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RFID AND INDUSTRY 4.0: THE TECHNOLOGY'S ROLE ON SHOP FLOOR CONTROL OPERATIONALISATION

RFID e Indústria 4.0: o papel da tecnologia na operacionalização do Shop Floor Control

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ABSTRACT

The advent of Information and Communication Technology brought some advances in the field of Operations Management. RFID, when used as Ordering Coordination System, provides benefits not only for Production Control but also for some organisational functions that support the manufacturing sector. To identify these benefits, this work used a Systematic Literature Review. The results presented 25 benefits, classified into 4 areas that impact the Shop Floor Control and a framework containing the information flow necessary to operationalise the SFC 4.0. The discussion presented some insights relating the benefits with the maturity level of the entire SFC ecosystem when adopting RFID technology as an Ordering Coordination System and a brief agenda for future studies in this field of knowledge. It was possible to conclude that although the use of RFID is not new, its use as a premise for SFC operationalisation is yet in its initial stage of maturity, which could be reinforced by the fact that the most cited benefits were related to the initial stage of informational flow presented in the framework.
Keywords: Industry 4.0; RFID; Manufacturing Planning and Control; Shop Floor Control; Systematic Literature Review.

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RFID and industry 4.0: the technology’s role on shop floor control operationalisation

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RESUMO

O advento da Tecnologia da Informação e Comunicação trouxe muitos avanços na área de Gestão de Operações. A tecnologia *RFID*, quando utilizado como Sistema de Coordenação de Ordens, traz benefícios não apenas para o Controle da Produção, mas também para algumas funções organizacionais que dão suporte ao setor de manufatura. Para identificar esses benefícios, este trabalho realizou uma Revisão Sistemática da Literatura. Os resultados apresentaram 25 benefícios, classificados em 4 áreas que impactam o *Shop Floor Control* e um *framework* contendo o fluxo informacional necessário para operacionalizar o *SFC* 4.0. A discussão apresentou alguns insights relacionados aos benefícios com o nível de maturidade de todo o ecossistema *SFC* ao adotar a tecnologia *RFID* como um Sistema de Coordenação de Pedidos e uma breve agenda para estudos futuros nesta área de conhecimento. Foi possível concluir que embora a utilização do *RFID* não seja nova, sua utilização como premissa para operacionalização do *SFC* ainda está em estágio inicial de maturidade, o que pode ser reforçado pelo fato de que os benefícios mais citados foram relacionados ao estágio inicial do fluxo informacional apresentado no modelo teórico.
Palavras-chave: Indústria 4.0; *RFID*; Planejamento e Controle da Manufatura; Controle de chão de fábrica; Revisão Sistemática da Literatura.

INTRODUCTION

The advent of technology, changes in marketing requirements, and the evolution of Information and Communication Technologies (ICT) have brought some challenges to organisations, grounding the natural development of the Strategic Paradigm of Manufacturing Management (SPMM). This evolution, however, got complexity for Shop Floor Control due to the Work In Process and Batch Size reduction, highly customised products required in a short period, with high-quality standards. (Poon et al., 2007) pointed out that Shop Floor Control Systems (SFCS) were developed to overcome these problems.

According to (Bauer et al., 1994), this approach seeks to solve the main issues related to productivity, improved management of SF information, reduced complexity in information handling, and facilitated decision-making processes. To (Poon et al., 2007), Shop Floor Managers face unpredictable risks in day-to-day operation, such as errors, defects in the supplies of components, failures, and machines breakdown. The problem of these occurrences in 4.0 environments depends on the dynamicity that evolves these environments. In traditional paradigms, the risks or events are reported only days or even monthly (Lam, 2003). This fact imposes high inertia on solving operational problems related to SFC. Notwithstanding these issues, organisations face fluctuations in demand and lead times, making a planned production control strategy unreliable.

The use of Radio Frequency Identification (RFID) technology as an Ordering Coordination System (OCS) for Industry 4.0 was proposed by (Pissardini & Sacomano, 2019) to operationalise Shop Floor Control 4.0. Despite this proposal and the high number of studies considering RFID application, not only in the manufacturing environment but also in the entire Supply Chain Management, to the best of our knowledge, no work systematically collects and analyses the benefits of RFID adoption as OCS for SFC in 4.0 environments. To fill this gap is just the objective of this research. Therefore, we use a SLR to collect and critically analyse the existing knowledge in this field of knowledge. To address the proposed objective, this study has three interrelated questions:

1– What are the benefits of RFID technology in SFC 4.0?

2– How do these benefits impact (allow the operationalisation) of SFC 4.0?

3– What does the identified state of the art say about new research opportunities?

Thus, the remainder of this paper is organised as described: Section 2 presents the theoretical background. Section 3 contains the methodological aspects. Section 4 shows the results. Section 5 discusses the results proposing a brief research agenda, and Section 6 offers the conclusion, inferring about theoretical and practical implications of this research.

1 THEORETICAL BACKGROUND

This section presents a brief literature review of the main constructs used in this research. The constructs include Industry 4.0, Shop Floor Control and RFID. It was chosen to present the following review in an integrated approach once it makes it easier to understand the main functionality of the technology when the literature adopted considers its application directly in the other construct. Thus, the RFID technology was studied inside the Shop Floor Control context in the Industry 4.0 environment.

1.1 Industry 4.0, shop floor control and RFID, an integrated approach

The complexity and dynamics of the manufacturing environment are growing due to the changes in manufacturing demand, requiring some types of products, small lot sizes, and short lead-time to market (Tran et al., 2019). To meet these new requirements, the industry 4.0 SPMM, which, in its essence, is composed of disruptive technologies responsible for giving "intelligence" to the cyber part of a physical entity, has data acquisition as a premise.

Strongly interrelated with the Fourth Industrial Revolution, RFID is an essential instrument of SFC operationalisation in a 4.0 environment. To summarise, Industry 4.0 utilises technology such as Cloud Computing, Big Data and Analytics and Digital Twin to evolute the machinery from automation to autonomy. Considering this evolution, the autonomy level is not acquired by a single machine but by the entire system, called Machine to Machine communication (M2M Communication).

Concerning SFC, we adopt the Gartner definition, for whom SFC is a system of computers and controllers tools used to schedule, dispatch and track the progress of work orders through manufacturing based on defined routings (*Gartner Glossary*, n.d.). This area is one of the most challenging for manufacturing managers, given the infinite possibility of disruptions that involve machinery, operators, raw material, and others. For each set of volume-variety combinations, there is an OCS that better fits the Manufacturing system's objective. In Industry 4.0, a consensus is being established about RFID as an OCS (Oluyisola et al., 2020).

Regarding RFID, (Kanagachidambaresan, 2020) points to this technology as the primary source of data generation in intelligent environments, such as Smart Factories. Being found in standard and long-range formats, the RFID, according to (Kanagachidambaresan, 2020), has the fastest recognition speed and can read tags up to 15 meters, being suitable for factory usage.

When IoT and RFID are applied to the manufacturing process, heterogeneous RFID-based data, real-time and substantial data, are generated and recorded, called industrial Big Data (C. Wang et al., 2017). Big Data is an Input for Analytics to treat and identify unknown relationships among data, which provide system feedback, adjust manufacturing, and machine parameters, and serve as a basis for decision making.

2 RESEARCH'S METHODOLOGICAL SEQUENCE

This study is theoretical-conceptual and presents a literature review on RFID applied to SFC 4.0 as the first attempt to show and explain the benefits of this technology for operations, proposing a literature classification and analysis. (Denyer & Tranfield, 2009) points that a SLR is an essential endeavour by itself and not merely a review of previous writing. Moreover, it responds to specific questions and is a "methodology that locates existing studies, selects and evaluates contributions, analyses and synthesises data, and reports the evidence to allow reasonable, clear conclusions about what is and is not known (Tranfield et al., 2003).

In addition, this SLR takes the three steps proposed by (Denyer & Tranfield, 2009) points, comprised of Planning, Conduction and Dissemination. The Planning step is summarised in the research protocol (Table 01). The defined parameters were applied in the conducting stage, and the scanning process was then started. In the dissemination stage, the data were treated, and the results were presented. The step-by-step is detailed in the following subsections.

2.1 Planning stage

The following table summarises the research criteria used to achieve the final sample of papers used to build this manuscript.

Table 1 - Research Protocol

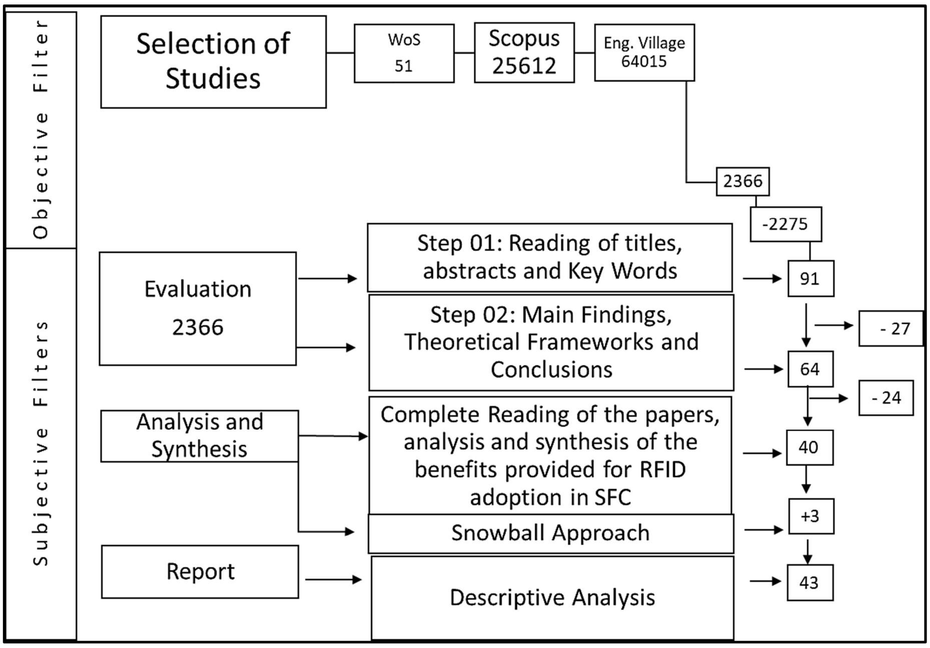
Research Protocol	
Objective	To identify the benefits of RFID technology for Shop Floor Control in Industry 4.0 environments;
Guiding Questions	*1 – What are the benefits of RFID technology in SFC 4.0?* *2 – How do these benefits impact (allow the operationalisation) of SFC 4.0?* *3 – What does the identified state of the art say about new research opportunities?*
Database	*Engineering Village, Scopus, Web of Science*
Period	*From 2011 to 2022*
Document Type	*Journal Articles, Articles In Press, Conference Papers, Review*
Language	*English*
((Data Ingestion AND Production Control) OR (Data Flow AND Production Control) OR (Data Collection AND Production Control) OR (Database AND Production Control) OR (Data Acquisition AND Production Control) OR (Data Processing AND Production Control) OR (Data Processing AND Production Control) OR (Data Management AND Production Control) OR (Smart Support AND Production Control) OR (Data Driving Simulation AND Production Control) OR (Data Driving Simulation AND Production Control) OR (Data Driving Simulation AND Production Control) OR (Data Driving Production Control) OR (Data-Driven AND Production Control)) AND ((shop floor) OR (Order Progress) OR (Order Monitoring) OR (Order Releas*) OR (Production Scheduling) OR (Production Sequencing) OR (Production Control) OR (Production Scheduling)) AND ((Industry 4.0) OR (Industrie 4.0) OR (Fourth Industrial Revolution) OR (Smart Factor*) OR (Smart Production) OR (digiti?ation) OR (digitali?ation) OR (Virtual factor*) OR (digital factor*) OR	

(data driven production) OR (real time production) OR (data collection) OR (machine learning) OR (Shop Floor) OR (data acquisition) OR (Data processing) OR (order progress) OR (Order release) OR (order monitoring))	
Criteria	**Criteria Explanation**
Exclusion (NR)	NR-1: Articles considering other disruptive technologies; NR-2: The definition of "RFID" is not related to the Operational Environment;
(LR)	LR: Articles that cite RFID but do not express discussion about the role of this technology in the 4.0's Shop Floor Control
Inclusion (PR)	PR: Articles that focus on one or a few benefits/barriers of RFID
(CR)	CR: Articles featuring RFID studies, pointing out benefits and their relationship with internal organisational functions;

2.2 Conducting stage

To screen the papers, we utilise the Software StArt. The screening process adopted is summarised in figure 1.

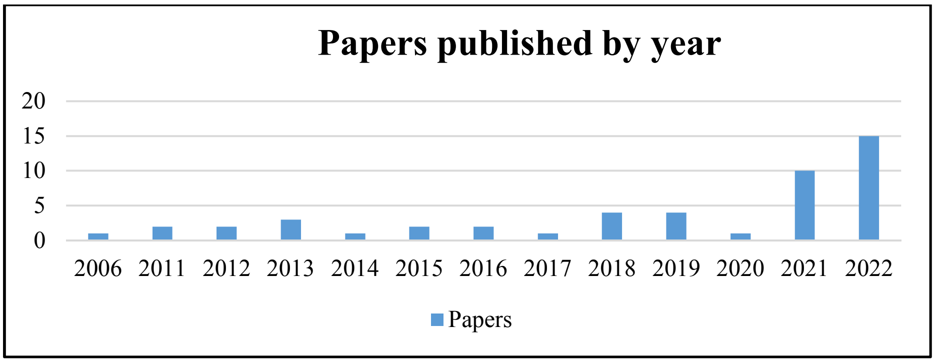
Figure 1 - Summary of article's selection



3 RESULTS

This research identified 43 papers that pointed out the benefits of RFID adoption for SFC 4.0 operationalisation. Figure 02 shows the number of documents published by year. Analysing this figure, we can see that the number of research has increased in the last years, which means that this field of study is growing.

Figure 2 - Papers published by year



Regarding the results, table 02 presents the benefits according to their respective area of impact. Maintenance Management was responsible for 06 benefits (24%), Quality Management was responsible for 04 benefits (16%), the same percentage as the Financial Impacts group. The last group, Operations Management, was responsible for 11 benefits (44%), being the most impacted area. The table also shows a code and description of each capability. This code allows us to insert the capabilities in the software NVivo 11, verifying the existence of any semantical similarity. The last row, containing the authors, shows many times the ability was pointed, considering the sample analysed.

Of the 27 Benefits, the most cited one was Real-Time Monitoring (pointed out by 62,80% of the authors. The second most cited benefit is Decision-Making optimisation. This benefit was cited by 18,60% of the authors. The third benefit with more studies is the Flexible Real-time Shop Floor Scheduling, with 16,29% of the studies. To better illustrate the objective of this research, a framework containing the informational flow between the physical and the cyber elements of an ecosystem for SFC 4.0 is presented above.

Table 2 - Benefits provided for RFID adoption for SFC 4.0 operationalisation

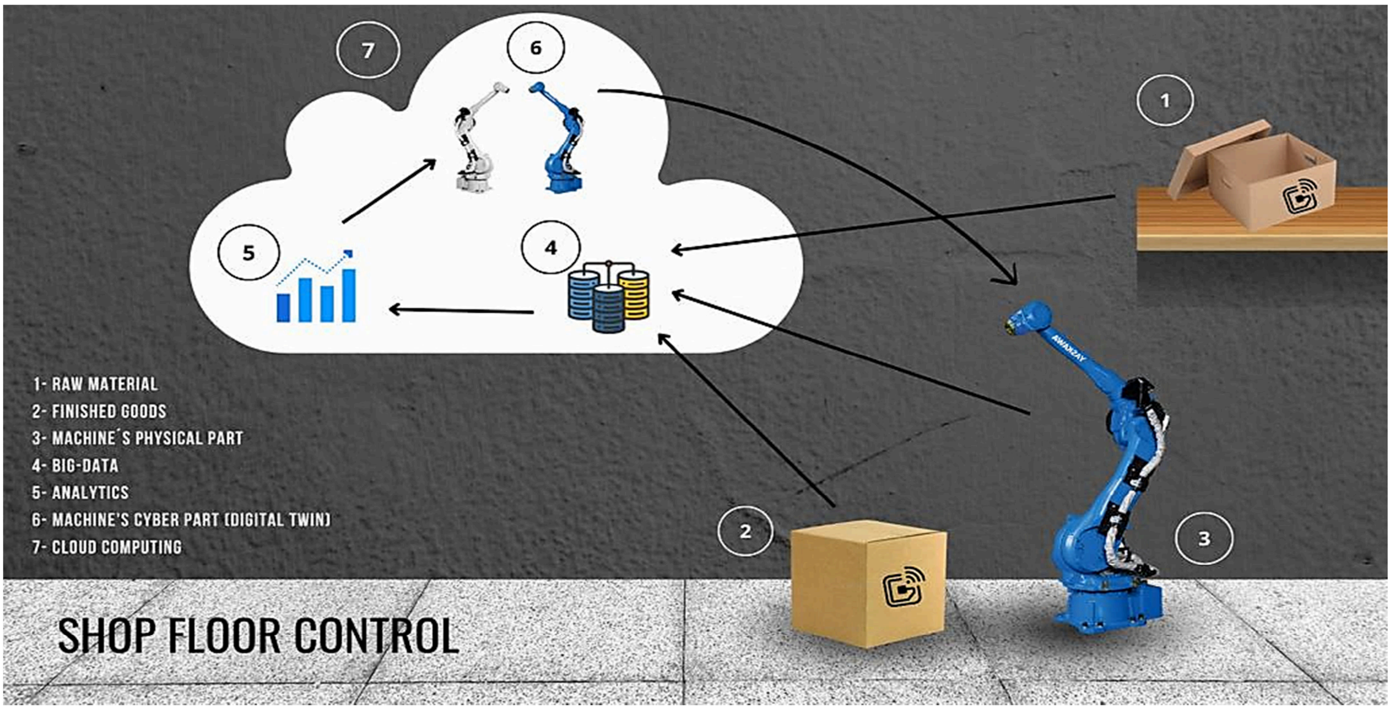
Benefits	Code	Description	Authors
Maintenance Management			
Allow Predictive, Reactive, Preventive and Prescriptive Maintenance	MM1	Real-time data gathering allows the adoption of diverse maintenance approaches	1, 17, 22, 24, 41, 42
Control Systems' Reliability and Security	MM2	Data gathering helps to improve the Security and Reliability of the Control Systems	8, 17, 20
Reduced Unplanned Downtime	MM3	Down-time identification capability is acquired as a result of the Improved Fault Prediction	17, 20, 22, 25
Development of Digital Maintenance	MM4	Maintenance can be remotely executed in the product through Digital Twin and replicated to the physical machine	17
Allow assessment of maintenance impacts on manufacturing	MM5	RFID allow managers to assess the impacts of the maintenance in the manufacturing system	17
Fault Prediction Capability is Improved	MM6	Fault Prediction Capability improves the machines' downtime, reflecting in better asse use	2, 3, 16, 20, 22
Quality Management			
Zero Defects Manufacturing	QM1	To produce beings without any defect	1, 8, 28
Real-Time Monitoring / Ongoing Quality Management	QM2	Real-time monitoring allows ongoing Quality Management and Problem Identification	2, 3, 7, 12, 15, 16, 17, 19, 20, 21, 23, 24, 25, 26, 28, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 43
Increased Production Efficiency through Quality Prediction	QM3	Monitoring the Machines' status related to the most diverse variables allows Quality Problems Prediction	2, 10, 15, 16, 22, 31
Improve Operational Efficiency and Productivity	QM4	The most diverse source of data, real-time updated, allows improved production scheduling, maximising efficiency	5, 21, 25, 32
Financial Impacts			
Reduced Production Costs	FI1	Through improved accuracy of data, the production cost is reduced	1, 2, 5, 24
Minimise machine repair costs for unexpected failures	FI2	Through SFC rescheduling, repair costs may be minimised	17, 24

Investment in the capital is reduced	FI3	RFID collects data that can allow the organisation to identify the better assets to invest	17
Maximise Value of Limited Resource	FI4	The most diverse benefits of RFID adoption, such as the one related to Quality, Process and Maintenance issues, allow maximisation of machines' financial value	14, 24
Operations Management			
Allow End-to-End 4.0 Functionalities	OP1	The entire benefits of I-4.0 are strongly dependent on the data-gathering quality	1, 25
Allow Digital Twin Implementation	OP2	The digital twin technology's fidelity depends on the amount of collected data	1, 7, 25, 27
Real-Time Process Inference	OP3	Managers can react fast in case of production problems once the manufacturing status is being on time managed	3, 19, 21, 23
Decision-Making Optimization	OP4	Making use of Big Data, the adoption of Analytics can identify relationships among variables not clearly identified by the human rationality	4, 5, 11, 24, 25, 28, 36, 38
Reduced Communication Overhead and Algorithm Delay	OP5	The Algorithm Overhead is Reduced through real-time data gathering, which can constantly update its status.	14, 23, 25, 27
Machine Learning Approach is assessed through Data Gathering	OP6	RFID is a source of real-time data gathering that, when used by analytics and replied to a Digital Twin, allows Machine Learning	19, 25
Integrated Production and Maintenance Scheduling	OP7	Data collected from product, production and machines parameters allow integrated production and maintenance scheduling	17, 24
Flexible Real-Time Flow Shop Scheduling	OP8	Through real-time monitoring, the status of the machine can be assessed, and the production scheduling be planned or replanned in case of any unexpected occurrence	4, 18, 19, 21, 23, 29, 30
Idle-Time Minimization in Low Volume High Variety Manufacturing Environment	OP9	The idle time can be minimised through improved SFC	21
Capacity loss of a bottleneck is improved	OP10	Real-time data gathering provided for RFID allows the use of constraints theory principles to manage bottleneck resources	21
Setup time is dramatically improved	OP11	Setup times can be minimised or even reduced to practically zero with the use of RFID	23

Sources: 1. (Christou et al., 2022); 2. (Qian et al., 2022); 3. (Han et al., 2022); 4. (Mendia et al., 2022); 5. (Haghnegahdar et al., 2022); 6. (Y. Liu et al., 2022); 7. (J. Liu et al., 2022); 8. (Kuftinova, Ostroukh, Maksimychev, Vasil'ev, & Pletnev, 2022); 9. (Kuftinova, Ostroukh, Maksimychev, Vasil'ev, & Klimenko, 2022); 10. (S. Arena et al., 2022); 11. (Zheng et al., 2022); 12. (H. J. Lee et al., 2022); 13. (Zermane & Drardja, 2022); 14. (Long, 2022); 15. (Dinesh et al., 2022); 16. (Fan et al., 2022); 17. (M. Arena et al., 2022); 18. (C. N. Wang et al., 2022); 19. (Oluyisola et al., 2022); 20. (Hoffmann Souza et al., 2021); 21. (Zhou et al., 2021); 22. (Chang et al., 2021); 23. (J. D. Lee et al., 2021); 24. (Ghaleb et al., 2021); 25. (B. Wang et al., 2011); 26. (Shieh et al., 2012); 27. (Saygin & Sarangapani, 2006); 28. (Altaf et al., 2018); 29. (Bayano-Tejero et al., 2019); 30. (C. Liu et al., 2019); 31. (Meng et al., 2019); 32. (Li et al., 2019); 33. (Yao et al., 2018); 34. (Yao et al., 2018); 35. (Kibira et al., 2016); 36. (Zhong et al., 2015); 37. (Zhang et al., 2014); 38. (Zhong et al., 2013); 39. (Fang et al., 2013); 40. (Zhang et al., 2011); 41. (Fang et al., 2011); 42. (C. K. H. Lee et al., 2014); 43. (Schäfers et al., 2019);

Figure 3 describes the informational flow between physical and cyber elements that compose an ecosystem 4.0 for Shop Floor Control. In this framework, the RFID, responsible for data-gathering, collects and uploads information for Big Data. An Analytics threats the data and identifies the relationship between variables. These relationships and opportunities for continuous improvement are tested in a Digital Twin, and if any gain is identified, the parameter is replaced with the physical machine.

Figure 3 - Informational Flow between Physical and Cyber resources in SFC 4.0



4 DISCUSSION

RFID technology is the main point of data gathering in SFC 4.0. Soon, it's a premise for SFC 4.0 operationalisation. Analysing the framework (Figure 3), it is possible to perceive that the informational flow that walks throughout the SFC, from raw material to the feedback point, in the Digital Twin, passes into 7 phases. The more phases organisations have, the higher is maturity level of their SFC toward a SFC 4.0. Building a parallel with the benefits presented in table 2, we can perceive that the benefits with the highest number of citations are related to the initial stages of implementation of ecosystem 4.0, such as real-time monitoring and decision-making optimisation. Benefits that directly depend on high maturity level as digital maintenance development didn't receive a high number of citations. Thus, we propose a research agenda according to the four areas where the benefits were previously classified:

- Maintenance Management: Although data gathering allows diverse maintenance approaches, as presented in table 2, some researches could focus on the integration of different approaches and their impacts on the main Key Process Indicators of the maintenance area;
- Quality Management: With the autonomy level acquired with a complete SFC 4.0 ecosystem, the quality managers and staff's role need to be studied;
- Financial Impacts: Researches focus on internal cost minimisation, however, future researches could focus on the implementation cost of building a SFC 4.0;
- Operation Management: Researches could focus on the development of the final stages of SFC 4.0 as the stages that allow feedback for a complete loop evolving an autonomous continuous improvement system;
- Integrated approaches such as ISM/Fuzzy MICMAC could hierarchise the benefits to provide a roadmap for RFID adoption as OCS for SFC 4.0;
- Considering the Industry 4.0 as an independent Strategic Paradigm of Manufacturing Management, as proposed by Pissardini & Sacomano (2019) do the natural evolution and maturity acquisition in applying the main disruptive technologies that allow the achievement of the Industry 4.0 change this status, from an independent paradigm to a maximizer of other previous paradigms as Mass Production, Lean Production, Quick Response Manufacturing, Agile Manufacturing and Mass Customisation?

CONCLUSION

Although the RFID technology is not new, its use as a premise for SFC 4.0 operationalisation is yet in the initial stage. Taking part in this work, it was possible to identify and classify the benefits of adopting RFID technology in SFC as a premise for Smart Shop Floor Control. These benefits were scattered in the literature and cited according to researchers' interests. After systematically reviewing the selected papers, state of the art was identified, and a plan for future research was then proposed. This research, like any other, has its limitations, some of them related to the SLR method as, for example, the selected language (English) can have to be naturally excluded important papers that was written in other idioms. The same problem can be seen with the category of selected works, that include only papers or review papers. Conference papers were not chosen because it normally is a primary version of an idea that is, after the conference, reworked, evaluated, and submitted for a journal. The subjectivism implicit in the authors interpretation can also be seen as a limitation. To minimise this last limitation, we use during the research process, the double-blind review.

We hope this study could be seen as a source for many others derived from the results presented here.

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