Inventory centralization and decentralization in spare parts supply chain configuration: a bibliometric review

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Abstract: In recent decades, the scientific literature has underlined the difficulties in configuring spare parts Supply Chains (SCs) due to the need of minimizing inventory stocks, while facing demand unpredictability and ensuring high service levels. When dealing with spare parts retail companies, it is essential to establish the optimal SC configuration. Indeed, aligning spare parts storage and distribution activities with customer needs ensures customer satisfaction, increased sales profits, and efficient company performance. Configuring spare parts SCs implies performing two tasks. First, defining the deployment strategies of spare parts into Distribution Centers (DCs), choosing between antithetical solutions such as centralization or decentralization. Then, establishing inventory control policies for each item in each DC, planning how many stocks to supply and how often. Regarding the task of establishing the spare parts supply, several contributions have been provided by the literature, proposing methods and tools to control inventories in a single DC. Conversely, against expectations, the literature overlooks the task of planning the spare parts deployment. Indeed, although the different characteristics of centralized or decentralized SCs are known since the 1960s, a few studies have been provided to support spare parts retailers in choosing between centralization and decentralization. In this context, the present paper offers a bibliometric review carried out with a Systematic Literature Network Analysis (SLNA) on the topic of spare parts deployment in SC configuration and the choice between centralization and decentralization. The proposed bibliometric review is useful to understand the state of the art in the analyzed domain, also identifying the top contributing research studies. As a result, descriptive metrics on the retrieved papers are provided to give an overview of the current body of knowledge and lay the foundations for defining possible gaps and future research activities.

Keywords: spare parts logistics, supply chain configuration, inventory allocation, inventory pooling, literature review.

I. INTRODUCTION

Spare parts are strategic assets to ensure the proper execution of maintenance activities in industrial plants. Indeed, they allow restoring the functioning of production equipment by replacing damaged components [1]. Given the significant role of spare parts, the scientific literature [2] has emphasized how crucial it is for spare parts retailers to ensure efficient supply chains (SCs), where the right spare parts are stored and distributed in the right place (close to the damaged components) at the right time (breakdown time [3]). In fact, efficient SCs enable spare parts retailers to optimize business performance by avoiding inventory stock-outs and delivering high service levels, while minimizing purchasing, storage, and distribution costs and efforts [4]. Moreover, efficient spare parts SCs trigger customer satisfaction by providing them with the Stock Keeping Units (SKUs) necessary for maintenance activities, thus minimizing unexpected equipment downtimes and the related financial and operational negative effects [5]. In this context, one of the actions that spare parts retailers can take to achieve efficient SCs is to optimally configure their SCs [6]. An optimal configuration of spare parts SCs enables companies to align logistics activities with customer demand, thus achieving higher performance and competitive advantage. Indeed, a well-configured SC allows a customer-oriented after-sales service, which encourages customers' loyalty, repurchase intentions, and market share [7]. However, the optimal configuration of spare parts SCs is hampered by specific features that distinguish spare parts from other items (commodities, raw materials, or productive supplies) [8]. Among these features, Huiskonen [9] mentioned the unpredictable demand, the prices of individual parts which can be very high, the high number of SKUs that spare parts retailers usually manage, and, finally, the expected customer service level which is typically very high. In addition to this, pursuing conflicting goals such as ensuring high service levels while minimizing inventory costs, another difficulty is faced when configuring spare parts SCs: choosing between SC configurations characterized by different degrees of inventory pooling (which are associated with antithetical benefits). Specifically, two opposite SC configurations can be selected (namely, centralization and decentralization) as well as any hybrid configuration that is a trade-off between the two above stated [10]. In centralization, the maximum degree of inventory pooling is achieved by storing all the SKUs in a single central distribution center (DC), which is tasked with serving all the customers. The advantages of centralization include mitigation of demand uncertainty

(risk-pooling effect), minimal inventory levels, low numbers of replenishment orders, and minimal inventory costs, but implying high delivery times and reduced SC flexibility [1]. In contrast, in decentralization, the minimum degree of inventory pooling is obtained by storing SKUs in multiple independent DCs, each serving nearby customers. Decentralization has countervailing advantages to centralization, including high SC flexibility and responsiveness due to short distances between DCs and customers, low spare parts delivery times, and consequent high service levels, but implying high inventory costs, high numbers of replenishment orders, low inventory turnover, and no advantages related to economies of scale and risk-pooling [11]. Given the aforementioned difficulties, structured methodologies should be provided to support spare parts retailers in overcoming issues and configuring SCs [12]. Specifically, such methodologies should help spare parts retailers in defining two aspects of an SC configuration [6]. First (step 1 of SC configuration), the optimal deployment of spare parts in DCs should be outlined, choosing between centralization, decentralization, and hybrid deployment alternatives with intermediate degrees of inventory pooling. Next (step 2 of SC configuration), optimal inventory control policies should be established in each DC, choosing for each SKU whether to supply it on replenishment or on-demand, when to issue supply orders and how many spare parts to supply. Concerning step 2 of SC configuration, many literature reviews [13], [14] prove that numerous methodologies have already been developed to select the optimal inventory control policy, thus optimizing spare parts supply in a single DC. Conversely, some authors [15], [16] have recently stated that step 1 of SC configuration (optimal deployment of SKUs in DCs) is overlooked by the literature. Specifically, Gregersen and Hansen [6] reported that the concepts of inventory centralization and decentralization were first introduced in 1960 [17], thus making known for a long time the impacts of different deployment strategies (with different degrees of inventory pooling) on a company's economies. Despite this, it was reported [1], [9] that few methods have been offered by the literature to deal with step 1 of SC configuration, planning the deployment of items in DCs and opting for centralization, decentralization, or hybrid configurations. Moreover, to the best of the authors’ knowledge, an overview of the research conducted on step 1 of SC configuration is still missing in the literature, as well as a bibliometric review on such a topic. Nevertheless, understanding the extant literature on the topic of spare parts SC configuration with a focus on step 1 of spare parts deployment and the choice between centralization and decentralization could be of great interest for two reasons. First, to reorganize the research carried out so far by identifying the main contributions and the most prolific authors, journals, and countries. Secondly, to identify current and future research trends in the analyzed topic, thus providing a solid basis on which to build new research studies. For this reason, based on a Systematic Literature Network Analysis (SLNA), this paper presents a bibliometric review on the topic of spare parts SC configuration with a focus on step 1 of planning the SKUs’ deployment in DCs, choosing between inventory centralization and decentralization. The bibliometric review is conducted aiming to answer two research questions: (**RQ1)** What are the most productive and influential countries, journals, and authors and the most influential contributions in the literature on inventory centralization/decentralization and the deployment of spare parts in DCs (step 1 of SC configuration)? (**RQ2)** What are the main themes and driving research streams that mainly concur in developing the research on the topic of inventory centralization/decentralization and the deployment of spare parts in DCs? Overall, the aims of this paper are three. First, to identify the extant literature on the analyzed topic. Secondly, to explore the top-contributing countries, journals, and authors in the field (together with their main contributions) by analyzing their number of publications and citations, and also proposing a novel graphical descriptive tool. Finally, to analyze past and current research themes related to the considered topic by examining the authors’ keywords and their co-occurrence. As an outcome of this study, descriptive metrics on the retrieved research documents are provided to give an overview of the current body of knowledge. The contribution of this paper is to lay the foundations for possible future research activities in the examined domain, providing researchers with results useful to identify potential literature gaps and propose further research studies. The remainder of the present paper is organized as follows: in Section 2, the general description of the materials collected through the SLNA, and the methodology followed to conduct the bibliometric review are described. In Section 3, the results of the bibliometric review are shown. Finally, in Section 4, some conclusions on the work are provided.

II. Materials and Methodology

A. Materials

The SLNA was conducted on February 28, 2022, by searching scientific contributions on the Scopus database, which is considered the best search engine in terms of scientific journal coverage [17]. Initially, contributions including (in the title, abstract, or keywords) keywords related to both spare parts and the specific step 1 of SC configuration (i.e., pooling, centralization, decentralization, deployment, location, allocation, and their synonyms or abbreviations) were investigated by means of the following search query: *TITLE-ABS-KEY("spare part*") AND (TITLE-ABS-KEY(*centrali* OR *location* OR deploy* OR pooling).* This search query yielded 770 documents. Aiming to extract all existing contributions in the analyzed domain, no filter on the papers’ publishing date was inserted. Instead, subject areas not related to the topic of research were excluded (i.e., Material Science, Energy, Earth and Planetary Sciences, Social Sciences, Medicine, Physics and Astronomy, Chemical Engineering, Chemistry, Agricultural and Biological Sciences, Biochemistry

Genetics and Molecular Biology, Arts and Humanities, Neuroscience, Health Professions, Pharmacology Toxicology and Pharmaceutics, Nursing, Immunology and Microbiology, Psychology). In this way, 682 results were found. Then, only Articles and Conference Papers were filtered, achieving 621 documents. Finally, documents written in English were filtered, obtaining 551 results. The number of contributions identified may seem high, in contrast with the remarks by the literature [1], [6] on the lack of studies on step 1 of SC configuration. However, it was considered appropriate to refine the search query based on the following semantic clarification. According to Melo et al. [18], when using keywords related to the topic of inventory "location" and its synonyms or abbreviations, Scopus finds papers dealing with three issues: (i) planning the allocation of items within a single DC, for example placing the articles on the shelves of a warehouse or planning how many items to allocate in a single DC [19]; (ii) choosing the geographical site for building a new warehouse [20]; (iii) determining how to allocate SKUs in multiple DCs, that is choosing inventory centralization, decentralization, or hybrid SC configurations [21]. Moreover, other research themes emerge not related to the topic of interest (e.g., the traceability of spare parts location using blockchains, the spare parts failure location, and the allocation of spare parts redundancies in a plant). Therefore, aiming to investigate only the aspect of inventory centralization and decentralization and the deployment of spare parts in DCs (step 1 of SC configuration), many of the 551 scientific contributions were considered not pertinent to this study. However, it was not possible to change the search query, excluding not interesting topics without discarding relevant scientific contributions in the analyzed domain. For example, modifying the search query by removing keywords such as "*location*" or "deploy*" would have removed useful papers such as the one by Patriarca et al. [22], which instead propose a method for optimally deploying spare parts in the DCs of multi-echelon SCs. Therefore, it was considered more appropriate to perform a manual selection of the collected papers, consulting their title and abstract and removing the documents not concerning the topic of interest. After the manual selection, 170 documents remained (excluding 381 papers), showing a greater interest of researchers towards the topics of spare parts positioning within a single DC, the geographical location of new facilities, or other topics, rather than on planning the stocks' deployment in DCs and choosing centralization or decentralization. Fig. 1 summarizes the followed screening process based on 4 exclusion criteria (EXs). The achieved database (170 papers) was extracted and used to develop the bibliometric review.

B. Methodology

A bibliometric network analysis was performed to develop this study, investigating the state of the art in the selected topic. To address RQ1, analyses on the publications and citations of each reference were developed to define the most productive and influential countries, journals, and authors in the field [23]. The most productive authors, countries, and journals were defined since they contain most of the publications on the topic of interest, being the first sources to be consulted when studying spare parts SCs and the choice between centralization or decentralization. Whereas the most influential authors, countries, and journals were identified to establish the literature contributions considered most interesting by other authors in the field. Moreover, the authors' characteristics and the most influential papers in the field were confirmed by developing and proposing for the first time a novel graphical tool. Instead, to address RQ2, a co-word network analysis was carried out [24] to investigate the main themes related to the analyzed topic and the driving research streams. Specifically, the co-occurrence of authors' keywords was examined. As far as the software packages used to perform the bibliometric review, three tools were used to elaborate statistics about publications, and citations of countries/journals/authors (RQ1) and investigate the authors' keywords (RQ2): *Microsoft Excel™, Bibliometrix* (*R*-tool), and *VOSviewer*.

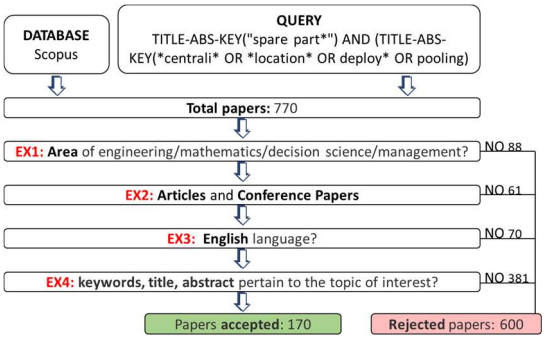

Fig. 1. SLNA performed to achieve the analyzed database

III. RESULTS AND DISCUSSION

The database is composed of 170 documents (66% Articles and 34% Conference Papers), published by 413 authors in 109 journals in a time span of 91 years (1931-2022). The average number of citations per document is 17.8 citations/paper and the total number of citations per year is shown in Fig. 2 (orange line) together with the temporal distribution of publications (blue histograms). In Fig. 2, the first paper published is a technical document dated back to 1931 [25], where the US Military Defense mentioned for the first time the concept of centralizing spare parts inventory as an opportunity to optimize maintenance operations. However, Fig. 1 clearly shows that the effective starting date for the publication of the papers is 1960, which validates the developed search query. Indeed, 1960 is precisely the year that Das and Tyagi [17] indicated as the beginning of the research stream on the topic of stocks' deployment and the choice between centralization and decentralization. Moreover, the evolution of publications and citations over time (Fig. 2) proves that the concept of spare parts centralization has been known to researchers for over 90 years.

However, the literature on this topic is rather lacking, especially until 2008. In fact, the average annual publication rate is relatively low (1.9 papers/year), and the percentage of documents published before 2008 is only 15.3%. However, the publication trend is strongly increasing, revealing an augmented interest of the scientific community towards this topic. Indeed, a spike in the publications curve has been recorded in the last 5 years (41.2% of papers) with a peak in 2021. Note that Fig. 2 shows only 2 articles published in 2022, but this is because the search query was conducted in February 2022. Therefore, it is reasonable to expect a significant increase of publications by the end of the year. Finally, Fig. 2 shows a remarkable peak in the citation curve during 2014, suggesting that one or more significant contributions were published on that year.

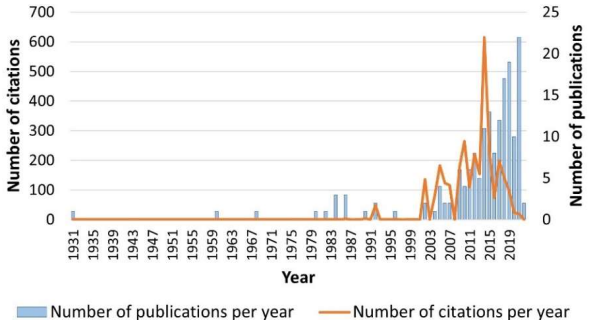

Fig. 2. Reference publication (blue) and citation (orange) year spectroscopy

A. Publication and citation analysis

To answer RQ1, first, the geographical distribution of publications and citations was studied, defining the most productive and influential countries. Fig. 3 shows the countries’ productivity based on their total number of publications on the topic of spare parts deployment and inventory centralization or decentralization. Darker colors are associated to China, Germany, Netherlands, and Italy, being the most productive countries with 138, 45, 43, and 43 publications, respectively. Moreover, as a matter of fact, Fig. 3 shows that both Eastern and Western countries contribute to publishing in the analyzed field, while Africa does not concur significantly to the research development. Instead, in terms of citations, Finland, United States, and Netherlands are the most influential countries, with 779, 473, and 397 citations, respectively. Comparing the most productive and most influential countries, it emerges that the only country leader in both fields is the Netherlands. This proves that not always the countries with a high number of publications provide scientific contributions considered interesting by other researchers. Hence, it is revealed the importance of not limiting a literature analysis to the most productive countries in the field, but also extending the investigation to other less prolific countries. This consideration also applies to authors, and journals, explaining why both productivity and influence of countries/authors/journals were analyzed in this work.

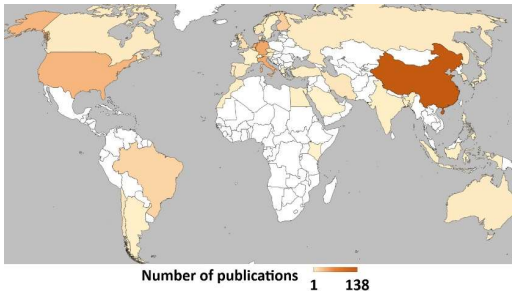

Fig. 3. Total number of publications per country

Subsequently, to identify the most productive and influential journals, three analyzes were performed. First, the journals mostly devoted to the considered topic were determined based on Bradford’s Law [26]: if journals containing papers on a given topic are arranged in descending order of publications, then successive zones of journals containing the same number of papers on the topic will form the geometric series $1: n: n^2: n^3: \ldots$. Fig. 4 shows the achieved results, indicating as the most productive journals (core sources) the ones situated in the first zone of Bradford’s ranking (grey rectangle, Fig. 4): Eur. J. Oper. Res. (EJOR, 14 publications), Int. J. Prod. Econ. (IJPE, 8 publications), Comput. Ind. Eng. (CAIE, 5 publications), Int. J. Prod. Res. (IJPR, 5 publications), Proceedings of the Int. Conf. on Ind. Eng. and Oper. Manag. (Proceedings of IEOM, 5 publications), IEEE Access (4 publications), IOP Conference Series: Mater. Sci. Eng. (4 publications), IFAC-Papersonline (3 publications), IFIP Adv. Inf. Commun. Technol. (IFIP AICT, 3 publications), Int. J. Logist. Syst. Manag. (IJLSM, 3 publications), and J. Oper. Res. Soc. (JORS, 3 publications). These 11 core sources (out of 109 journals) globally contain 57 papers, covering one-third (34%) of the analyzed database.

As a second analysis, the publication trend of the top 5 core sources was defined (Fig. 5). EJOR showed a high persistence, being the only journal with regular publications over the time (especially in the last 15 years). However, CAIE, IJPR, and the Proceedings of IEOM confirmed their significance, revealing a marked interest in the topic in the last decade. Conversely, IJPE showed declining interest, producing only 2 papers in the last 11 years.

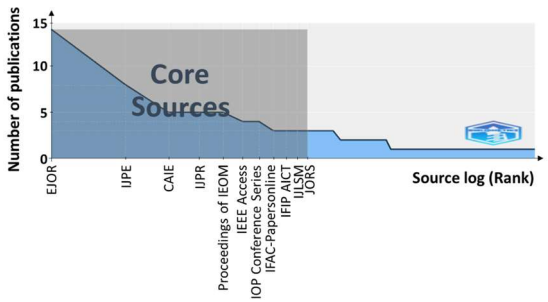

Fig. 4. Most productive journals according to Bradford’s law

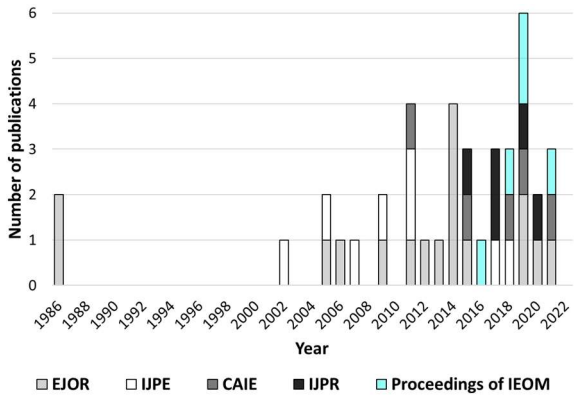

Fig. 5. Publication trend of the top 5 core sources

Since Bradford's Law highlights the most productive journals, but not the most influential ones, a third analysis was conducted, calculating the journals' average number of Citations Per Publications (CPP, Eq. 1).

$$CPP = \frac{Total\ number\ of\ citations}{Total\ number\ of\ publications} \quad (1)$$

Hence, the most influential sources were identified as the ones with the highest CPP (Tab. 1 lists the top 5). Based on Tab. 1, it is worth noting two aspects. First, the CPP analysis allowed identifying not only the most influential journals, but also the most significant papers in the field. For instance, the contribution by Computers in Industry [27] was highlighted, receiving 400 citations in 8 years, and confirming the peak in citations noted in Fig. 2. Secondly, none of the journals in Tab. 1 appears in Fig. 4-5, pointing out that the most significant literary contributions were not published in the core sources and remarking the difference between the most productive and most influential journals.

TABLE I

TOP 5 MOST INFLUENTIAL JOURNALS BASED ON CPP

Source (with references)	Number of publications	Number of citations	CPP
Comput. Ind. [27]	1	400	400
J. Manuf. Technol. Manag. [28][29]	2	276	138
Rel. Eng. Syst. Saf. [30]	1	86	86
Prod. Plan. Contr. [31][32][33]	3	255	85
IIE Transactions[34]	1	81	81

Finally, the most productive and influential authors were identified considering their publications and CPPs, and proposing a novel graphical descriptive tool (called *Qualitative Authors' Relevance Assessment - QARA*), which summarizes the main information on authors' productivity and influence. The QARA is shown considering the top 15 authors in terms of CPP (Fig. 6). However, it could be extended to all authors. In the QARA, a dot is used to describe the annual publications provided by each author. Specifically, the dots' size can be small, medium or large according to the number of annual documents published by each author (1, 2, or 3, respectively). The dots' color follows a chromatic scale based on the total number of annual citations received by each author (dark blue corresponds to 1 citation, while dark red corresponds to 10). Finally, the authors' names are ranked on the y-axis in descending order of CPP.

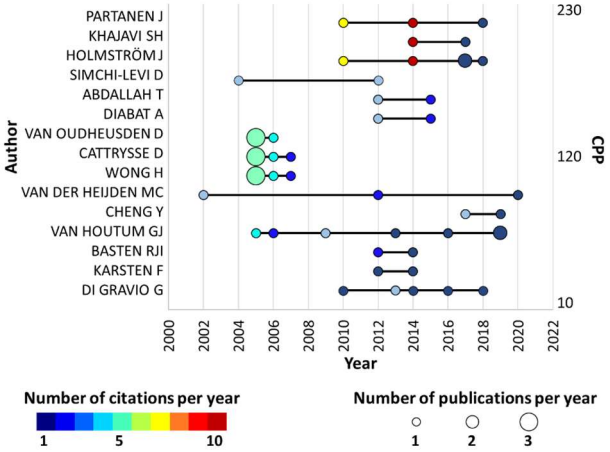

Fig. 6. Qualitative Authors' Relevance Assessment

From the QARA (Fig. 6), four considerations emerge that are useful for answering RQ1. First, the most productive authors in the field appear based on the total number of publications (number and size of dots). In particular, the most productive author is Van Houtum, with a total of 7 publications. Secondly, the most influential authors are identified based on the highest CPPs, recognizing Partanen, Khajavi, and Holmström as the top 3 authors in the y-axis (with CPP equal to 224.3, 201.5, and 135.6, respectively). This result shows the difference between most productive and influential authors. Thirdly, looking at the dots' distribution and size, it is possible to check the temporal publication trend of each author, also observing the publication cadence and the date of the first publication. Finally, it is possible to identify the most influential papers in the existing literature on the analyzed topic. As instance, in the upper part of Fig. 6, the papers characterized by the highest CPP are shown. Moreover, three red dots and two yellow dots both of small size (1 publication associated with each dot) are clearly visible, corresponding to the contributions with the highest number of citations [27], [28]. It is worth noting that these two most influential publications deal with the same topic, thus suggesting an emerging research stream in the analyzed field. Such emerging stream is to investigate the impacts of Additive Manufacturing (AM) on the SC configuration process, also considering the possibility of removing spare parts

inventories by setting decentralized SCs, where each DC owns its 3D-printer for producing items on-demand.

B. *Co-word network analysis*

To answer RQ2, first, the main themes related to the topic of inventory centralization/decentralization and the deployment of spare parts in DCs were examined by studying the co-occurrence of authors’ keywords in *VOSviewer*. Results are shown in Fig. 7, where keywords with a minimum number of co-occurrences of 2 are mapped together with their reciprocal links. Based on the colors and keywords of Fig. 7, 5 main research themes were identified related to the analyzed topic, which were confirmed by consulting the abstract of the database papers: (pink) the optimal deployment of spare parts in SCs with single or multi-location DCs and two or multiple echelons; (red) AM as an opportunity to switch from centralized to decentralized SCs, changing the spare parts deployment in SCs; (yellow) the optimization of spare parts deployment to improve maintenance activities in the sectors of aeronautics and military industry; (brown) the design of spare parts deployment in SCs where emergency and lateral shipments are allowed; (green) sustainability and reverse logistics with a focus on spare parts deployment in SCs.

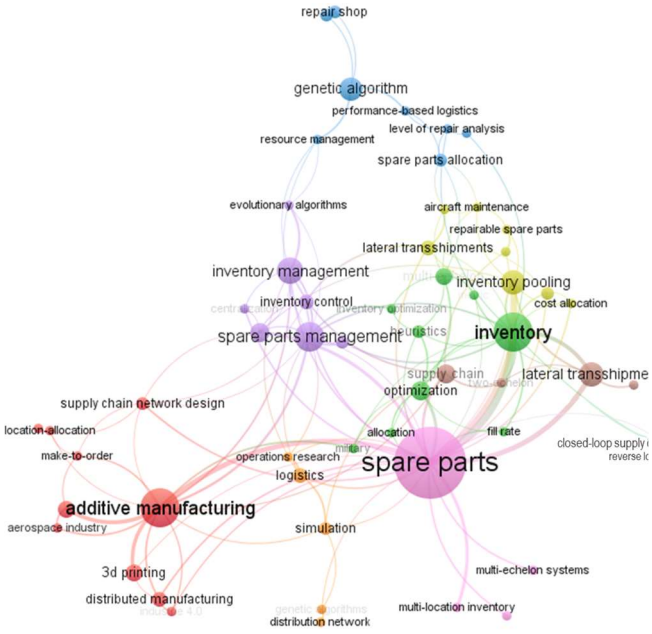

Fig. 7. Co-occurrence of authors' keywords

Finally, the answer to RQ2 was completed by building a Thematic Map of authors’ keywords following Cobo et al. [35] and using *Bibliometrix* (Fig. 8). Besides confirming the results of Fig. 7, Fig. 8 emphasized two driving (motor) themes that mainly concur in developing the research on the analyzed topic: the design of spare parts deployment in closed-loop SCs and the design of spare parts deployment with AM spare parts. In addition to this, Fig. 8 can also be used to define well-established (basic) themes on the analyzed topic, as well as some niche themes and emerging or declining research streams. Based on this, another consideration appears regarding the methods used by researchers to plan the spare parts deployment: while exact optimization models are widely used in the literature, simulation models seem to be scarcely proposed (emerging or declining themes), and heuristic optimization models are still partially considered a driving theme for research development. Concerning heuristic models, Fig. 8 underlines the authors' interest in using genetic algorithms to optimize the spare parts deployment and the SC configuration.

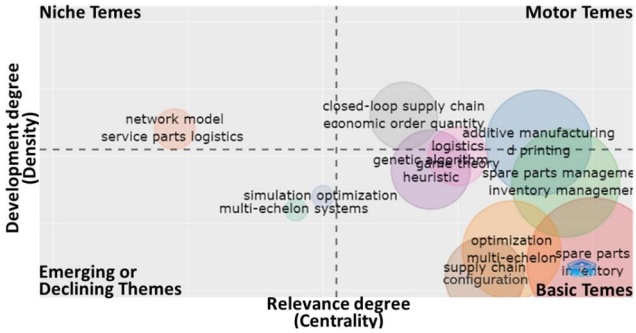

Fig. 8. Thematic Map of authors’ keywords

IV. Conclusions

This paper explores the extant literature on the topic of inventory centralization or decentralization and the deployment of spare parts in DCs (step 1 of SC configuration). Based on the numbers of publications and citations and developing a novel graphical tool (here called QARA), the most productive and influential countries, journals, and authors, as well as the 2 most influential contributions in the field were identified. Subsequently, the main themes related to the analyzed domain were investigated based on the co-occurrence of authors’ keywords, also determining what are the driving research streams that mainly contribute to developing the literature in the considered field. Results prove that, despite it has been almost 100 years since the considered topic was first mentioned, the literature in this field is rather lacking (especially until 2008). However, such a topic is attracting the attention of researchers in the last 10 years. Specifically, researchers are mainly interested in 2 driving research streams: (i) planning the deployment of spare parts by considering sustainability issues and on closed-loop SCs; (ii) evaluating the impact of AM in SCs, exploiting its advantages to optimize the spare parts deployment. Besides, concerning the methods used to define the spare parts' deployment, results show that exact optimization models are widespread among the documents in the analyzed domain. Conversely, simulation models are rarely used, while heuristic optimization models seem driving elements, which favor the development of research in the considered field. Finally, results underline the difference between the most productive and most influential countries, journals, and authors, underlining the importance of studying both.

Limitations of this research are related to having manually screened the sources of the dataset used for developing the bibliometric review. This was necessary since different semantic meanings were associated with the term "location" and its synonyms, leading to articles not relevant to the analyzed topic. Instead, the contribution of this work is to outline the characteristics of the current body of knowledge on the considered topic, enabling researchers to identify gaps in the literature, thus discovering future research opportunities. Future developments of this work could be two. First, to consult other databases in addition to Scopus to validate or deepen the bibliometric review. Secondly, to expand the systematic literature analysis by consulting in detail all the dataset papers, defining appropriate clusterization criteria to analyze them based on different perspectives.

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