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A bibliometric analysis on collaborative robots in Logistics 4.0 environments

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Abstract

Logistics activities were included in the wave of changes brought with the advent of the fourth industrial revolution. Several applications can be recognized for several activities, aiming all at efficiently optimizing processes and consequently production and volumes. Among them, collaborative robots involved for instance in picking, palletizing or assembly operations are quickly spreading, as also demonstrated by the increase in the number of publications available in literature. In response, this paper presents the results of a bibliometric analysis carried out on 64 scientific papers which deal with this topic within the logistics field. Analysis were made through two different software applications, namely Microsoft Excel™ and VOSviewer. Results are quite optimistic as they delineate great opportunities for collaborative robots to establish their position in the industrial context.

Keywords: cobot; industry 4.0; human-robot interaction (HRI); smart systems.

1. Introduction

Unsurprisingly, logistics as well was affected by what it is called the fourth industrial revolution, better known with the epithet Industry 4.0.

Taking a step back, Industry 4.0 starts spreading from 2011 in German territory, and just like the three revolutions that preceded, brings along with it significant improvements, new technologies and tools which aim this time at digitalizing the manufacturing field through the connection between physical and digital systems, and prompt analysis based on big data nowadays available.

According to [1] the main concepts resulting from this new phase of industrialization are the following:

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Smart Factory. Manufacturing will be *smart*, thanks to the implementation of sensors, actors and autonomous systems (precisely, *smart* technologies);
Cyber-Physical Systems. Intelligent systems allowing to collect and monitor information which are synchronized between the physical factory floor and the cyber computational space [2];
Self-Organization. Since manufacturing systems become decentralized, it follows a decomposition of the classic production hierarchy requiring more autonomy;
New systems in distribution and procurement. New channels are now available, with an extremely high level of individualization;
New systems in the development of products and services. Thanks to approaches of open innovation and product intelligence, product and service development as well will be individualized;
Adaptation to human needs. New systems and technology are required to follow human needs instead of reverse;
Corporate Social Responsibility. This last concept takes into account the sustainability perspective, considered now inseparable from industrial manufacturing processes.

Among the main technologies adopted to implement the abovementioned concepts, it is worth mentioning tools such as autonomous robots, internet of things (IoT), the cloud, additive manufacturing, augmented reality, machine learning techniques and many others [3].

As the incipit of the present section states, logistics is not exempt from the wave of changes recently brought. Indeed, up with the times, the term Logistic 4.0 was coined, whose definition provided by [4] after having carried out a careful literature review states: “a strategic technological direction that integrates different types of technologies to increase both the efficiency and effectiveness of the supply chain, shifting the focus of the organizations to value chains, maximizing the value delivered to the consumers as well as the customers by raising the levels of competitiveness. This is achieved by increasing the levels of transparency and decentralization among different parties through digitalization”.

According to [5] the main applications of Industry 4.0 in logistics are autonomous robots and vehicles; tracking and decision-making systems able to keep control over inventory; smart products and cloud-supported network for enhancing the information flow; real-time big data analytics of vehicles; products and facilities locations for finding materials and products’ optimal routing transport. Overall, IoT is the main application of Logistics 4.0 [6], especially supported by Radio Frequency Identification (RFID) systems.

Thanks to these kinds of innovation deriving from the Industry 4.0 paradigm, it is expected an overall 34.2% saving in costs, and additional revenues equal to 33.4% concerning logistics activities [7].

In the present manuscript the focus is on a specific recent technology, mentioned few lines above, namely autonomous collaborative robots, or rather cobots, which stem from the promising discipline of robotics called Human-Robot Collaboration (HRC) focusing on enabling robots and humans to jointly operate to complete collaborative tasks [8].

Cobots is a name that originates from the union of two English words, namely robot and collaboration. Despite its first mention goes back to 1999 [9], they became popular around fifteen years later [10]; just think that in 2017 their global sales reached 374,000 units, generating an increase equal to 217% compared to 2010 [11].

The definition provided by the ISO standard (ISO 10218-2:2011) recognizes collaborative robots as robots designed for direct interaction with a human within a defined collaborative workspace; according to that, the idea of danger which may derive from this interaction is overstepped: robots have no more to be kept away in caged areas, and it was demonstrated that operators are willing to collaborate with these tools and agree on the fact that competitiveness, quality, productivity and working conditions could be significantly improved [12].

Within the logistics field, cobots are mainly involved in activities such as pick and place, palletizing and assembling or applied on automated guided vehicles (AGV).

Since publications related to this topic start being numerous, the aim of the paper is to present some key results from a bibliometric analysis carried out on 64 scientific papers. To be more precise, the analysis takes into account the following main parameters: year of publication, journals/conference proceedings, citations, keywords, authors (and co-authors) and geography. Two different software packages were involved in carrying out the analysis, namely Microsoft Excel™ and VOSviewer (https://www.vosviewer.com/); this latter is a common software developed properly for constructing and visualizing bibliometric networks, and in this case, it allowed to deepen citation and co-authorship analyses.

In the remainder of the paper, section 2 defines the methodology followed; results from the analysis obtained through both software packages are presented in section 3; brief discussion and conclusions, finally, are provided in the last section (4).

2. Methodology

Many different queries were launched on the Scopus database (www.scopus.com) in February 2020 to define the sample of papers relevant to this study. The following keywords related to the topic were properly selected: "cobots" AND "logistics"; "collaborative robots" AND "logistics"; "collaborative system" AND "logistics"; "human computer interaction" AND "logistics"; "human-robot collaboration" AND "logistics"; "automation" AND "logistics"; "logistics 4.0". As it is easy to notice, all the queries make use of a common keyword (logistics), as the main focus fits in this field; the second keywords paired with logistics, instead, refer to synonyms or groups of words which can be indirectly associated to the technology in question.

After having carefully removed redundancies since many papers resulted from more queries, and off-topic manuscripts identified from title and abstract, the final number of collected papers corresponds to 64. Note that no constraint was set on the year of publication.

As far as the software packages, Microsoft Excel™ was used to elaborate statistics about the evolution over time of the topics, the journals or conference proceedings, the citations, the keywords, the authors and the geographical distribution of the studies. VOSviewer, instead, allowed to deepen the investigation on citations and co-authors relationships.

3. Review results

In this section, evidences from the bibliometric analysis carried out on 64 scientific papers whose topic deals with collaborative robots and their usage in the logistics contexts are presented.

Firstly, results from the analysis made through Microsoft Excel™ are depicted; the analyses made with VOSviewer follow. Due to length constraints, the geographical distribution will not be detailed; the main finding is that most of publications come from Germany (10 papers), homeland of Industry 4.0, followed by China (9 papers) and USA (8 papers).

3.1. Descriptive Statistics

3.1.1. Evolution over Time

The first descriptive parameter taken into account is the trend of the publications on cobots over time. Figure 1 below shows this trend.

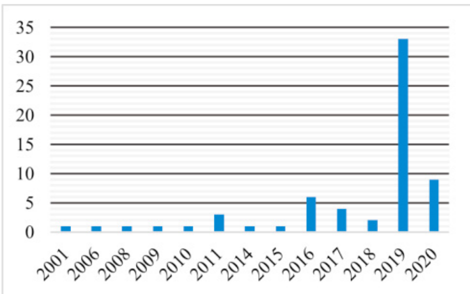

Fig. 1. Evolution over time of the analyzed papers.

The first published paper [13] dates back to 2001, precisely two years after the appearance of the term cobot, when the concepts of Logistics and Industry 4.0 did even not exist. Until 2015, production is rather lacking; indeed, only 15.65% of papers belongs to this period. The remaining 84.35% was published in the five years that follow, in line with the development of the technology and the implementation of several cobots within logistics systems, which became subject of case studies. It is worth mentioning year 2019, in which 33 papers were published (more than half of the total sample). Finally, note that for 2020 year only January and February are included in the time span of the analysis; in these first two months, a total of 9 papers was recorded; it is therefore reasonably expected a significant increase by the end of the year.

To completion of the analysis, the type of document was identified and related to the year of publication. The resulting histogram is below depicted (Figure 2).

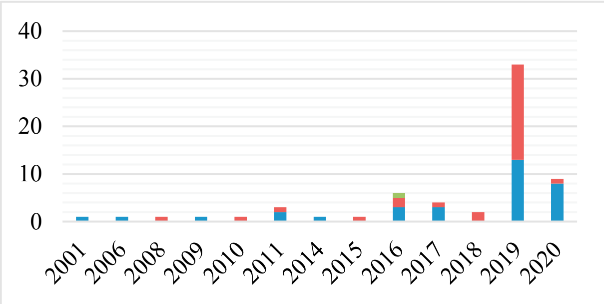

Fig. 2. Type of document vs. year of publication (blue color refers to articles, red to conference papers and green to the review).

As Figure 2 shows, the sample is quite well shared among conference and journal papers: 30 works were presented in international conferences and 33 articles were published in international journals. Finally, only one review paper was found in 2016, which deals with an examination of the current state of art for collaborative robotics, factors driving their entry within the industrial context and their outlook for the future [14]. This last result is not surprising; indeed, review studies require a significant number of articles to be carried out, and the topic is fairly recent.

3.1.2. Journal and Conference Proceedings Analysis

Most productive journals and conferences were secondly investigated. A total of 25 scientific journals and 20 international conferences/conference proceedings journals was identified. Most of them (20 journals and 13 conferences), presents only one paper. The only exceptions are all from conferences, and it is worth mentioning the IEEE International Conference on Emerging Technologies and Factory Automation – ETFA with 6 papers all presented in the 24th edition which took place in 2019 in Zaragoza (Spain). Indeed, the focus of this specific conference is on the latest developments and new technologies in the field of industrial and factory automation, and it is perfectly in line with the topic in question. Moreover, it confirms 2019 as most productive year. As far as journals, the number is quite well shared among journals whose main focus is on technical specifications of technologies (e.g. Cluster Computing or Industrial Robots) and on journals focusing specifically on logistics activities and supply chains (e.g. Supply Chain Management or Transportation Research Part E: Logistics and Transportation Review).

3.1.3. Citations Analysis

The third interesting parameter deepened is the number of citations recorded for each of the 64 papers. Overall, the sample in question received 411 citations. Specifically, manuscripts that turned out to have more than 20 citations are presented in Table 1 in descending order of the number of citations received (note that only for identification purpose, the authors' group is reported instead of the title).

Table 1. Most cited documents.

Authors	Publication year	Journal/Conference	Number of Citations	Reference
Barreto et al.	2017	Procedia Manufacturing	90	[15]
Chandra and Kumar	2001	Industrial Management & Data Systems	74	[13]
Barolli and Xhafa	2011	IEEE Transactions on Industrial Electronics	66	[16]

Sheu et al.	2006	Supply Chain Management	51	[17]
Dias et al.	2009	Annual Reviews in Control	22	[18]

As it is possible to note, these papers belong to the first period of time, preceding the advent of Industry 4.0, and they are considered pioneers in the field. The only exception is an overview of logistics implications thanks to these new technologies and developments by [15], which clearly results after many case studies and implementations and dates to 2017.

Furthermore, concerning the subdivision of citations among the nineteen years, overall 74 citations were recorded in both years 2001 and 2011, which is a surprising result as the topic started spreading years later; in 2017, instead, 92 citations are counted, the most active year. Clearly, for more recent publications it is difficult to reach high numbers of citations, as the process of peer reviewing requires time; but it is reasonable to expect an increase of citations for papers recently published.

3.1.4. Keywords Analysis

Fundamental in this kind of analysis is the deepening of keywords frequency; indeed, they allow to deduce the most common trends and topics associated to the subjects under investigation. To carry out this analysis, it is typically necessary to make some preliminary adjustments on the sample of papers.

First of all, the sample was reduced to 57 papers since in seven cases (specifically, two from journals and five form conferences) keywords were not provided; second, keywords used for executing queries were removed, as they would obviously reach high values in terms of numbers; third, synonyms, redundancies, spelling and acronyms were checked and standardized. As a result, a total of 185 words was obtained.

Results from the analysis will be provided only for the keywords turned out to be the most common (greater than or equal to 5 mentioning), i.e. Industry 4.0, Internet of Things (IoT), Supply chain, Intelligent system, Smart systems.

Industry 4.0 appears precisely sixteen times, in around 25% of the papers investigated; its first mention is in 2016, a little bit late compared to its spread (2011), but in line with the evolution over time of publications. From that year, it was constantly mentioned; specifically, two times in 2017, one in 2018, ten in 2019 and only one in 2020, as already said due to its short time span considered in the analysis. This result does not surprise, since it demonstrates that cobots are treated as applications brought from the fourth industrial revolution.

IoT follows, in precisely ten papers. As for the first keyword, the trend is regular and up with the times; indeed, despite it first appeared in 2011, most of the production related to this topic is in 2017 (two times), 2019 (five) and 2020 (two). Moreover, the joint use of cobots and IoT platforms brings multiple advantages, as it allows for programming them and collect/visualize all the data scanned from robots [10].

In line with the topic of this paper, the keyword Supply Chain as well is worthy of attention. This topic was mentioned seven times, more precisely two times in 2001, one in 2009 and four in 2019. The reason why for several years it was not used, is that probably at the beginning cobots were primarily studied from a technological point of view, in the light of their newness; then, once they reached a good maturity, they started to be implemented in real contexts; it follows their presence in 2019. Another reason could be that since logistics is an area of supply chain management and the queries made focused on logistics, this last term was preferred by the authors instead of a more general keyword.

Six times authors refer to the expression Intelligent systems: one respectively in 2016 and 2017, four in 2019. There is no doubt, in fact, that “intelligence” is one of the major attributes associated to this kind of robots, which are able to autonomously move and execute tasks.

The last keyword most spread among the sample is Smart systems; two times respectively in 2016 and 2019, and one in 2020. Indeed, in the introduction the use of actors allowing manufacturing to became smart were stated; cobots, are right those actors.

To be more thorough with the keyword’s analysis, a diagram highlighting frequency vs. persistence was also built. According to relating results, four categories of topics were identified:

- Emerging topics. Both frequency and persistence are low, meaning that these keywords are relatively new, and not well established (yet?). Among them we find Industrial automation and Automated warehouse, whose first mention is in 2019; for these keywords an increase in the usage can be surely expected, as the future relies on automation. The reason why they were mentioned only recently, specifically for Automated warehouse, is that real implementations are relatively recent compared to the first introduction of collaborative robots;

- Trendy topics. These keywords show high values of frequency but low persistence. This means that these keywords were spread for a limited period. We find the word Autonomous systems, which first appear in 2019 and then in 2020. For this keyword, therefore, the period of usage is limited to the recent years; it is reasonable to expect that if repeating this analysis in the future (hopefully on a greater number of papers), this keyword could have moved to the group of well-established topics;
- Intermittent topics. As the name of this category suggests, these terms have low frequency values, but high persistence. Among them there is the word Digitalization, appearing few times in various different years. Besides, this is a very general keyword, not very specific, but at the same time it accompanies almost all the innovations within the Industry 4.0 paradigm;
- Well-established topic. The last quadrant, of course, deals with keywords having high values of both frequency and persistence, so certainties in the field. The keywords before detailed all belong to this class.

Note that keywords which appeared only once were excluded from the construction of the graph, to be more effective in the representation.

3.1.5. Authors Analysis

Starting from 64 papers, the final number of authors considered is 219. Indeed, almost the whole sample is made of publications having more than one author. All the authors have collaborated to the development of only one paper, exception made only for two professors. They are Professor Leonard Barolli from the Department of Information and Communication Engineering of the Faculty of Information Engineering (Fakuoka Institute of Technology, Japan), who contributed to the literature with two papers both presenting a P2P (peer-to-peer) platform supporting distributed and collaborative systems [19] and [16]. This last paper was already mentioned few sections before, as it is got 66 citations and is, therefore, very well known to the scientific community.

The second name resulting from the analysis is Professor Vera Hummel, mechanical engineer from the ESB Business School of the Reutlingen University (Germany). She is co-author of two publications [20] and [21] both published in 2019 on Procedia Manufacturing. The first publication deals with the development of a solution to facilitate operators in programming cobots, so that they can perform tasks and be integrated with other smart devices within the factory; the second paper, instead, presents a collaborative tugger train system combined to other manual and semi-automated conveyor systems, which is implemented in order to reach self-organization and autonomous control of intralogistics systems.

3.2. Bibliometric Analysis

3.2.1. Citations Analysis

The software VOSviewer allowed to further explore the citation analysis, by offering different interesting visualizations of results and links.

The first aspect took into account is whether the citations identified appeared in some of the papers constituting the sample under observation (internal citation). Also papers with no citations were here included, as they may contain citations of other papers comprised in the sample.

The first visualization, shown in Figure 3, depicts the network; the size of each sphere associated with a publication (represented by the group of authors) depends on the absolute number of citations, and confirms the results from the analysis made under Microsoft Excel™. Indeed, authors to whom larger symbols correspond are the same listed in Table 1.

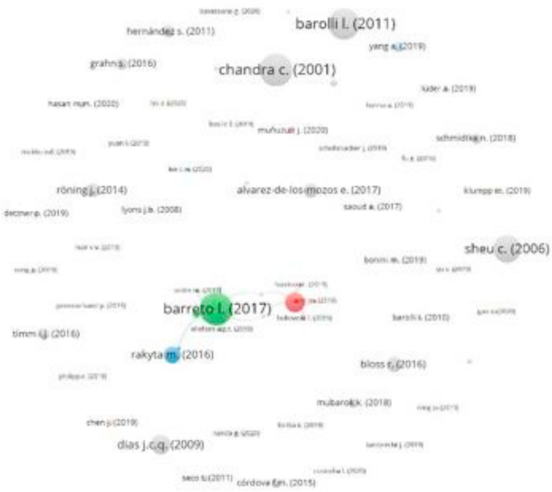

Fig. 3. Network visualization.

Figure 4, instead, illustrates the density visualization, whose shades occur in presence of most cited works, as the weight was set in accordance with the number of citations. This visualization confirms what as well has been said few lines above as far as most cited papers.

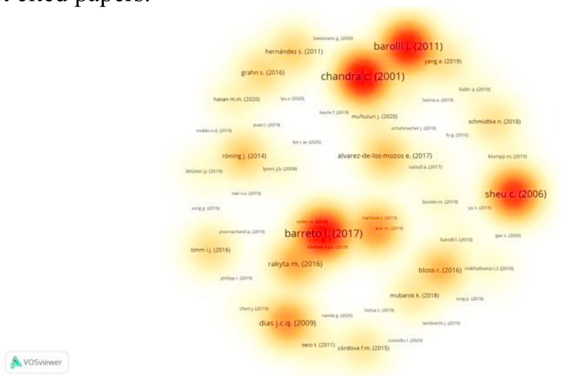

Fig. 4. Density visualization (weight set: number of citations).

If the weight moves from the number of citations to the links between papers, namely citations within the sample of these 64 papers, part of the graph obtained is shown in Figure 5, below.

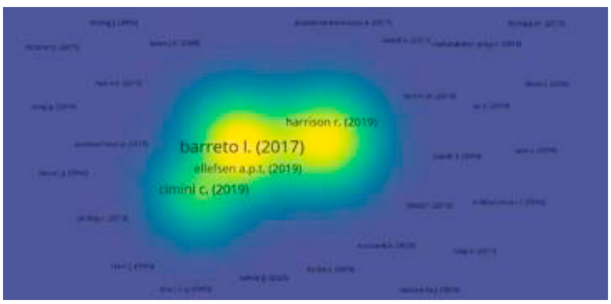

Fig. 5. Density visualization (weight set: links among the sample of papers).

Once again, [15] stands out, and this means that some of the 90 citations recorded are among the paper analyzed in the present manuscript. This did not happen for the remaining publications, since the names emerging are different: [22], [23] and [24], indeed, appeared here. Note that all these papers were published in 2019; it follows that they necessarily were mentioned in recent papers published in 2019 or in the early beginning of 2020. According to this result, apart from [15], the remaining top cited papers of Table 1 were not mentioned in papers having a similar specific topic (i.e. cobots).

The third overlay visualization, instead, allows to focus on the year. Specifically, in Figure 6 that follows, only a specific zoom of the whole visualization is presented, referring to the two papers receiving the highest number of citations within the sample. Both papers were published in 2017. Links were set as weight; consequently, the size of each sphere corresponds to the number of citations within the 64 papers, the color refers to the year of publication and each connection leads to the paper of the sample in which it was mentioned.

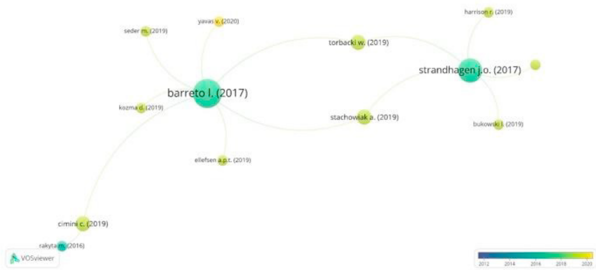

Fig. 6. The two top-cited papers resulting from the overlay visualization (weight set: links among the sample of papers).

The two publications in question are, once again, [15] and [25]; this last publication deals with Logistics 4.0 and emerging sustainable business models. Note that almost all the papers which later mentioned them were published in 2019 (and one in 2020), two year after their issue; indeed, it corresponds to the temporal spread of papers concerning this topic, so authors more frequently avail of literature publications and they focus on more recent papers, increasing the likelihood that citations are inside the sample, unlike in the past.

3.2.2. Co-authorship Analysis

The last aspect investigated refers to the collaboration mechanisms between authors. Specifically, by using the VOSviewer package it was possible to build a network showing 62 different clusters of authors. This reduced number, compared to the original value of 64, is justified because as already stated two authors contributed to two different papers, i.e. prof. Barolli and prof. Hummel. Indeed, their sphere is bigger, as its size in this case depend on the number of published papers; color, instead, refers to the publication year.

What emerged, is that there are no connections between the different clusters; this means that there are no collaborations among the authors (or co-authors) of the sample of papers under investigation.

By zooming the overlay visualization on the two clusters including the two names previously mentioned, we can see that Barolli is linked only to Xhafa, while Hummel, instead, is linked to Schuhmacher, Khun and Nair; moreover, Khun and Nair are also linked together.

The two representations are in line with the characteristics of the publications in question. Indeed, Barolli is single author of his first contribution (in 2010), while for the second (in 2011) Xhafa was included; as far as prof. Hummel, instead, she is co-author of both her studies with other researchers, specifically Schuhmacher for one paper, and Nair and Kuhn (who are also linked together, as already stressed) for the other.

By shifting the weight from the number of documents to the links and the visualization from the overlay to the density, shades in correspondence of an author will depend on the number of links, namely on the working group numerousness.

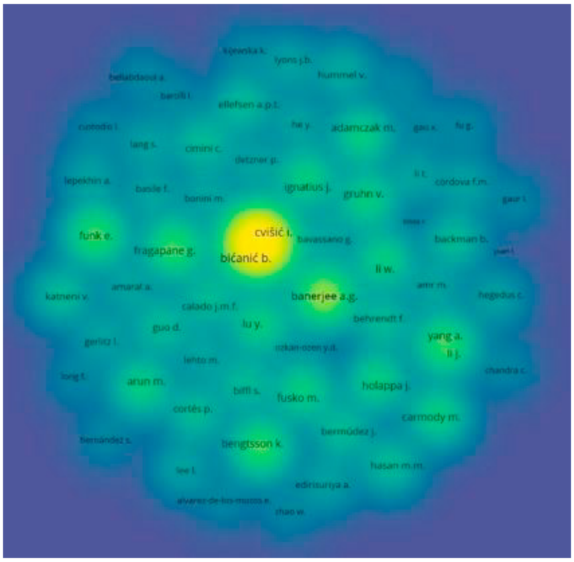

Fig. 7. Density visualization (weight set: links among the authors).

As it is possible to notice from Figure 7, where the density visualization is provided, it is clear that some groups are more wide than other, and this fact suggested the overlay visualization with the same weight, which proves that most of the numerous groups have worked over the years 2018, 2019 and 2020, so the most recent. This is an important signal, meaning that not only the number of publications recently increased, but also the academics and practitioners working on them. It follows a gain in the attention payed towards collaborative robots within the logistics context.

4. Conclusions

This paper aimed at presenting some key results from a bibliometric analysis carried out on 64 papers whose focus is on collaborative robots ("cobots") applied to logistics systems.

As it is possible to deduce from the results illustrated in section 3, the topic is spreading and many different contributions are coming from different countries; specifically, in terms of time, we can identify an upward trend, supported by the fact that more scholars and practitioners are making efforts towards research, as the working groups are becoming larger in terms of number of components. This also confirms that the logistics field is one of the most promising for their practical implementation, as also deductible from the keywords anlaysis.

It is expected in the years that will follow a further increase, as we still cannot consider this technology as steadily accepted and mature for its routinely implementation; indeed, improvements are still almost revolutionary, than evolutionary.

It is planned for the future a more in-depth literature review for investigating qualitative aspects related to the main tasks and activities which can be found in the same sample of the paper, and more in general to the contents; moreover, other queries will be launched by the end of the year to assess whether the number of publications has grown.

From a practical point of view, anyway, the only sore point is the global economic crisis due to the Covid-19 pandemic expected for the next months and years, which may delay investments of this kind as in many industries the attention is now shifted to different issues and problems.

Acknowledgements

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