his paper *"Computing Machinery and Intelligence,"* considered whether machines could think. In this article, Turing first coined the term artificial intelligence and presented it as a theoretical and philosophical concept (Amazon, 2022). This is how the concept of artificial intelligence has evolved in such a way that today it is used in many branches of industry in applications such as autonomous guided vehicles; artificial neural networks; autonomous learning; robotics; expertsystems; and natural language processing (The In sight Partners, 2023; Madrigal Marino, & Muñoz Ceballos, 2023; Mordor Intelligence, 2024; Redalyc, 2023).

Each of the applications of artificial intelligence (AI) focuses on various practical fields, among which is the supply chain, understanding it as the interconnected system of people, activities, technologies and resources that participate in the creation, production and delivery of goods and services from the initial supplier to the final consumer. It includes key processes such as planning, procurement, production, distribution, and returns management. Currently, digitalization and sustainability are essential components to optimize their management and improve resilience to external disruptions (Emprendedor Inteligente, 2024; KPMG, 2024; Maersk, 2024; Mercately, 2024).

In the supply chain, AI has benefited from the improvement of connection networks, generating new ways of solving problems, as well as optimizing the ability of machines to process information, perform tasks autonomously, and learn. That is why, when artificial intelligence is applied in the supply chain, it processes a large amount of data, improves logistics flow, as well as decision-making, and impacts the synergy of operations. And, above all, it helps reduce costs (BeeDIGITAL, 2023; The Logistics World, 2023; McKinsey & Company, 2023; MIT Technology Review, 2024; UnnOtec, 2024).

In the field of the supply chain, there is a common question that is asked repeatedly when talking about this topic: How can artificial intelligence help improve the supply chain? The most common answer, in a synthetic way, is that AI benefits the improvement in the efficiency and effectiveness of decision-making, reduction of logistics costs and increase in business profitability (Accenture, 2024; CargoON, 2024; Harvard Deusto, 2023; The Logistics World, 2024). There are several key factors that are involved in improving performance when it comes to mixing AI with the supply chain, some of them are:

- Process optimization: Artificial intelligence is designed to analyze large amounts of data and make decisions based on defined algorithms. This allows you to optimize supply chain processes such as demand planning, transportation route scheduling, inventory management, and warehouse management. By using AI, patterns, trends, and correlations can be identified in the data, leading to greater operational efficiency and cost savings.

- Demand forecasting: Analyzing data, historical, socioeconomic, political and market trends, AI is an excellent ally to more accurately manage production volumes and thus reduce storage costs by having the necessary volume that the market requires.
- Transportation optimization: at this point, artificial intelligence has the area where it is most easily developed, by taking as a base, traffic, fast routes, greater fuel economy, weather conditions, road safety among others, it can suggest effective transportation routes and thus be able to have a positive effect on customer satisfaction.
- Intelligent inventory management: By using artificial intelligence algorithms, storage, assortment, and stock management systems are implemented that maximize space and reduce the resources required, this directly affects the costs of handling and storing products.
- Mandatory maintenance: AI can monitor the health of supply chain assets, such as machinery and equipment, and predict failures or maintenance needs before they occur. This to generate proactive planning of maintenance activities, avoiding unplanned interruptions in the supply chain and reducing the costs associated with breakdowns and urgent repairs.

The use of AI algorithms in each of the factors mentioned above promotes savings in operating and administration costs in general, as well as reduction of management times for key tasks in organizations, which can be monitored at all times by data integration and decisions based on the emulation of rational human thinking.

The integration of artificial intelligence in the supply chain is giving way to the so-called Logistics 4.0 where automation, Big Data, virtual reality, autonomous learning, the Internet of Things, as well as the analysis of large amounts of data in real time are already integrated into the logistics cycle (Calatayud, & Katz, 2024). See Figure 1

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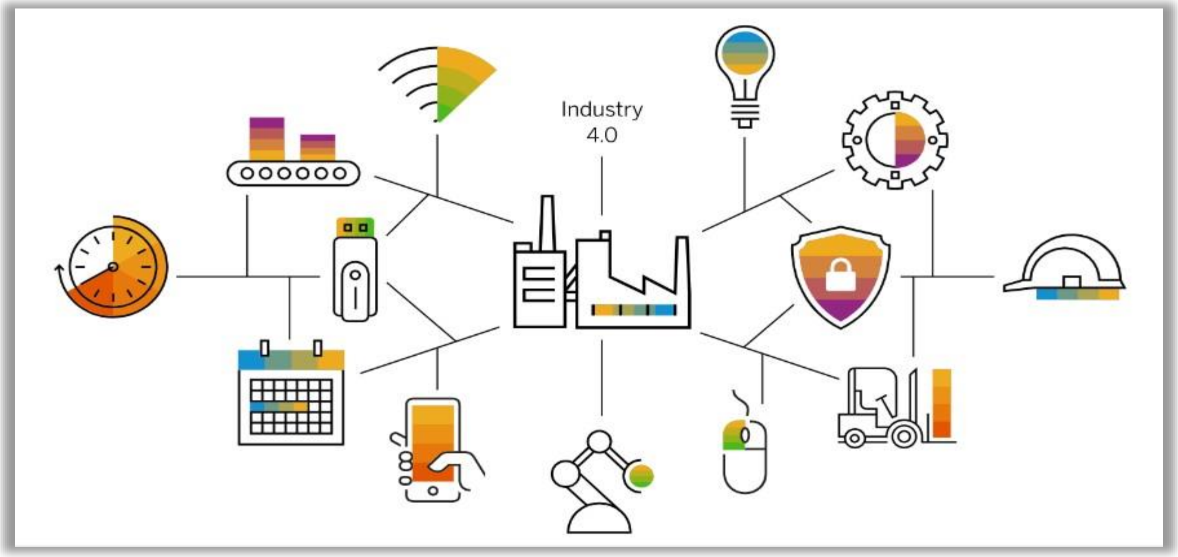
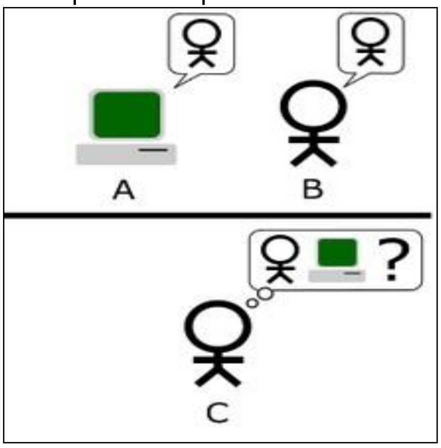
Figure 1. Industry 4.0 interaction scheme



Source: Calatayud, & Katz, 2024).

Turing, 1950 (cited by Aden, 2024, p 69) asked a question, *"Can machines think?"*, this questioning led him to develop in those years the famous *"Turing Test",* in which the interrogator called entity C, is given the task of determining which entity, with which a conversation is had through a screen and a keyboard (entity A or B) is a computer and which is a human being. Questioning is limited to using the answers to written questions to make the decision, making room for what is known as *Machine Learning* and *Deep Learning* see Figure 2.

Figure 2. Graphical interpretation of the Turing test.



Source: Aden, 2024

Machine Learning and *Deep Learning* are the two main artificial intelligence techniques currently in use. *Machine learning* is an application of artificial intelligence in which computer programs use algorithms to find patterns in data. They can do so without being specifically programmed to do so, without relying on humans. In today's world, machine learning algorithms are behind almost all technological advances and artificial intelligence applications on the market (Analytics Vidhya, 2024; Tecton, 2023).

Deep Learning is a complex part of *Machine Learning* where, through algorithms that imitate human perception inspired by the brain, the machine is sought to deepen its learning, identifying connections and, when necessary, modifying the input data to achieve the best possible results (Goldblum, Anandkumar, Baraniuk, & Wilson, 2023; Sainju, & Wang, 2023)

Both *Machine Learning* and *Deep Learning* have been a methodological support in the development of artificial intelligence and this in turn within the technology applied in the supply chain, as described by Zhang (2023) when he stated that intelligent logistics and the supply chain in the digital era is an understandable advance and of great transformation in the field of logistics due to the use of technology of information, with *Big Data, Machine Learning* and *Deep Learning,* this due to constant innovation and technological progress. Intelligent logistics management models have become a vital strategy for business competition.

Big Data and *Cloud Computing* are revolutionizing the field of the supply chain, allowing machines to connect to the internet through a heterogeneous system with the execution of wired or wireless connections, as well as through the use of wireless sensor networks (WSN) that are responsible for collecting thousands of data in real time to be able to analyze them and generate patterns of correct operation of machinery and/or logistics systems (He, H., Li, X., Chen, P., Chen, J., Liu, M., & Wu, L. , 2024; Techopedia, 2024).

Big Data and Artificial Intelligence can influence companies by guiding the customer experience, speed, and interconnectivity between customer, company and product, tend to analyze data management in software such as *Enterprise Resource Planning* (ERP), *Warehouse Management System* (WMS), *Business Intelligence* (BI), *Customer Relationship Management* (CRM), which are of great help to companies by being able to more effectively manage the large amount of data that is generated in all links of the logistics chain.

OBJECTIVE OF THE RESEARCH

To determine how the use of machine learning, advanced optimization and the inclusion of algorithms has a positive impact on inventory management, mainly in the reduction of stock and in the saving of internal or external storage within the supply chain. The hypotheses are as follows:

- H1: The implementation of artificial intelligence algorithms in inventory management reduces stock dispersion levels, making the use of storage space in the supply chain more efficient.
- H2: The implementation of artificial intelligence algorithms in inventory management has a positive impact on internal or external storage savings.

METHODOLOGY

The warehouse management system method known under the acronym WMS (SAP WMS complex mode, 2024: SAP Latam, 2024; SAP EWM, 2024). This system considers the following sections:

WMS SAP WAREHOUSE MANAGEMENT SYSTEM

SAP *WMS* is a software that helps companies manage and control the daily operations of warehouses, from the moment goods and materials enter a distribution center or warehouse, to the moment they leave and are delivered to different destinations, whether internal or external customers; this system displays historical data to improve management in real time, such as: inventory reporting; provides empty locations; stock management according to ABC parameters; and report on stock consumption.

In addition, with the integration of AI clustering algorithms, it proposes operational efficiencies that fall directly on better management of storage spaces. This tool was used to obtain data that do not help to test the H1 hypothesis.

WMS SAP COMPLEX MODE

WMS complex mode [20] is an advanced warehouse management tool in which, through previously defined saturation optimization algorithms, AI analyses can be generated to reduce inventory and labor costs, improve the use of space and storage and increase transparency in locations. This tool was used to obtain data and find the correlation in the H2 hypothesis.

This tool generates a great competitive advantage compared to the traditional SAP WMS, which only handles storage management, and locations defined with specific rules, while the *WMS complex mode* goes further, proposing internal movements of material to optimize resources, through real-time reports of the stock level.

According to the context of the WMS and its significance applied to the object of the research and the hypotheses raised, the Pearson correlation was also applied, being a statistical measure that evaluates the linear relationship between two quantitative variables. In other words, it determines whether there is an association between these variables and, if so, in what direction (positive or negative) and to what degree. This technique provides a correlation coefficient ranging from -1 to 1, where a value close to 1 indicates a perfect positive correlation, a value close to -1 indicates a perfect negative correlation, and a value close to 0 indicates a lack of correlation. The formula used for the formulation of the two hypotheses is as follows:

$$r_{xy} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Where:

- r_{xy} es el coeficiente de correlación de Pearson entre X e Y.
- X_i y Y_i son los valores individuales de las variables X e Y, respectivamente.
- $\bar{X}$ y $\bar{Y}$ son las medias de las variables X e Y, respectivamente.
- n es el número total de observaciones.

Pearson's correlation is widely used in scientific and social research to explore relationships between variables, identify patterns, and predict behaviors. In the present case study, the use of AI algorithms in warehouse management systems and storage-cost savings (X and Y variables) was used to examine the possible relationship, which allows us to understand the underlying dynamics between the research objective and the proposed hypotheses.

PARTICIPANTS

In the state of Guanajuato, the auto parts industry is highly developed, with approximately 157 companies dedicated to the production of auto parts according to 2024 data. These companies play a crucial role in the automotive sector, contributing 13.8% of the national production of auto parts and positioning Guanajuato as the second state with the highest contribution in this sector after Coahuila. In addition, Guanajuato is a leader in attracting investment in the automotive and auto parts industry, with companies that supply both the domestic market and the United States, the main export destination (Secretariat of Sustainable Economic Development of Guanajuato, 2024). Of these companies, 130 companies participated in the study, which represented a margin of error of 3.58%, with a confidence level of 95%. The participants were explained the objective of the research and its confidentiality.

RESULTS

For hypothesis H1, it was observed that the WMS SAP system logically defined which locations should be consolidated and which material movements should be proposed to the To obtain a gain of space and to be able to increase the saturation of the warehouse, thanks to the algorithms of grouping by AI, tables 1 and 2 show how the WMS SAP is formed, proposesimprovements in the grouping ofproducts.

The SAP WMS proposes two types of storage optimization: the first is aimed at moving material between two different locations with the same part number in order to generate a new empty location or more space in the location that can be used to store product, see table 1.

Table 1. SAP WMS Location Optimization Proposal Table (Bin to Bin) (n=130)

WMS: Warehouse optimization Proposal				
Storage Type	Storage Thousand	Material	Typology	Proposal
LC1	CF5-1	3828480	STOCK MOVING	You can move 9 pallets to bin LC1 5FA224 to get an EXTRA place ON THE BIN
LC1	6FL228	4243210	STOCK MOVING	You can move 9 pallets to bin LC1 4FX204 to get an EXTRA place ON THE BIN
LC1	3FN117	3917400	STOCK MOVING	You can move 9 pallets to bin LC1 3FP205 to get an EXTRA place ON THE BIN
LC1	6FH218	2709913	STOCK MOVING	You can move 8 pallets to bin LC1 6FL226 to get an EXTRA place ON THE BIN
LC1	6FG224	2711410	STOCK MOVING	You can move 8 pallets to bin LC1 6FL223 to get an EXTRA place ON THE BIN
LC1	6FF209	2347710	STOCK MOVING	You can move 8 pallets to bin LC1 6FD231 to get an EMPTY BIN
LC1	6FG213	2709913	STOCK MOVING	You can move 8 pallets to bin LC1 6FD115 to get an EXTRA place ON THE BIN
LC1	5FA217	3976610	STOCK MOVING	You can move 8 pallets to bin LC1 5FB227 to get an EXTRA place ON THE BIN
LC1	6FG113	4210310	STOCK MOVING	You can move 7 pallets to bin LC1 6FH111 to get an EXTRA place ON THE BIN
LC1	6FH211	2720010	STOCK MOVING	You can move 7 pallets to bin LC1 6FH106 to get an EXTRA place ON THE BIN
LC1	6FH213	3973510	STOCK MOVING	You can move 7 pallets to bin LC1 6FG212 to get an EMPTY BIN
LC1	6FG127	3973610	STOCK MOVING	You can move 7 pallets to bin LC1 6FG123 to get an EMPTY BIN
LC1	5FC212	2884910	STOCK MOVING	You can move 7 pallets to bin LC1 5FC208 to get an EXTRA place ON THE BIN
LC1	3FR123	2711200	STOCK MOVING	You can move 7 pallets to bin LC1 4FX202 to get an EXTRA place ON THE BIN
LC1	4FX204.	4243210	STOCK MOVING	You can move 6 pallets to bin LC1 6FL220 to get an EXTRA place ON THE BIN
LC1	6FF204	3572711	STOCK MOVING	You can move 6 pallets to bin LC1 6FL117 to get an EXTRA place ON THE BIN
LC1	CF6-22	3976210	STOCK MOVING	You can move 6 pallets to bin LC1 6FL116 to get an EXTRA place ON THE BIN
LC1	6FK229	2711210	STOCK MOVING	You can move 6 pallets to bin LC1 6FK227 to get an EXTRA place ON THE BIN

Source: Own elaboration based on WMS SAP, Storage Optimization Transaction

The second optimization method indicates the consolidation of two or more pallets in the same location to generate spaces that store the same part number in the same location, see table 2.

Table 2. Partial Optimization Proposal Table in SAP WMS Locations (Locations) (n=130)

WMS: Warehouse optimization Proposal				
Storage Type	Storage Thousand	Material	Typology	Proposal
LC1	3FP218	4258500	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	3FR112	4450900	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	3FR201	4111200	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	4FV119	2637600	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	4FV228	2154200	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	4FW208	4218300	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	4FW226	2154200	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	4FW227	3635300	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	5FB221	2751515	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	CF5-5	3373510	PALLET MERGING	There are 9 partial pallets on the bin. You can merge them.
LC1	3FN125	2745000	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	3FN225	4448100	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	3FN230	1555300	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	3FR104	3920900	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	3FR115	2707200	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	3FR222	3920800	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	3FR223	3789400	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.
LC1	4FW216	4333880	PALLET MERGING	There are 8 partial pallets on the bin. You can merge them.

Source: Authors' elaboration based on WMS SAP, Partial Optimization Transaction in Location.

To determine the correlation between the use of AI grouping algorithms and the percentage of saturation or storage efficiency by location within the warehouse, 20 locations were selected, of which the AI algorithm for X=0 grouping was not used in 10 of them, and in the remaining 10 if the movements proposed by the SAP WMS are carried out with the X=1 algorithm, resulting in the following data, see Table 3.

Table 3. Pearson correlation coefficient calculation on storage efficiency (n=130)

Pearson Correlation Coefficient Calculation		
Location	Implementation of AI algorithm (X)	% Efficiency of Storage (Y)
2FH202	1	96
2FH213	1	88
2FH226	0	65
2FH227	1	88
2FK101	0	70
2FM219	1	96
2FZ103	0	43
3FN101	0	80
3FP222	1	94
3FP226	1	91
3FP227	0	77
3FQ206	0	67
3FQ211	1	95
4FV205	0	59
4FV212	1	91
4FV227	0	69
4FW204	1	94
4FW206	0	72
4FW208	1	97
6FL102	0	81
	Pearson's correlation coefficient	0.84437
	% Average Saturation X=1 with algorithm	93
	% Average Saturation X=0 without algorithm	68

Source: Own elaboration

The result of Pearson's correlation was *rxy= 0.844, which indicates that there is a* moderately strong positive association, since in cases where the SAP WMS algorithm was used for location grouping, an average saturation of 93% was obtained compared to the locations where stock was managed without this algorithm. resulting in a saturation of 68%.

For the H2 hypothesis, the results in terms of average saturation obtained from table 3 were used as a basis, where X=1 had a space saturation percentage of 93 % and for X=0 obtained a space saturation percentage of 68%.

It is important to mention that the average optimal saturation of a storage area according to experts should be greater than or equal to 85%, which indicated that using the AI grouping algorithms proposed by the SAP WMS, a saturation above the industry standard can be achieved, which generated significant savings in the location where it was implemented. Table 4 shows the comparison of savings in USD/m2 obtained by using the grouping algorithm versus not using this algorithm in a 56,000 m2 tire warehouse.

Table 4. Comparative table of expenditure/savings in the use of AI algorithm (n= 130)

Comparative table of spending/savings in using AI algorithm to optimize storage					
Warehouse Type	% Efficiency of storage	Total m2 in warehouse	Extra-cost of storage USD/m22	Gain/ M2 Vs Standard Loss 85%	Spend/Saveo USD Vs Standard
With Use AI	93%	56,000	8.9	4,480	MX$39,872.00
No use of AI	68%	56,000	8.9	-9,520	-$84,728.00
Standard in industry	85%	56,000	8.9	0	$0.00

Source: Own elaboration

It was observed that using clustering AI algorithms for a 56,000 m2 warehouse can obtain an average savings of $84,728 USD/month.

CONCLUSIONS

The results showed in both hypotheses that the use of the artificial intelligence clustering algorithm generated a considerable improvement in both warehouse saturation by going from a utilization level of 68% to a maximum average utilization of 93%, which indicates a gain of around 25%; This resulted in better optimization of storage space and zero requirement for external storage space.

It was also observed that, when applying these saturation optimization algorithms, the savings in terms of dollars per surplus square meter were in the order of

$84,728 USD per month, this is the amount of resource that should be allocated if the warehouse even with a low saturation trend in the order of 68%.

The use of artificial intelligence in the optimization of storage spaces offers a number of significant benefits. First, AI enables more efficient and accurate inventory management, resulting in reduced costs and improved utilization of available space. In addition, using advanced AI algorithms, it is possible to analyze large volumes of data in real-time to identify patterns and trends, making it easier to make informed decisions about the arrangement and distribution of products in the warehouse. This predictive analytics capability contributes to more effective demand planning and supply chain optimization. Similarly, by using machine learning techniques, AI can continuously adapt and improve based on changes in the operating environment and business needs.

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