

ORIGINAL RESEARCH ARTICLE

Opportunities for the digital transformation of the banana sector supply chain based on software with artificial intelligence

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ABSTRACT

Artificial intelligence offers great opportunities for the supply chain, being this a competitive advantage for today's changing market. This article aims to identify the impacts and opportunities that artificial intelligence software can offer to facilitate the operation and improve the performance of the supply chain in the banana sector in Colombia. The work methodology consists of six steps in which a total of 72 investigations were obtained. The sources of information were four databases. As a main conclusion, the supply chain of the banana sector has everything necessary for intelligent software based solutions to be implemented in order to achieve adaptation, flexibility and sensitivity to the context and domain of execution.

Keywords: software; artificial intelligence; banana sector; supply chain; digital transformation

1. Introduction

Supply chain management is key to the success of companies and the economy in general; having precision in decision making offers an important competitive advantage. However, there are many internal and external factors that affect the performance of the supply chain^[1]. The agricultural sector, especially the banana sector, is significant for the national economy and is not exempt from internal and external factors that limit the performance of its supply chain^[2]. In recent years it has been shown that Artificial Intelligence (AI), supports human capacity, allowing an improvement that had not been considered possible, thus helping mankind to potentialize

strategies and creativity in companies to achieve a significant economic growth where it is applied.

Nasiri et al.^[3] state that the supply chain and its digital transformation can be positively impacted with the use of AI techniques in their solutions, in aspects such as: business integration, cost reduction, time optimization, resources, among many uses, allowing to visualize how supply chains should be digitally transformed. Integrating the supply chain with AI techniques, envisions opportunities for the banana sector. It should also be noted that the supply chain depends on the very details associated with the products it controls.

Due to the importance of these areas, a sys-

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tematic review of the use of AI techniques in supply chains has been carried out.

Wu et al.^[4] define research trends that still have great potential for use in the banana supply chain. These trends are oriented to: implementation of intelligent analysis from large volumes of data, software systems adaptive to the context and environment, task automation and decision logic and information integration. For their part Zhao, Ji and Feng in^[5] conclude challenges for the generalized supply chain, such as: Cost reduction, risk management, customer reliability, adaptation to globalization and visibility.

This paper proposes a comprehensive review of AI techniques and their applications in the banana supply chain, in order to identify opportunities and improvements within the associated processes, as well as in the reasoning, adaptation and reaction mechanisms.

This article also presents the work methodology used to perform the systematic review of articles of interest, which consists of six steps to follow and in each of them seeks to ensure order and control to achieve reliable results that validate the possible answers to questions such as What are the main impacts generated by software with artificial intelligence in the supply chain of the banana sector in Colombia? Does the software based on artificial intelligence provides opportunities for digital transformation to the supply chain of the banana sector in Colombia?

The search conditions are focused on the following filters: Titles, abstracts and keywords, in a time interval of five years between 2015 and 2020, in open content articles and in Spanish and English languages. From this, a compilation of the authors' contributions to supply chain management in supply chain transformation was made.

The rest of the article is structured as follows: Section 2 presents the conceptual framework that

supports the review, followed in Section 3 by the working methodology defined and the findings of the review. Section 4 presents the analysis of the impacts of AI techniques with respect to supply chains, and finally, Section 6 consolidates the information on digital transformation with respect to the impacts analyzed.

2. Conceptual framework

This section presents the concepts related to the proposed topic, where the reader is contextualized in: the banana sector in Colombia, intelligent supply chain, artificial intelligence, expert systems, fuzzy logic, genetic algorithms, neural networks, intelligent agents and software, and digital transformation of the supply chain.

2.1. Banana sector in Colombia

The banana sector in Colombia is significant for the national and regional economy, the main production and commercialization area is located in the Urabá Antioqueno one of the most important productive nuclei is in the municipalities Apartadó, Turbo and Chigorodó with a production of 1,246,209 Ton.

In 2018 about 100,491,531 boxes of bananas were produced in Colombia, 2,472,738 more than in 2017, the main consumer is the European Union who receives 82% of exports and the United States 13% the banana sector generates 1.5% of the agricultural GDP^[6,7].

The supply chain of the main banana companies is composed of suppliers, farms, transporters, distributors, supermarkets and end consumers, in these interactions there are many challenges associated with the management of the supply chain, one of them is the need to have trust between the parties involved, improve the speed of communication, create bonds of trust, have transparent transactions and have traceability in all operations necessary to

reach the end user.

2.2. Intelligent supply chains

The traditional supply chain is characterized by physical flows that move products, money and information between all those involved, from raw materials to the delivery to the satisfaction of a consumer's requests^[8].

The concept of smart supply chain varies and there is still no academic consensus on the definition, as for example in^[5] propose that the smart supply chain is an integrated system built within and between companies to combine management systems and modern information technologies for the intellectualization, digitization, networking and automation of the supply chain.

A smart supply chain manages its own with a wide variety of innovative technologies, e.g. unmanned aerial vehicles, cloud computing and internet of things, among others^[6].

2.3. Artificial intelligence

Artificial intelligence (AI) is the area of study that makes use of computational models to enable machines to perform tasks that are currently performed better by humans^[7]. These tasks are mainly oriented to solve problems related to: reasoning, perception, communication, learning, optimization, acting on environments, artificial vision, planning and decision making.

An AI technique is seen as a method that uses knowledge represented in such a way that it represents generalizations, is understandable, modifiable and usable^[8]. AI techniques have been used according to the nature of the problem, i.e., those designed for learning should be used for problems with similar characteristics.

The best-known AI techniques are: fuzzy logic, rule-based expert systems, genetic algorithms, artificial neural networks, intelligent agents, computer

vision, planning, among others. However, the techniques can be combined, which is known as hybrid techniques^[9]. The classification of the techniques has a much wider range, for the purposes of this article, we consider those techniques of greater relevance identified in the study of the problem, however, there are other techniques such as: artificial vision, planning, natural language processing, intelligent data networks, among others.

Expert systems (ES) are systems based on production rules, which allow reasoning similar to that of a human being^[10]. They are characterized by high performance, reliability and fast response time; however, their weakness is the complexity of their maintenance, since changes in their knowledge base cannot be made dynamically. Expert systems are a useful tool in the area of knowledge engineering, precisely because they are oriented to the design and construction of rules and knowledge bases that facilitate intelligent reasoning. They are also appropriate to complement other techniques such as neural networks.

Fuzzy logic (DL) is a technique associated with approximate reasoning, where an element can belong to one or several sets at different levels of membership. Fuzzy logic allows the construction of "vague" concepts and therefore facilitates the construction of systems that reason differently from Boolean logic^[11]. ML, like SEs, are mature techniques that have already been applied to household appliances such as washing machines, air conditioners and children's toys.

Genetic algorithms (GA) is a technique associated with automation problems, which seek to improve solutions based on the maximization of objective functions^[12]. GAs belongs to the area of evolutionary computation, which is oriented to the design of algorithms that take advantage of evolutionary theories, such as natural selection, reproduction and mutation of individuals within a population.

Machine learning techniques include artificial neural networks, support vector machines, clustering, among others^[13]. These techniques are characterized by working with data sets, in order to predict, classify, group or compare them. Based on learning techniques, recommendation or prediction systems can be implemented, appropriate for different domains.

Intelligent agents are techniques typical of distributed environments, considered as the main technique within distributed artificial intelligence. They are known as software components capable of performing autonomous tasks in an environment in order to achieve an objective^[14]. The agents work together with other agents and form what are known as multi-agent systems (MAS), where the capacity for communication, perception, coordination and negotiation is enhanced.

The AI techniques described do not represent all of them, as there are a larger number associated with specific problems, such as artificial vision, natural language processing or planning. It should be noted that the techniques selected in this article are those that were identified as fashionable in the study and analysis of the problem.

2.4. Digital transformation in supply chains

The global systemic integration of the supply chain identifies four transformation requirements for digital business ecosystems, which constitute a basis for the development of business and innovation^[15] and which adopt digital transformation requirements based on disruptive technology for the supply chain, such as artificial intelligence, expert systems, fuzzy logic, genetic algorithms, neural networks, agents and intelligent software.

Digital transformation within supply chains seeks to enhance the technological systems that support it. Whether it is production costs, machinery and materials expenditure or data management. In addition, it is possible to integrate cyber-physical

systems that allow interaction with the environment and thus aim to achieve sustainable agriculture^[16].

The use of clean technologies without major impact on the environment is a characteristic of the digital transformation within the chains. Thus, agriculture 4.0 arises from the need to strengthen and adapt the fundamentals of industry 4.0 in agricultural production chains^[17].

Digital transformation in the supply chain is an open area for research, due to its ability to be coupled with other technological trends. As an example, works such as Ehie and Ferreira^[8], show how the digitization of supply chain processes influences the capabilities and operational performance, focused on building frameworks within the area of transformation, to plan, design, build and distribute products within the supply chain.

3. Methodology of work

The methodology consists of six steps, each of which seeks to ensure order and control in order to achieve reliable results that validate the proposed discussion.

3.1. Definition of research questions

The collection of information was designed based on the following research questions:

Question 1: What are the main impacts generated by software with artificial intelligence in the supply chain of the Colombian banana sector?

Question 2: Does software with artificial intelligence strengthen the supply chain of the Colombian banana sector in the face of critical change in the environment?

3.2. Definition of the search strategy

The following conditions were defined for the search:

The search fields used were: Title, abstract and key words.

The time interval was 5 years, i.e., articles from 2015 to 2020.

The type of articles was open content (open access).

Only full journal articles and conference proceedings were consulted.

The search criteria are related as follows: “Digital Supply chain AND Intelligent Software”, “Supply Chain AND Artificial Intelligence”, “Supply Chain AND genetic algorithm”, “Supply Chain and Neural Networks”, “supply chain and intelligent agents”.

ply chain AND genetic algorithm”, “Supply chain AND intelligent agents” and “Supply chain AND Neural Networks”.

The selected databases were: Science Direct, Scopus, IEEE Explore, Proquest.

4. Report of findings

Once the search strategy was applied to the defined sources, a total of 1530 articles were found. From this initial record, 103 articles were selected for further analysis (**Table 1**).

Table 1. Consolidated initial registry

Search criteria	Found	Selected	English	Citations
Digital Supply chain AND Intelligent Software	317	20	20	333
Supply Chain AND Artificial Intelligence	148	14	14	281
Supply Chain AND genetic algorithm	501	47	47	483
Supply Chain and Neural Networks	391	5	5	30
supply chain and intelligent agents	163	7	7	28
Total consulted	1,530	103		1,125
Final filter		72		

It can also be seen that genetic algorithms are one of the techniques with the greatest number of applications. This phenomenon may occur because supply chains are susceptible to improvements through optimization techniques, either to reduce costs or increase production.

After reading the summaries and eliminating duplicate articles that were found in one or more criteria, a total of 72 articles were found, which were

used to extract information and the corresponding discussion. Based on the above, **Figure 1** shows the behavior of the selected publications by year. A growth is observed in the last 2 years, which is supposed to be due to the rise of Industry 4.0 technologies and their possible application in the supply chain. In total, in the period of 2018 and 2019 we have approximately 48% of the total number of articles.

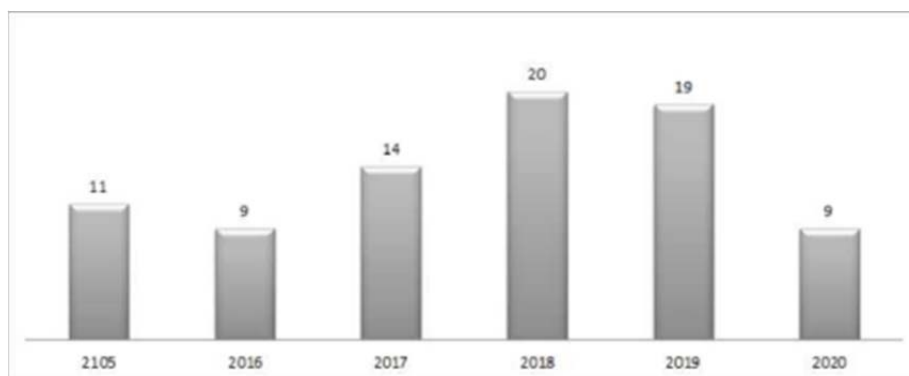


Figure 1. Articles distributed by year.

Figure 2 shows the relevance of the solutions from the point of view of the sum of citations of the articles in each of the search criteria used. Once again, the GAs present significant data, since the

technologies and solutions within the supply chain are currently only focused on improving time and costs.

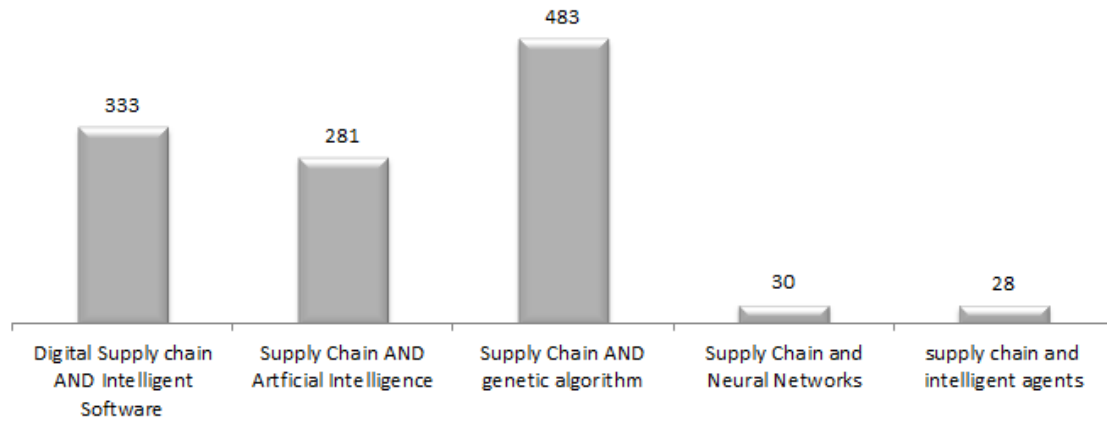


Figure 2. Citations by topic.

4.1. Description of AI impacts

This section presents the analysis of the selected articles, discussing the impacts of each of the techniques with their application in supply chain solutions, mentioning the areas in which each AI technique previously mentioned contributes.

4.2. Genetic algorithms

One of the main areas in which GAs have an impact on the supply chain is the optimization of production and resource use; in reference 18^[18], a solution based on GAs is proposed that allows optimizing production levels in a multiple cycle chain. Similarly, in reference 19^[19] and reference 20^[20], they plan network models to improve performance in the production of multiple products.

Similarly, there is research aimed at reducing the generation of waste materials in supply chains, whether in the food sector^[21] or the construction sector^[22]. Research is also focused on improving the sustainability of supply chains, for example, by measuring and reducing the carbon footprint generated^[23]. Other studies have focused on production optimization, on specific problems such as scheduling and allocation of dispatch shifts at docks^[24], on

cargo planning systems^[25] and on improving distribution mechanisms in warehouse systems^[26].

In supply chains, GAs have been working hard in the area of routing problems; such is the case of research^[27–29] that proposes internal route optimization systems for the location and loading of products stored in warehouses, allowing the use of different types of vehicles according to the context, which lead to cost reduction and service improvement. Proposals have also been made to improve the delivery and collection of products, optimizing the allocation of vehicles according to the place of residence of customers^[30–32] and the scheduling of shipments according to orders^[33–35].

Another representative area of GA impact is the design and modeling of supply chains. For example, in cost minimization^[36], the design of production sequences in closed-loop environments^[37–40] and flow design with varying intervals^[41]. An approach with great potential within design and modeling is the construction of integration networks between supply chains^[42–44].

Last but not least, GA contributions are presented in the area of warehousing and inventory management^[45–51] and in the area of supplier selec-

tion and evaluation with respect to variable demand^[52–57].

4.3. Intelligent agents

Considering that intelligent agents are software components that allow the perception and action on an environment, as well as the coordination, collaboration, negotiation and integration of information when agent-based systems are built, interesting contributions are presented in the supply chain.

In reference 58^[58], they propose a system of perception and reasoning about a supply chain that can be served by an agent and its perception; likewise, in reference 12^[12], they propose an agent-based approach for the distribution and reasoning of functions.

It is important to point out that another strength of the agents is the capacity to structure multi-agent systems (SMA), where coordination and negotiation are strengthened. In reference 59 to 61^[59–61], they present solutions based on SMAs where it is possible to negotiate on policies to complement production and logistics processes; they also allow this exchange to generate learning data with which it is possible to implement prediction methods. Likewise, SMAs encourage cooperation between agents in order to achieve common objectives^[62]. In addition, due to their ability to interact, perceive and act on the environment, SMAs are a useful tool for tracking, monitoring and securing supply chain flows^[63, 64].

4.4. Artificial neural networks

ANNs are artificial intelligence techniques designed to solve problems associated with learning capabilities. An intelligent system that is capable of learning can be tuned to perform classification, regression, clustering or adjustment tasks, which allow prediction, diagnosis or recommendation. Thus, supply chains present interesting challenges for ANNs, such is the case of^[65] that propose a con-

sumer demand prediction model for the definition of appropriate strategies, using perceptron-type network architecture. Likewise, in reference 66^[66], they present the main strengths of ANNs for recommending suppliers and use of resources within supply chains. In reference 67^[67], ANNs are applied to the design of prediction and monitoring systems that allow the construction of warning mechanisms.

A correct selection and classification of the resources used in logistics processes are of vital importance when measuring the performance of supply chains, and reference 68^[68] states that ANNs are appropriate for the selection of suppliers according to a set of historical compliance data. Likewise, it is possible to achieve an evaluation of suppliers using learning data that allow correct decision making^[69–71] and grouping of suppliers by means of pattern identification^[72, 73].

4.5. Reasoning systems and fuzzy logic

Supply chains are structured on the basis of various processes that are susceptible to improvement, optimization or information management. With the information it is possible to make reasoning rules and take advantage of basic techniques such as expert systems and fuzzy logic. An example of the above is the work done, which risks to which the design of a new supply chain is subjected.

Fuzzy logic with its ability to evaluate elements based on their degree of membership, achieves that an individual belongs to 1 or more sets, thus the outputs of fuzzy control systems are characterized by being more accurate than other AI techniques. Based on the above, they present a solution that allows reasoning related to the level of customer satisfaction. Likewise, they propose a solution for the design of supply chain networks in the context of complex and uncertain environments.

Decision-making is no stranger to the impacts of fuzzy logic; this is evidenced in works, which proposes a model that supports decisions in negoti-

ations, allowing greater precision in the evaluation of the negotiation. They propose a fuzzy control system that allows an appropriate selection of suppliers under uncertainty in circular supply chains. Also in^[22] they present a predictive model that employs adaptive fuzzy logic for the improvement of the use of resources within the supply chain, such as the use of water, construction tools and materials.

5. Opportunities in the digital transformation of supply chains

This section analyzes the information gathered; initially, the findings are presented from the point of view of the opportunities that can be highlighted within supply chains. This is followed by a discus-

sion in the light of the research questions posed for this study.

5.1. Analysis of findings

The approach to supply chain transformation, as perceived from the perspective of the opportunities and the authors' vision, is presented in **Table 2** below. This table integrates the information taking into account the current requirements of the different business stakeholders and the results of the related system.

As shown in **Table 2**, AI impacts warehousing management, inventory management, demand forecasting, integrated supply chain management, supplier management and distribution management.

Table 2. Opportunities for Digital Transformation of the Supply Chain with AI

Process	AI Techniques	Opportunity
Soulcenation Management	Genetic Algorithms	-Optimization of storage search capacity.
	Genetic Algorithms	-Optimization in the selection and assignment of dispatch operators in uncertainty environments.
	Intelligent agents	-Cost reduction. -Improvement of the average service level.
Inventory management	Genetic Algorithms	-Control for availability. -Efficient location. -Supply chain modeling.
	Neural Networks	-Inventory integration. -Tracking of process variability.
	Intelligent agents	-Demand forecasting. -Demand forecasting to reduce the whiplash effect. -Improved decision-making process.
Demand / forecasting	Machine learning	-Context-based data analysis. -Demand prediction from classification and clustering data.
	Neural Networks.	-Risk factor analysis.
	Intelligent agents	-Integration of supply chains. -Use of shared vocabularies. -Minimization of delivery times and production costs. -Production scheduling. -Tracking and provision of information. -Collaborative negotiation.

Table 2. Continued.

Process	AI Techniques	Opportunity
Supplier management	Fuzzy Logic	-Improving the use of resources within the supply chain. -Network design in the context of complex and uncertain environments. -Improved negotiation and collaboration.
	Neural Networks	-Reduction of subjectivity in the supplier selection process. -Improved work efficiency.
	Intelligent Agents	-Improved retail supplier performance.
	Genetic Algorithms	-Optimization of costs in supplier selection and evaluation.
Distribution Management	Genetic Algorithms	-Improving distribution stability through early warning risk modeling. -Cost optimization through agent collaboration, cooperation and negotiation.
	Intelligent Agents	-Minimize delivery times and production costs.
	Fuzzy Logic	-Improve customer service level through fuzzy logic-based model for reasoning.

5.2. Discussion of identified opportunities

Based on the information collected and the analysis and consolidation of the information, the following is a response to each of the research questions posed (see section 3.1).

Question 1: What are the main impacts generated by software with artificial intelligence in the supply chain of the banana sector in Colombia?

Answer: The main impacts that are generated in the supply chains of the banana sector and that can be exploited by professionals in the sector are:

Impact 1: Optimization in storage management: The banana industry depends particularly carefully on storage times. Depending on the context, type of product and context, changes in times can ostensibly affect the quality of the products; with intelligent systems based on genetic algorithms or neural networks, these times can be optimized or predicted in an appropriate manner.

Impact 2: Improved demand prediction: Intelligent systems especially artificial neural networks, facilitates decision making in banana marketing improves, since, data from populations and customers can be taken into account, in order to consider changes in the environment and thus be prepared.

Impact 3: Intelligent inventory management support: Intelligent agents, neural networks and genetic agents, allow optimization in inventory management, as they guarantee to maintain adequate inventories with respect to demand and significant improvement in costs and service level.

Impact 4: Supplier management: Through neural networks, fuzzy logic, intelligent agents and genetic algorithms, the subjectivity of the evaluation of supplier selection, evaluation and identification processes is reduced, likewise improving work efficiency in environments with uncertainty.

Impact 5: Intelligent methods for distribution: Early warnings of risk in distribution, generates stability in distribution environments from cooperation, collaboration and negotiation, minimizes delivery times and transportation costs, through solutions such as fuzzy logic and intelligent algorithms.

Question 2: Does software with artificial intelligence strengthen the supply chain in the face of critical change in the environment?

Answer: Artificial intelligence offers great opportunities for supply chains, which can be realized in methods that facilitate early risk identification, adaptation, flexibility and sensitivity to the supply chain execution context. However, progress must be made and lines of work must be defined in

which the following aspects can be addressed:

Definition of methods for the identification, analysis, design and validation of supply chain flows, taking into account information from the environment and the execution context.

Design of communication and information and knowledge exchange protocols that enable integration between supply chains.

Design logistics processes that allow the collection, processing, storage and distribution of information that facilitate learning from data for the construction of prediction and recommendation systems.

Construction of domain ontologies for the banana sector that facilitate the exchange of knowledge and in turn support the construction of intelligent reasoning mechanisms based on semantics.

6. Conclusions

Optimization in supply chain management becomes a competitive advantage, which software based on AI techniques offers. AI supports human decisions and potentiates the results quickly required in the face of changes in demand and the environment, thus assessing risk factors in the supply chain, improving communication, improving the prediction of forecasts, and improving the selection and evaluation of suppliers under high uncertainty.

This literature review identifies the main contributions of AI in the supply chain, from which an analysis is made of the impacts reflected in opportunities for the banana sector in Colombia. These impacts focus on opportunities in the following verbs: prediction, recommendation, selection and optimization.

In particular, an area that has great potential is the representation based on context and semantics, as research such as intelligent agents allow them.

Such representation will facilitate the integration of different supply chains, where it will be possible to support each other and exchange information that will lead to flexibility and adaptation to the changes of today's world.

Conflict of interest

The author declares no conflict of interest.

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