Artificial Intelligence in Supply Chain Operations Planning: Collaboration and Digital Perspectives

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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 hybridization 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) allow obtaining precise data in real time [1]. 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 in the whole Supply Chain Management (SCM). There is a lack of consensus about the definition of SCM in the literature. Along these lines after a deeper literature review on this concept, [2] propose the following SCM definition: "*The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final*

Published by Springer Nature Switzerland AG 2020
L. M. Camarinha-Matos et al. (Eds.): PRO-VE 2020, IFIP AICT 598, pp. 365–378, 2020.
https://doi.org/10.1007/978-3-030-62412-5_30

customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction".

Since SCM requires the comprehension of complex and interrelated decision-making processes [3], 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 [4].

Because of the increasing 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 with the aim of discovering the focus of the analysis made and detecting gaps for future studies. 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 Sect. 2 describes relevant AI techniques for the purpose of this paper. In Sect. 3, the research methodology followed for the literature review is presented. In Sect. 4, the structural dimensions used for the review are described, meanwhile in Sect. 5 the material evaluation is made based on these structural dimensions. Finally, in Sect. 6 the conclusions and suggestions for future reviews are made.

2 Artificial Intelligence (AI)

There is no commonly accepted definition of AI [5]. 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*" [6], 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*" [7], 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 analyzing their environment and taking actions – with some degree of autonomy – to achieve specific goals*" [8]. 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.

In the AI history, there have been different periods known as "AI winter" and "AI summer" characterized by low and high investment periods in the research field, respectively [9]. The first winter was in the 1970s for the failure with the speech recognition research program, and few years after, in 1980s, the AI summer arrived with the commercialization of expert systems (ES). But in 1984, the ES had many issues and were heavily criticized, and the investment fall down [10]. This is known as the second winter. In late 1990s became a new summer, by IBM's Deep Blue system, which beat the actual chess world champion. Finally, after 2010s the arrival of new technologies like Industry 4.0 drive to an explosive growth that has reached the present day [11]. 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 some ambiguity in the definition of different AI branches depending on their development discipline creating some confusion due to the lack of consensus. In this context and for the purpose of this paper, the most relevant branches considered 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 [12]: 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 [4]:

- *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 real-time and 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.

[13] show 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 [14] 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 Sect. 4).
4. ***Material evaluation***: the material was analysed according to the structural dimensions in Sect. 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) LR *Future Research Lines.*

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* (Fig. 1) and the *LR Dimensions* employed to review the literature (Table 1) are analyzed. As can be observed in Fig. 1, the number of LR is uneven over the years, with a clear increase in the last two years which means an increasing interest of researchers focusing on reviewing papers in this area.

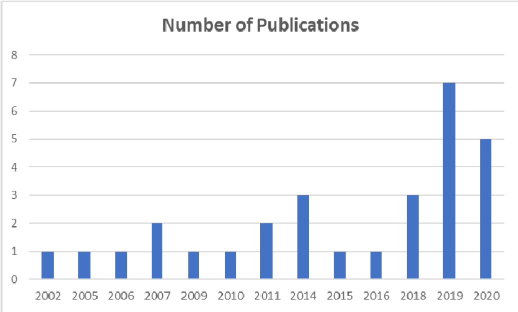

Fig. 1. Number of publications per year on AI applied to SC operations planning.

The most common *LR Dimensions* used to analyse research works (Table 1) are the problem scope (**PS**) (decision-making processes) and/or application area (specific problem to be solved) (65,5%).

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

Ref	Year	DL	PS	PC	SCS	AIT	AITD	I/C	DS	TE	CO	P/MC
[15]	2002		X			X						
[16]	2005	X						X				
[17]	2006		X			X						
[18]	2007		X			X						
[19]	2007					X	X			X		
[20]	2009		X									
[3]	2010	X	X			X						X
[21]	2011		X			X						
[22]	2011		X			X						
[23]	2014					X	X					
[24]	2014		X			X						
[25]	2014				X							X
[26]	2015		X			X						
[27]	2016		X									
[28]	2018		X					X				
[29]	2018		X				X				X	X
[30]	2018											
[31]	2019		X									
[32]	2019					X			X	X	X	
[33]	2019			X					X			
[34]	2019		X			X						
[35]	2019		X									
[36]	2019				X	X						

(*continued*)

Table 1. (*continued*)

Ref	Year	DL	PS	PC	SCS	AIT	AITD	I/C	DS	TE	CO	P/MC
[37]	2019		X			X						X
[38]	2020		X			X						
[39]	2020			X		X						
[40]	2020		X			X	X		X	X		
[41]	2020		X									X
[42]	2020											
(%)		**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.

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.

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, 86% on tactical level and 93% on operational level. Many of them include additional SC decision processes and strategic levels. The majority of LR do not focus on specific sectors (**GE**) (62%). The rest have addressed specific sectors such as the fashion and apparel 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 reflected on it (**I/C**) (Table 2): more specifically in the integration of tasks at different decision levels [16, 17], enterprise integration [17, 19] e-synchronised SCM [3] and SC collaboration [28].

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

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
[15]	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
[16]	Low -level (data acquisition, reconciliation, regulatory control), Mid-level (fault detection & diagnosis, supervisory control), High-level tasks (PP&C)			**X**	X	PI	
[17]	Intelligent Manufacturing		**X**	**X**	X		X
[18]	Design, scheduling, Process planning & control, Quality, Maintenance & Fault diagnosis	X	X	X		MM	
[19]	Manufacturing scheduling, Manufacturing control, Enterprise integration, SCM & Process planning	X	X	X	X		X
[20]	Design engineering, Process planning, Assembly line balancing, & Dynamic scheduling.	X	X	X			
[3]	Design, Schedul, PP&C, Quality, Maint & fault diagnosis	X	X	X	X		X
[21]	Operations Management	X	X	X			X
[22]	Apparel design, manufacturing, retailing, and SCM	X	X	X		F&A	
[23]	Manufacturing scheduling			**X**			X
[24]	Design of dedicated & reconfigurable manuf. systems	X					X
[25]	Textile prod., Apparel manufac., Distribution/sales		X	X		F&A	
[26]	General		X	X			X
[27]	Well Planning, Drilling Optimization, Well integrity, Operat. Troubleshooting, Drilling problem detection	X	X	X		DS	
[28]	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
[29]	Planning, implementing & controlling		**X**	**X**			X
[30]	Production Management	X	X	X			
[31]	Industrial prognosis	X	X	X			X
[32]	Demand/sales, procurement & supply management, production, inventory & storage, transportation & distribution, SC improvement	X	X	X			X
[33]	Process synthesis & design, PP&C	X	X	X			X
[34]	Exploration & Production operations, drilling and completion, stimulation treatment	X	X	X			
[35]	Wholesaling and retailing in SC		X	X			X
[36]	Design, fabric production, apparel product., & distribution	X	X	X		F&A	
[37]	Manufacturing Planning, Part Variety, Process Planning, Machining, Tool Selection, Welding, Tool Design, Product Development	X	X	X		MM	
[38]	Planning & operations decisions		**X**	**X**		FT	
[39]	Supplier Selection	X					X
[40]	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
[41]	Marketing, Distributed management, Decision making, Prediction, Efficiency, Security, Classification	X	X	X			X
[42]	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,

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
[15]	X						X						
[16]	X			X									
[17]			X										
[18]	X	X		X	X	X	X						
[19]			X										
[20]	X	X	X	X	X	X	X						
[3]	X	X	X	X	X	X							
[21]	X	X		X	X	X							
[22]	X	X	X	X	X	X							
[23]	X	X		X	X	X							
[24]				X	X		X						
[25]	X	X		X	X	X							
[26]	X		X	X	X								
[27]	X	X		X	X	X							
[28]			X										
[29]		X			X		X						
[30]	X	X	X	X	X	X			X				
[31]	X	X		X	X		X					X	X
[32]		X		X									
[33]		X		X			X						
[34]					X			X					
[35]													
[36]	X	X	X	X	X	X		X					
[37]	X												
[38]		X		X			X						
[39]	X	X	X	X		X	X						
[40]		X		X							X		X
[41]		X		X	X				X	X		X	
[42]		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.

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, becoming more cost effective and convenient in a dynamic environment. As regards the hybridization of AI tools, the majority considers the combination with more traditional 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.

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 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.

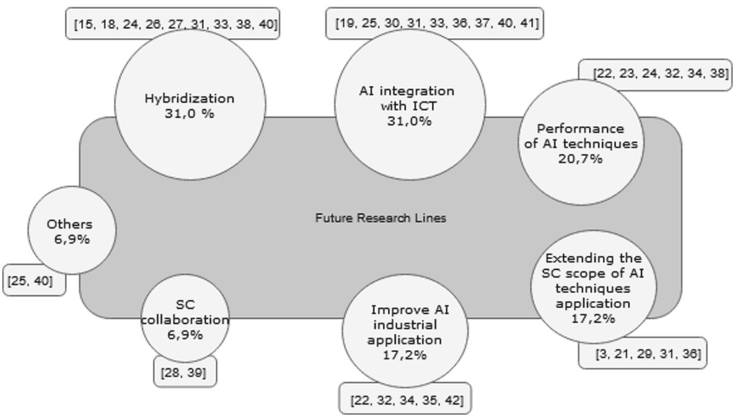

Fig. 2. Future research lines identified in the LR revised

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 [30]; 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 [36]; the fusion of KBS into web environment can ensure the benefits of KBS to the remote environment [37], to reinforce the role of IoT in ML-PPC [40] and to address challenges to combine Blockchain and AI such as scalability, lack of standards, issues in consensus protocols [41].

The 20.69% of the publications devise as future research directions the study of the **performance of** different **AI techniques** and its 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, [28], group and negotiation process [39]. Other research lines (6,89%) include to seek the use AI technologies to enhance their efforts to 'go green' [25]; 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 [40].

6 Conclusions and Suggestions for Future Reviews

Based on the analysis of the previous sections, we propose in the following some guidelines for future literature reviews and AI applications in SC itself. In this regard, more attention should be paid on the following aspects in order to detect potential gaps and boost the real applicability of AI in SC. The temporal integration across decision levels (i.e. tactical and operational plans) and on the spatial integration/collaboration (i.e. across different plans of SC stages and/or stakeholders) requires more attention specially in a real-time environment. The connection between AI and ICT should be better analyzed by future literature reviews in the specific papers in order to identify gaps and increase the use of AI in the context of Industry 4.0.

To improve AI industrial applications, it will be helpful for practitioners more literature reviews focused on specific sectors instead of addressing them in a general way. Besides, although all the literature reviews focus on the different AI techniques applied, the objectives pursued by them are not analyzed, even less from the SC sustainable point of view (economical, environmental and social). To focus on these aspects can support a better assessment of the improvements achieved by the AI implementation on these three different dimensions.

For the social dimension of sustainability, it is very important 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 in order to design and implement responsible AI systems. To achieve this, next AI projects are encouraged to report the way in which they have achieved the FAST Track Principles [43]: Fairness, Accountability, Sustainability, and Transparency.

Finally, the role of the AI systems in pandemic situations such as COVID-19 are fundamental to provide robust and resilient SC models [44]. Besides to assess the robustness of existing or future SC plans against these type outbreaks and the risk propagation should require to combine AI with simulation. This shows the necessity of including simulation techniques in the AI hybridization.

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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