Artificial Intelligence in SC Operations Planning: Collaboration and Digital Perspectives

María Ángeles Rodríguez[1], MME Alemany[1], Andrés Boza[1], Llanos Cuenca[1], Ángel Ortiz[1]

[1] Research Centre on Production Management and Engineering (CIGIP), Universitat Politècnica de València, Camino de Vera S/N, 46002 València, Spain
{marodsa4, mareva, aboza, llcuenca, aortiz}@cigip.upv.es

Abstract. Digital transformation provide supply chains (SCs) with extensive accurate data that should be combined with analytical techniques to improve their management. Among these techniques Artificial Intelligence (AI) has proved their suitability, memory and ability to manage uncertain and constantly changing information. Despite the fact that a number of AI literature reviews exist, no comprehensive review of reviews for the SC operations planning has yet been conducted. This paper aims to provide a comprehensive review of AI literature reviews in a structured manner to gain insights into their evolution in incorporating new ICTs and collaboration. Results show that hybrization man-machine and collaboration and ethical aspects are understudied.

Keywords: Artificial Intelligence, Supply Chain Operations Planning, Hybridization, Industry 4.0, Big Data, Internet of Things, Blockchain

1 Introduction

The digital transformation has driven hyper-connected organizations. An example of this is Industry 4.0, which represents a concept of intelligent manufacturing networks in which machines and products interact with each other without human control. In this context, the new Information and Communication Technologies (ICT) such as Radio Frequency Identification (RFID), Blockchain or Internet of Things (IoT), allow to obtain accurate data in real time. This abundance of data together with the analytical capabilities of techniques such as Big Data Analytics (BDA), Artificial Intelligence (AI) or Operational Research (OR) allow combine multiple independent data analysis models, historical data repositories and real-time data flows, enabling a more intelligent management of supply chains (SCs) including smarter planning and operational decisions.

Since Supply Chain Management (SCM) requires the comprehension of complex and interrelated decision-making processes [1], their integration with the above technologies can improve their efficiency, sustainability, flexibility, agility, robustness and resilience. The SC operations planning is crucial for this. However, the increasing uncertainty and the dynamic environment make the synchronized planning necessary. Synchronized planning describes a state in which a constant flow of data from the supply network enables organizations to accurately plan production to match the actual demand. But this new paradigm of SC planning will require transforming data, facilitating real-time decision making using online data, automating decision making and making it smarter, not only for pre-programmed decisions but also with some learning capability. These necessary capabilities can be achieved using techniques that fall within the broad spectrum of AI [2].

Because of the great number of AI applications, the main objective of this paper is to conduct a comprehensive review of literature reviews: i.e. analyse in a structured manner previous reviews in the AI field applied to SC operations planning. Different reviews exist on the topic that either exclusively focus on SC planning or address a broader perspective of SCM dealing with SC planning jointly with other SC decision making processes. However, we have not found any review of reviews that is the scope of this paper and, even less, none review that consider all the structural dimensions of our analysis. These dimensions are defined with the aim of answering the following research questions (RQs):

- **RQ1**. What have been the interest for revising AI applied to SC operations planning over the past two decades and from which perspectives?
- **RQ2**. To what extent has the AI research addressed the SC operations planning alone or jointly with other SC processes taking into account some type of integration or collaboration?
- **RQ3**. What are the most studied AI methods alone or jointly with other techniques and new ICTs (hybridization)?
- **RQ4**. What are the main future research lines identified by existing literature reviews?

To answer these RQs, this paper has been organized as follows. The Section 2 describes relevant AI techniques for the purpose of this paper. In Section 3, the research methodology followed for the literature review is presented. In Section 4, the structural dimensions used for the review are described, meanwhile in Section 5 the material evaluation is made based on these structural dimensions. Finally, in Section 6 the conclusions and suggestions for future reviews are made.

2 Artificial Intelligence (AI)

There is no commonly accepted definition of AI [3]. In 1956, the father of AI, Dr. Marvin L. Minsky, defined it as "*the science of making machines do things that would require intelligence if done by men*" [4], emphasizing that machines would have reasoning processes like humans. In 1982, the father of Expert Systems Dr. Edward Feigenbaum described AI as "*AI is the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics one associate with intelligence in human behavior*" [5], concretizing the field of science that must be dedicated to developed it, the computer science. Nowadays, the High-Level Expert Group on Artificial Intelligence by European Commission proposes this updated definition: "*AI refers to systems that display intelligent behaviors by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals*" [6]. This improved definition adds new components such as the analysis of the environment and the action on it, no longer considers it an isolated system, now it must interact with its environment.

Since the beginning of AI in 1956, researchers from many disciplines contributed to build this field of knowledge. For this reason, AI must be understood from a multidisciplinary perspective. This has originated the definition of different AI branches depending on their development discipline. The most relevant branches for the purpose of this paper are the following:

- ***Expert Systems (ES)*** contains techniques that simulate knowledge of decision-making human to solve complex problems.
- ***Machine Learning (ML)*** is based on techniques that learn from the input data. Several types of learning can be distinguished [7]: Supervised Learning, when both input and output data are known; Unsupervised Learning, when only the input data is known; and Reinforcement Learning, when learn from the output data whether it has been a success or a failure.
- ***Multi-Agent Systems (MAS)*** use a multiple interact intelligent agents. An intelligent agent perceives its environment and acts.
- ***Neural Networks (NN)*** comprises techniques composed of processing elements or neurons that solve problems together.
- ***Fuzzy Logic and Fuzzy Sets (FL/FS)*** are based on techniques that deals with imprecise, vague or partial information.
- ***Metaheuristics (MH)*** comprise techniques to solve hard optimization problems where the value of certain decision variables should be found in order to optimize one or several objectives subject to different constraints.

In situations of large volumes of data provided by new ICTs, AI techniques provide capabilities for [2]:

- *Integrate and Transform Data*: ML can help create value by providing companies with intelligent analysis of big data and capturing structured interpretations of the wide variety of increasingly available unstructured data.
- *Automate decision making*: create a set of intelligent decision making models to collect accurate data; solve the models quickly; and evaluate the results.
- *Real-time decision-making:* ES increase the probability of making right decisions and facilitate real-time, low-cost decisions at the expert level by non-experts.
- *Learning capability*. AI goes one step further, not only applying pre-programmed decisions, but exhibiting some learning capabilities.

[8] shows that the new generation of AI simulates, extends and reinforces human intelligence: AI replaces the need for people to analyze, judge, optimize and make decisions through autonomous perception, autonomous learning, autonomous thinking and intelligent behavior. They identify a new generation of AI originated by the irruption of new technologies they call, **AI 2.0** which includes ML, Natural Processing Learning (NPL), Big Data, Cloud Computing, IoT, etc.

Next sections try to find out the application of AI techniques to SC operations planning in the era of digital transformation analysing existing reviews on the topic.

3 Research methodology

The literature review (LR) is recognized as a valid approach and a necessary step in exploring new research directions guiding the research toward new theoretical development. During this LR, the four-step process proposed by [9] was adopted:

1. ***Material collection:*** The first step was to define the research scope in which to search for material: in this case, AI applied to the SC operations planning. Since several papers were found dealing with this decision-making process jointly with others in the SC or manufacturing context, they will be also included. The search process was carried out by using the search engine of Web of Knowledge. Publication search was conducted in terms of structured combination of the key words in title, abstract and keywords: (“artificial intelligence” OR “expert system” OR “machine learning” OR “agent” OR “neural networks” OR “fuzzy” OR “metaheuristics”) AND (“review” OR “survey” OR “revision” OR “report” OR “study” OR “state of the art” OR “conceptual framework” OR “conceptual model”) AND (“production planning” OR “operations planning” OR “aggregate planning” OR “tactical planning” OR “master planning” OR “operative planning” OR “network planning” OR “process planning” OR “supply chain management” OR “supply chain processes” OR “supply chain planning” OR “production sequencing” OR “production scheduling” OR “scheduling” OR “timing” OR “planning”). Since one of the main objectives is to analyse the impact of new ICTs on the AI application to SC operations planning, the search was limited to the last two decades. A total of 135 references were found.
2. ***Descriptive analysis***: formal aspects of the material were assessed. During the material revision, some references were discarded and other were found of interest and added to our LR. A total of 29 references were finally selected for our LR.
3. ***Category selection***: the structural dimensions for analysing the collected material were defined to answer our RQs (see Section 4).
4. ***Material evaluation:*** the material was analysed according to the structural dimensions in Section 5. Finally, the identification of relevant issues and the interpretation of the results was performed.

4 Category selection: structural dimensions for the LR analysis

A final total of 29 publications were considered to fit in our scope. In order to answer the four RQs, the selected papers were systematically analysed based on these structural dimensions: 1) *Year of publication* for identifying research trends over time; 2) *LR Dimensions* being the structural dimensions of previous reviews when analysing papers; 3) *SC decision making processes* addressed and 4) their *decision level* in the strategic, tactical and operational hierarchy; 5) *Collaboration/Integration* to identify if existing LR consider the spatial integration (along the SC members) and/or temporal integration (along the different decision levels); 6) *AI techniques* considered; 7) *Hybridization*: other technologies/techniques addressed in the context of digital transformation, 8) *Sectors* contemplated and 9) *Future Research Lines* identified by the LR.

5 Material evaluation: LR analysis

To answer the **"RQ1**. *What have been the interest for revising AI applied to SC operations planning over the past two decades and from which perspectives?*" the *Year of publication* (Figure 1) and the *LR Dimensions* employed to review the literature (Table 1) are analyzed. As can be observed in Figure 1, the number of LR is uneven over the years, with a clear increase in the last two years which means an increasing interest in this area.

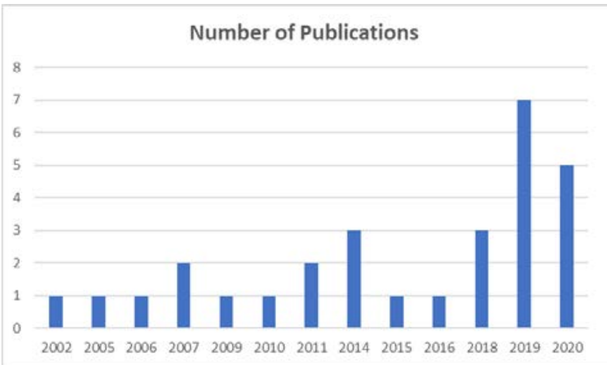

Fig. 1. Number of Publications on AI applied to SC Operations Planning.

The most common *LR Dimensions* used to analyse research works are the problem scope (**PS**) (decision-making processes) and/or application area (specific problem to be solved) (65,5%). It is followed by the AI techniques employed (**AIT**) (58,6%) and specific details on them (**AITD**) (13.8%) such as agent architectures and communication, information model, selection of techniques parameters or attributes and validity methods. Then, the data source (**DS**) used by the AI techniques (10,3%) as regards how the data has been generated (specialist's judgments, based on other studies, case study, historical, simulated, etc) or its source (management, equipment data, user, product, public or artificial data). In the LRs found, very little attention has been paid to aspects such as the AI application techniques to specific decision level (**DL**) of the hierarchy (strategic, tactical and operational), the number of SC stages covered (**SCS**), the problem characteristics (PC) addressed, for instance, related to the structural degree (structural, semi-structural, non-structural) and the environment (deterministic, uncertain, risk). It should be noted that despite the rise of new technologies (**ICT**), not very much attention has been paid to their connection with the AI (10,3%) when revising existing applications. It is worth noting, the even greater scarcity of LRs (6.9%) that analyse papers with AI applications from a collaborative point of view (**I/C**) so important for the SC.

Table 1. *Year* and *LR dimensions* used for revising the specific papers on AI applications to SC

Ref	DL	PS	PC	SCS	AIT	AITD	I/C	DS	TE	CO	P/MC
[10]		X			X						
[11]	X						X				
[12]		X			X						
[13]		X			X						
[14]					X	X			X		
[15]		X									
[1]	X	X			X						X
[16]		X			X						
[17]		X			X						
[18]					X	X					
[19]		X			X						
[20]				X							X
[21]		X			X						
[22]		X									
[23]		X					X				
[24]		X				X				X	X
[25]											
[26]		X									
[27]					X			X	X	X	
[28]			X					X			
[29]		X			X						
[30]		X									
[31]				X	X						
[32]		X			X						X
[33]		X			X						
[34]			X		X						
[35]		X			X	X		X	X		
[36]		X									X
[37]											
(%)	**6,9**	**65,5**	**6,9**	**6,9**	**58,6**	**13,8**	**6,9**	**10,3**	**10,3**	**6,9**	**17,2**

Ref: Reference, **DL**: Decision level, **PS:** Problem scope and/or application area, **PC**: Problem characteristics, **SCS:** SC stages, **AIT**: AI techniques, **AITD**: AI techniques details, **I/C**: Integration/Collaboration, **DS**: Data source, **ICT**: Information and Communication Technologies, **CO**: Country, **P/MC**: Purpose/Main contributions.

The answer to **"*RQ2*.** *To what extent has the AI research addressed the SC operations planning alone or jointly with other SC processes taking into account some type of integration or collaboration?***"** can be found by observing the Table 2. Five papers (shaded in grey) have exclusively focused on SC operations planning (SCOP), 86% on tactical decision level and 93% on operational decision level meanwhile many of them include additional SC decision processes and strategic decision levels too. The majority of LR do not focus on specific sectors (**GE**) (62%) meanwhile the rest have addressed some specific sector such as the fashion and apparel sector and the mechanical manufacturing (**SP**). Although only two papers (6,9%) has used the integration/collaboration as a dimension for the literature analysis (Table 1), five papers (17%) have made some reflection on this aspect (**I/C**) (Table 2): more specifically with regard to the integration of tasks at different decision levels [11] [12], enterprise integration [12] [14] e-synchronised SCM [1] and SC collaboration [23].

Table 2. SC decision making processes, their decision level and the integration level

Ref	**SC Decision-Making Process**	**Decis Level**			**IC**	**Sectors**	
		S	**T**	**O**		**SP**	**GE**
[10]	Scheduling, Process design, Maintenance & repair, Process Select., Facility Layout, Material Select., PP&C, Capacity Planning, Facility Location, Project Management, Tool & Data Selection, Quality Control, Forecasting, Storeroom design, Vendor selection	X	X	X			X
[11]	Low -level (data acquisition, reconciliation, regulatory control), Mid-level (fault detection & diagnosis, supervisory control), High-level tasks (PP&C)			**X**	X	PI	
[12]	Intelligent Manufacturing		**X**	**X**	X		X
[13]	Design, scheduling, Process planning & control, Quality, Maintenance & Fault diagnosis	X	X	X		MM	
[14]	Manufacturing scheduling, Manufacturing control, Enterprise integration, SCM & Process planning	X	X	X	X		X
[15]	Design engineering, Process planning, Assembly line balancing, & Dynamic scheduling.	X	X	X			
[1]	Design, Schedul, PP&C, Quality, Maint & fault diagnosis	X	X	X	X		X
[16]	Operations Management	X	X	X			X
[17]	Apparel design, manufacturing, retailing, and SCM	X	X	X		F&A	
[18]	Manufacturing scheduling			**X**			X
[19]	Design of dedicated & reconfigurable manuf. systems	X					X
[20]	Textile prod., Apparel manufac., Distribution/sales		X	X		F&A	
[21]	General		X	X			X
[22]	Well Planning, Drilling Optimization, Well integrity, Operat. Troubleshooting, Drilling problem detection	X	X	X		DS	
[23]	Inventory Control & Planning, Transportation Network Design, Purchasing & Supply Management, Demand Planning & Forecasting, Order Picking Problems, Customer relationship management, e-synchronised SCM	X	X	X	X		X
[24]	Planning, implementing & controlling		**X**	**X**			X
[25]	Production Management	X	X	X			
[26]	Industrial prognosis	X	X	X			X
[27]	Demand/sales, procurement & supply management, production, inventory & storage, transportation & distribution, SC improvement	X	X	X			X
[28]	Process synthesis & design, PP&C	X	X	X			X
[29]	Exploration & Production operations, drilling and completion, stimulation treatment	X	X	X			
[30]	Wholesaling and retailing in SC		X	X			X
[31]	Design, fabric production, apparel product., & distribution	X	X	X		F&A	
[32]	Manufacturing Planning, Part Variety, Process Planning, Machining, Tool Selection, Welding, Tool Design, Product Development	X	X	X		MM	
[33]	Planning & operations decisions		**X**	**X**		FT	
[34]	Supplier Selection	X					X
[35]	Smart Maintenance, Quality Control, Process Control & Monitoring, Inventory and Distribution Control, Smart Planning & Scheduling, Smart Design of Products and Processes, Time estimation	X	X	X			X
[36]	Marketing, Distributed management, Decision making, Prediction, Efficiency, Security, Classification	X	X	X			X
[37]	Business Management		X	X			X
	Total (%)	**69**	**86**	**93**	**17**	**38**	**62**

S: Strategic, **T**:Tactical, **O**:Operat, **I/C**:Integrat/Collaborat, **SP**:Specific, **GE**:General, **PI**:Process Industries, **MM**:Mechanical Manufacturing, **F&A**:Fashion & Apparel, **DS**:Drilling Sector, **FT**:Freight Transportation, To answer the "***RQ3***. *What are the most studied AI methods alone or jointly with other techniques or new ICTs (hybridization)?*" it is necessary to deepen in the study of the Table 3. As can be observed, the most covered AI techniques by the LRs are those belonging to the Neural Network (**NN**) (72,4%) and Machine Learning (**ML**) (65,5%), followed by Fuzzy Logic/Fuzzy Sets (**FL/FS)** (58,6%), Expert Systems (**ES**) (55,2%) and Metaheuristics (**MH**) (41,4%), being the least reviewed Multi-Agent Systems (**MAS**) (34,5%). The rise of Big Data in the context of Industry 4.0 which uses ML and NN Algorithms to build models to analyse the data can explain the above figures. Artificial NN has the advantage also of execution speed, once the network has been trained with data sets, rather than having to write programs, that convert them in more cost effective and convenient in a dynamic environment.

Table 3. AI Techniques and their hybridization with other Techniques & Technologies

Ref	**AI Branches**						**Hybridization: Techniques &Technologies**						
	ES	**ML**	**MAS**	**NN**	**FL/FS**	**MH**	**OR**	**BD**	**IoT**	**BC**	**RFID**	**EC & CC**	**I4.0**
[10]	X						X						
[11]	X			X									
[12]			X										
[13]	X	X		X	X	X	X						
[14]			X										
[15]	X	X	X	X	X	X	X						
[1]	X	X	X	X	X	X							
[16]	X	X		X	X	X							
[17]	X	X	X	X	X	X							
[18]	X	X		X	X	X							
[19]				X	X		X						
[20]	X	X		X	X	X							
[21]	X		X	X	X								
[22]	X	X		X	X	X							
[23]			X										
[24]		X			X		X						
[25]	X	X	X	X	X	X			X				
[26]	X	X		X	X		X					X	X
[27]		X		X									
[28]		X		X			X						
[29]					X			X					
[30]													
[31]	X	X	X	X	X	X		X					
[32]	X												
[33]		X		X			X						
[34]	X	X	X	X		X	X						
[35]		X		X							X		X
[36]		X		X	X				X	X		X	
[37]		X		X	X	X		X					
Total (%)	**55,2**	**65,5**	**34,5**	**72,4**	**58,6**	**41,4**	**31,1**	**10,3**	**6,9**	**3,4**	**3,4**	**6,9**	**6,9**

Ref: Reference, **ES**: Expert Systems, **ML**: Machine Learning, **MAS**: Multi-Agent Systems, **NN**: Neural Networks, **FL/FS**: Fuzzy Logic/Fuzzy Sets, **MH**: Metaheuristics, **OR**: Operational Research, **BD**: Big Data, **IoT**: Internet of Things, **BC**: Blockchain, **RFID**: Radio Frequency Identification, **EC&CC**: Edge Computing and Cloud Computing, **I4.0**: Industry 4.0.

As regards the hybridization of AI tools, the majority considers the combination with more traditional solution techniques such as Operational Research (**OR**) (31.1%). It is noteworthy that despite the growing interest in new technologies, AI literature reviews have not analysed in depth the integration of AI techniques with them: only 10.3% have studied it in a Big Data (**BD)** context, 6.9% with **IoT**, 3.4% with Blockchain (**BC**), 3.4% with **RFID**, 6,9% with Edge Computing and Cloud Computing (**EC&CC**) and 6,9% with **I4.0**. Therefore, it is necessary to incorporate this new dimension in the analysis of IA techniques applied to SC operations planning.

6 Conclusions and suggestions for future reviews

Finally, with the aim of answering the "***RQ4***. *What are the main future research lines identified by existing literature reviews?"* we have carefully analysed the future research lines in the LR and grouped them into seven main blocks (Fig. 2). It can be observed that nearly one third of the papers (31,03%) identify the **hybridization** as one of the main future research areas. This hybridization includes mostly approaches taking advantage of the strengths of the different AI techniques, with other classical methods like operations research and less on integration in software packages**.**

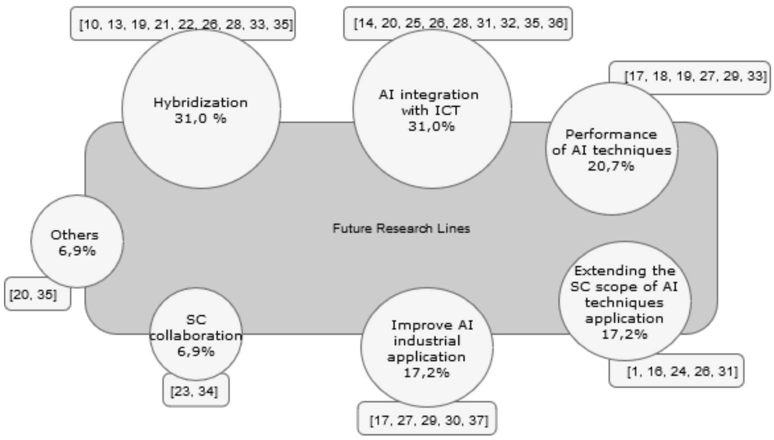

Fig. 2. Future research lines identified by the LR

Also, the 31,03% of papers, being relatively recent, highlighted the necessity of **integrating AI with other technologies** such as RFID, mobile computing, IoT, Blockchain, Big Data for data-driven optimization and on-line learning for reducing uncertainty. More specifically, in the field of SC operations planning, different authors point out the necessity of new models that are capable of representing a more cyber-centric Production Environment [25]; integrating their business with cloud-based technologies like Microsoft Azure, Amazon web services, IBM Watson, etc., and parallel computing tools for big data analytics like Hadoop and Hive [31]; the fusion of KBS into web environment can ensure the benefits of KBS to the remote environment [32], to reinforce the role of IoT in ML-PPC [35] and to address challenges to combine Blockchain and AI e.g. scalability, lack of standards, issues in consensus protocols [36].

The 20.69% of the publications devise as future research directions the study of the **performance of** different **AI techniques**, the performance comparison among different AI methods in order to justify the choice of some parameters and/or an algorithm rather than another for a given problem or data set, ensuring more objectivity, variety and robustness. The 17.24% identify as new research lines **extending the SC scope of AI Techniques** applied in **some SC problems to other ones**. Also, the 17.24% of the papers pointed out the necessity of **improving AI industrial application in SCM:** the oversimplification of decision-making problems hinders their application in industrial practice.

Although **SC collaboration** is recognized as one pillar of improving SC performance, only two papers that represent the 10.34% of the total address collaboration as a future research line: collaboration dynamics by using Agents, [23], group and negotiation process [34]. Other research lines (6,89%) include to seek the use AI technologies to enhance their efforts to ‘go green’ [20]; improve the integration between the PPC, logistics, design and the customer and set human interaction and environmental aspect as priorities to ensure the development of ethical manufacturing in I4.0 [35].

Finally, we propose that future AI techniques and LRs incorporate the hybridization (networks consisting of organizations, people, machines and intelligent systems), collaboration between humans and intelligent autonomous systems with the ethical aspects.

Acknowledgments. This research has been funded by the project entitled NIOTOME (Ref. RTI2018-102020-B-I00) (MCI/AEI/FEDER, UE). The first author was supported by the Generalitat Valenciana (Conselleria de Educación, Investigación, Cultura y Deporte) under Grant ACIF/2019/021.

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