





## Exploring the Nexus of RFID and Industry 4.0: Bibliometric Analysis to Investigate the Strategic Themes and Thematic Evolution

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### Abstract:

**Purpose:** This article aims to identify themes associated with RFID technologies (Radio Frequency Identification) and industry 4.0. Using key articles from the database developed for this study, the main themes underlying key technology features and their relationships will be uncovered.

**Design/methodology/approach:** Systematic quantitative literature review is conducted to uncover hidden relationships between RFID and industry 4.0. The research methodology encompasses a systematic analysis of pertinent literature and resources, employing a structured approach to identify and categorize crucial topics and keywords that constitute the basis for our exploration. Subsequently, we delve into the relationships within these identified dimensions, aiming to synthesize a holistic interpretation of the connections between RFID and Industry 4.0.

**Findings:** Through our rigorous analytical process, we have unveiled significant attributes embedded within the three delineated dimensions. These findings contribute to our capacity to construct a synoptic depiction that encapsulates all relevant associations between RFID technology and the Industry 4.0 paradigm. The synthesis of relationships between Radio Frequency Identification (RFID) technology and the Industry 4.0 framework, derived from our analysis of pivotal dimensions and keywords, offers a profound insight into the intricate interplay between these domains. As industries continue to evolve in the wake of technological advancements, this study contributes to the foundation of knowledge necessary to navigate the dynamic landscape of modern industrial systems.

**Research limitations/implications:** Bibliometric network analysis offers a systematic approach to literature review, aiding researchers in identifying seminal works, influential authors, and emerging trends within a field. By visualizing the relationships between authors, journals, and keywords, bibliometric network analysis facilitates the mapping of academic disciplines, enabling researchers to comprehend the intellectual landscape. Network analysis highlights potential collaboration opportunities by revealing clusters of authors or institutions with closely related research interests and specific works related industry 4.0 and RFID, was not found, however, being a potential limitation, it proved to be a way to maintain the originality and necessity of this work we are presenting.

**Practical implications:** The practical employs bibliometric research to explore the synergy between Industry 4.0 and Radio Frequency Identification (RFID), aiming to provide a comprehensive understanding and

practical applicability of these interconnected themes. The study's findings offer practical implications such as facilitating technology integration, optimizing operations, guiding investment decisions, fostering collaborations, informing policy-making, supporting professional development, and enabling knowledge dissemination. These insights underscore the tangible real-world impact of academic research in enhancing industry practices and driving innovation within the context of Industry 4.0 and RFID integration.

**Originality/value:** This study stands as one of the pioneering works to delineate the themes linked with both Radio Frequency Identification (RFID) technologies and the Industry 4.0 paradigm.

**Keywords:** RFID, industry 4.0, bibliometric analysis, technological trends

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## 1. Introduction

In 2011, industry 4.0 was first introduced as a paradigm to promote systematic integration of information and communication technology in industrial manufacturing (Acatech, 2015). Industry 4.0 is touted as the fourth phase of the industrial revolution, which began in the 18th century, as illustrated in Figure 1.

Compared to RFID, Industry 4.0 is a relatively recent concept. RFID originated from radar technology after the Second World War and later commercialized in the 1970s (Liukkonen, 2015; Velandia, Kaur, Whittow, Conway & West, 2016). RFID is a wireless communication tool for automatic identification and data capture (Irani, Gunasekaran & Dwivedi, 2010). Industry 4.0 integrates newer technologies, for digitalization, the manufacturer, or physical processes (Schuh, Anderl, Dumitrescu, Krüger & Hompel, 2020). Industry 4.0 can be construed as a group of modern tools including: Autonomous robot, Augmented reality, Cloud computing, Internet of Things, System integration, Additive manufacturing, Cyber-security, Simulation, and Big data analysis (Dubey, Gupta, Kumar & Kumar, 2022).

This article addresses the following questions: What are the key correlating research themes between RFID technologies and Industry 4.0 and are those themes effectively bridging RFID technologies to Industry 4.0? The article is organized as follows: the first part will systematically survey the literature (Chapter 2, 3 and 4). The second part will analyze the themes from the results of the survey to extract key topics that relate RFID technologies with Industry 4.0, positioned in chronologically from the last 10 years (Chapter 5 and 6). The third part (Chapter 7 and 8) will discuss and analyze those themes and conclude with a matrix illustrating their evolution from a unified vantage point bridging RFID to Industry 4.0.

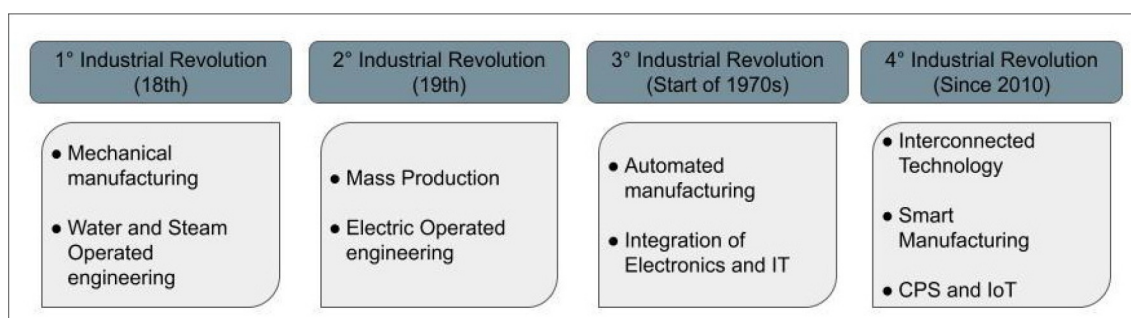


Figure 1. Four phases of Industry 4.0 (Muhuri, Shukla & Abraham, 2019)

## 2. Theoretical Background

Industry 4.0 refers to the transformation of organizations to the digital form to the extent that it is a completely new way of operating organizations. All the functions of organizations, from manufacturing to all other activities are taking place (internal and external) must change (Rajnai & Kocsis, 2018). It encompasses transformation of production in which silo cells become a fully integrated, automated, and optimized production flow while changing traditional production relationships among suppliers, producers and customers as well as between humans and machines for greater efficiencies and effectiveness. It is debatable whether to consider such a digitization of organizations an industrial revolution, nonetheless the idea of Industry 4.0 was initially originated in Germany, and later it was accepted by other countries (Sony & Naik, 2020). Among various features such as IOT, Internet of Service (IOS) and ERP, RFID is the most important feature that enables Industry 4.0 more effectively (McGowan, Andrews, Criscuolo & Nicoletti, 2015). RFID is generally recognized as an economical technology with powerful capabilities in identifying, tracing and tracking physical objects, systems, and services enabling communication and sharing information among them). RFID in conjunction with Industry 4.0 supports superior supply chain management, smart factories and smart cities (Zhou, Liu & Zhou, 2015). RFID tags are a crucial part of businesses today. RFID sensors function through radio transmissions and can provide information in real time and in particular the manufacturing logistics operation can be benefits several ways as it takes minimal human intervention in maintaining control over the departments. RFID is the key technology to improve manufacturing stage of businesses without any additional cost (Unhelkar, Joshi, Sharma, Prakash, Mani & Prasad, 2022). Focusing on the manufacturing area in the time of Industry 4.0, there are numerous ways RFID continues to work in synchronous with manufacturing companies for producing customized products, making cataloging more effective, and producing better results (Dopico, Gómez, De la Fuente, García, Rosillo & Puche, 2016). All the information from the production floor is managed through RFID and some plants operate entirely on the machines (Mldineo, Veza, Gjeldum, Crnjac, Aljinovic & Basic, 2019). This provides an opportunity to humans to devote their more time to supervising the plant and human errors can become a past thing.

As the world of technology expands, there are endless possibilities for businesses, for example, RFID can be a crucial tool for companies to become more productive and economical in production. Using an RFID system is an ideal tool for companies desire to automate processes and connect systems. RFID has the ability to support Industry 4.0 in connectively and integration of systems that can help businesses to be efficient and effective in all kinds of activities within and across organizations.

## 3. Methodology and Tools

This study uses Bibliometric Network Analysis (BNA). This is a method typically used to support researchers in understanding research, in the discovery of relevant themes, and uncovering the evolution structure over time (Gingras, 2016). The analysis uses different bibliometric measures and uses the software SCIMAT's analysis tools for clustering, centrality assessment, uncovering evolutionary and crossover maps (Hook & Börner, 2005). The analysis helps to understand the development of theoretical and applied works, for generating new knowledge. In our context, it will answer the following questions:

RQ1: For the period with a higher frequency of publications which ones are more relevant?

RQ2: Which element has propagated most during the period analyzed?

RQ3: Which themes show highest correlation between Industry 4.0 and RFID and correlate to various industry applications?

Based on systematic review, which inspires our approach, there are these five steps to be followed, which will be the topics of the study:

- Collection of raw data: Definition of the parameters for search in Scopus database.
- Selection of the segmentation periods: Analysis about amount of document in timeline.
- Selection of the theme filters: statistical analysis of the main themes of the work and their correlations.

- Data analysis and clustering: Execution of the SCIMAT system and analysis of the results, this topic will be divided into 4 subtopics:
  - Scimat execution
  - Analysis of Overlapping Map
  - Analysis of Evolution Map
  - Analysis of the Strategic Diagram
- Correlation analysis by period: in this topic, the correlations of the themes will be analyzed and how they are clarified in the articles of the base studied (Cobo, López-Herrera, Herrera-Viedma & Herrera, 2011).

In our research, we employ SCIMAT, a visualization tool designed to present a visual representation of network centrality and density. Centrality, a measure of a network's interaction with other networks, reflects its external cohesion, while density, measuring the network's internal strength, signifies its internal cohesion. By utilizing a bi-dimensional graph (Figure 2) where density is represented on the 'vertical-axis' and centrality on the 'horizontal-axis,' SCIMAT enables an insightful analysis of various themes (Cobo, López-Herrera, Herrera-Viedma & Herrera, 2012).

The visualization provided by SCIMAT relies on a diagram plot, which effectively portrays the interplay between network density and centrality. Each theme is represented as a point on the graph, with its position indicating its specific density and centrality values.

Leveraging this visualization tool, our analysis reveals the presence of four major theme groups (Figure 2a). The grouping of themes is based on their distinct positions within the bi-dimensional graph, highlighting similarities and differences in terms of density and centrality.

SCIMAT proves to be a valuable tool in visualizing and analyzing network themes' centrality and density. By plotting themes on a bi-dimensional graph, we gain a deeper understanding of the network's internal and external cohesion, leading to the identification of significant theme groupings. This visualization technique contributes to a more comprehensive analysis of network structures and paves the way for insightful research findings (Cobo et al., 2012).

Using this visual tool, we can segregate the finding into four major groups (Figure 2a) (Cobo et al., 2012):

- Motor themes (1o quadrant–Q1): High centrality and density.
- Basic and transversal themes (2o quadrant–Q2): High centrality and low development.
- Emerging or declining themes (3o quadrant–Q3): Low centrality and density.
- Highly developed and isolated themes (4o quadrant–Q4): low centrality and high development.

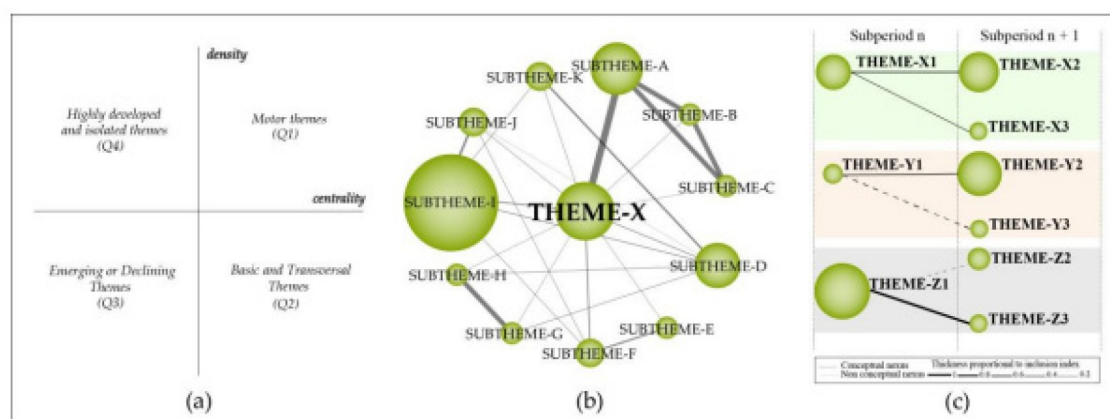


Figure 2. Diagram Network structures (Cobo et al., 2012)

Depending on their position on the plane, four types of themes can be identified as described by (Cobo et al., 2012):

- Upper-right quadrant: “are both well-developed themes and important for the structuring of a research field. They are known as the motor themes of the specialty, given that they present strong centrality and high density. The placement of themes in this quadrant implies that they are related externally to concepts applicable to other themes that are conceptually closely related”.
- Upper-left quadrant:” themes with well-developed internal ties but unimportant external ties and so are of only marginal importance for the field. These themes are very specialized and peripheral in character”.
- Lower-left quadrant: “both weakly developed themes and marginal, mainly representing either emerging or disappearing themes”.
- Lower-right quadrant: “important themes for a research field but are not developed. So, this quadrant groups transversal and general, basic themes”.

Aiming to explore the relationships between various themes within a network, thematic network analysis is a valuable method. By quantifying the size of nodes based on the frequency of associated documents and measuring the thickness of links through the equivalence index (Figure 2b) (Cobo et al., 2012), this approach enables a deeper understanding of the thematic landscape.

Figure 2c offers insights into the co-occurrence between research themes, shedding light on the number of relationships through Centrality and internal strength while considering their density. The analysis of these interactions contributes to a comprehensive view of the thematic web.

The thematic evolution map (Figure 2c) presents a visual representation of how these themes maintain a conceptual nexus across successive sub-periods. This visualization aids in identifying the continuity and evolution of themes over time, allowing researchers to discern trends and shifts in the thematic landscape.

In addition to node size, the size of clusters in the network is proportional to the number of core documents associated with each cluster. These clusters signify groups of related themes and provide a higher-level perspective on the thematic structure.

Solid lines between clusters indicate the sharing of main themes, pointing to significant thematic overlaps and common research areas. On the other hand, dashed lines represent shared cluster elements that do not correspond to the theme names, offering further insights into thematic relationships that might not be immediately apparent.

The thickness of the lines connecting themes is determined by the inclusion index, indicating the extent to which themes have common elements. A higher inclusion index suggests a stronger thematic association, highlighting shared characteristics and connections between themes.

Thematic network analysis, as demonstrated through Figure 2c, provides a powerful tool for understanding the intricate interplay and evolution of research themes within a network. By employing quantitative measures and visualization techniques, researchers can gain valuable insights into the dynamics of thematic relationships and contribute to a more comprehensive understanding of knowledge domains.

The checklist as well as the flowchart recommended by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement, published in 2020, were used to support the systematic review process of this work.

The analysis of key authors and highly cited articles pertaining to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) demonstrates the significance and impact of these guidelines in the academic realm. PRISMA has played a crucial role in standardizing and improving the presentation of systematic reviews and meta-analyses, contributing to the advancement of scientific research. The recognition and continued utilization of these guidelines are essential to ensuring the quality and integrity of research in this field (Haddaway, Page, Pritchard, & McGuinness, 2022).

#### 4. Collection of Raw Data

The database choice was SCOPUS, because to source relevant articles and use the search term “RFID” - instead of “Radio Frequency Identification”, and “Industry 4.0”, however the query resultant: TITLE-ABS-KEY (“RFID”) AND TITLE-ABS-KEY (“industry 4.0”) limit the SCOPUS search to the scope of the proposed study. We combine this with “4.0” (Table 1).

The use of the term “industry 4.0” would exclude some relevant studies, such as logistics 4.0, supply chain 4.0, and among other themes that are relevant to this study. Scopus search output (an RSI extension format) can be directly imported to SCIMAT for analysis.

Imported RSI file in SCIMAT, was found 2.995 different words, 374 documents and 1.127 author. (processing date: 09/09/2022).

The first step is however cleaning the data, this includes purging duplicate data, singular and plural words, for example: INDUSTRY, INDUSTRIES, INTELLIGENT-MANUFACTURING-SYSTEM, INTELLIGENT-MANUFACTURING-SYSTEMs, etc.

In SCIMAT, this type of grouping can be performed in groups of words, so words with the same meaning can be grouped together, mitigating the bias and achieving 2718 groups/words.

In accordance with methodology, the exploration of values and quantities was conducted employing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach. Through the systematic application of the PRISMA framework, the investigation harnessed its structured flow to precisely identify and delineate the discernible quantities and pertinent factors amenable to rigorous analysis, as we can see in Figure 3.

Criteria	Search Parameters
Publication period	Articles published from 1980 until 2022
Scopus data search	(TITLE-ABS-KEY (“RFID”) AND TITLE-ABS-KEY (“4.0”))

Table 1. Search Parameters

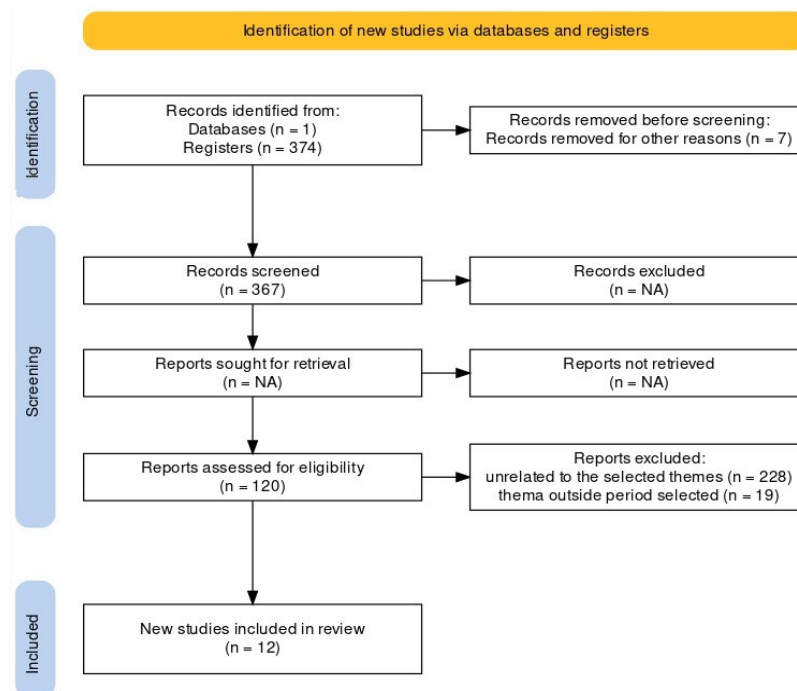


Figure 3. Sort documents

Figure 3 represents the systematic review process carried out in the SCOPUS database, with 374 documents listed in the extraction. Subsequently, in chapter 5 it will be explained how the selection of the segmentation periods (2012 to 2022) was made. At that stage, seven documents that were outside the analysis period were eliminated. Chapter 6 will show how the definition of the filter themes was as well as the identification of the most cited authors in the literature. Chapter 7 will show the analysis of the data and the clusters, after eliminating 228 documents because they are not related to the topic as well as another 19 because they appear repeated, to finally do the analysis with 120 documents. Another 12 documents are included in the theoretical background.

## 5. Selection of the Segmentation Periods

The next step is to co-relate the publications produced with their respective period, by exporting the data set from SciMAT to excel (Figure 4).

This temporal analysis provides the answer for our RQ1. One quick conclusion that we can initially make is that before 2011, there is no relevant document produced, and from 2016 to 2022 we had a higher number of publications. The main reason for the increase in the first decade of 2000, is explained by (Schuh et al. 2020). The term “Industrie 4.0” was introduced in 2011 by the Communication Promoters Group of the Industry-Science Research Alliance”.

The statistical trend analysis uses the R squared, which shows us an increased document quantity. Understanding a trade increased, applying year by year the % relative to the sum of all documents, the number of documents between 2018 and 2022 is more than 78%.

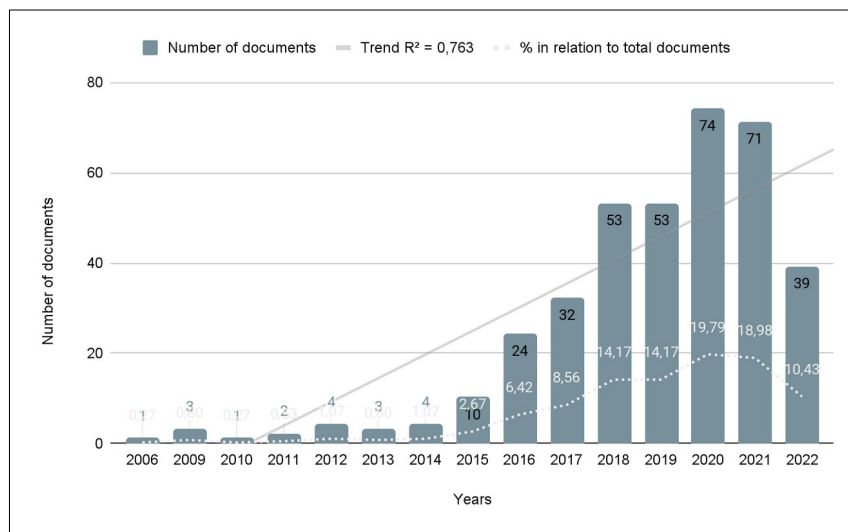


Figure 4. Published documents by calendar year

## 6. Selection of the Theme Filters

To answer RQ1, as to whether the relevance of the publication was concentrated in a certain period, we have chosen the period starting from 2012 up to the current year, 2022. This positions the temporal context of articles from the last 10 years. This leads to 367 documents, equivalent to ninety-eight percent (98%) of the entire sample. The distribution across each year is shown in Table 2. We use a linear correlation to understand which theme, “RFID” or “INDUSTRY 4.0” have correlation with the search realized for this study (RFID + 4.0). The result from linear correlation to “RFID + 4.0” and “INDUSTRY 4.0” is 0.92 and “RFID + Industry 4.0” and “RFID” is -0,55. In according (Adeniji, 2019), values near 1 have a strong correlation, and then the theme “INDUSTRY 4.0” has more correlation than “RFID”, and negative near -1 has a relation, but it is contrary, in this case the documents amount found “RFID + Industry 4.0” and “INDUSTRY 4.0” are growing together and “RFID + Industry 4.0” and “RFID” diverge.

Year	RFID + Industry 4.0	% total documents	Industry 4.0	% total documents	RFID	% total documents
2011	2	0,54	0	0,00	2.986	9,82
2012	4	1,08	2	0,01	2.951	9,71
2013	3	0,81	31	0,13	3.005	9,88
2014	4	1,08	91	0,38	2.722	8,95
2015	10	2,71	219	0,90	2.298	7,56
2016	24	6,50	569	2,35	2.482	8,16
2017	32	8,67	1.211	5,00	2.535	8,34
2018	53	14,36	2.244	9,26	2.513	8,26
2019	53	14,36	4.565	18,84	2.693	8,86
2020	74	20,05	5.186	21,40	2.226	7,32
2021	71	19,24	5.472	22,58	2.321	7,63
2022	39	10,57	4.642	19,16	1.674	5,51
Total	369	100,00	24.232	100,00	30.406	100

Table 2. Compare the number of documents of themes

This correlation helps to explain the increase in the number of documents starting in 2016 to the themes of this study. Another relevant number is the same % concentrate of number the documents if using Pareto laws to detect the most important period, by dividing the 80/20 (Adeniji, 2019; Arsenova, 2013; Kalibatiene and Miliauskaitė, 2021) to achieve approximately 80 % “RFID + 4.0” achieve between 2018 and 2022 (78%), “INDUSTRY 4.0” 2019 and 2022 (81%), and “RFID” 2013 and 2022 (80%).

Figure 5 visualizes the relationship between the number of documents, previously mentioned the relationship between “INDUSTRY 4.0” and “RFID + 4.0”, as we can see, blue (“RFID + 4.0”) and red (“INDUSTRY 4.0”) present a greater degree of similarity, than yellow (“RFID”). Based on the % of documents number that increased during the same period, as well as the linear correction, it is evident that “RFID + 4.0” and “INDUSTRY 4.0” have a more significant relationship than “RFID + 4.0” and “RFID”. Using the database, we also identified the ten most cited author (as shown in Table 3,) related to the themes “INDUSTRY 4.0” and “RFID”.

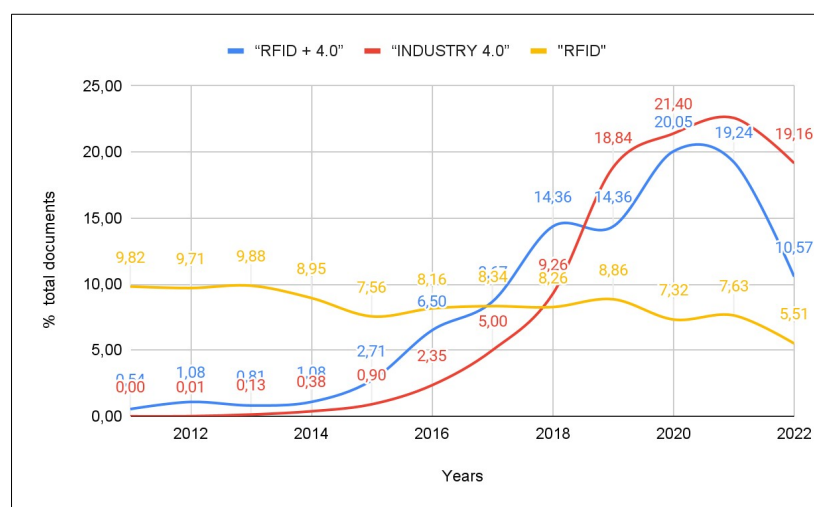


Figure 5. % of documents by periods



Table 3 contains the range of 760 (72,94%) of all 1042 citations from database. Fernández-Caramés, was the most cited author with 3 documents but is the same amount of Holland, but and Zhong, but Fernández-Caramés has 196 (18,88%) of all citation then another two, that have respective 113 (10,84 %) and citation 108 (10,46%). Pal has two documents and 2 documents 40 (3,84 %). Ivanov, has the most cited document, with 127 (12,19%). After them, Fraga-Lamas, Lv, Ding, Frankó and Li, have one document too.

Authors	Citation count	Title	Year
Fernández-Caramés, Blanco-Novoa, Froiz-Míguez & Fraga-Lamas	103	Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability Applications in Big Data-Driven Supply Chain Management	2019
Fernández-Caramés et al.	41	Smart pipe system for a shipyard 4.0	2016
Fernández-Caramés et al.	52	A fog computing based cyber-physical system for the automation of pipe-related tasks in the industry 4.0 shipyard	2018
Ivanov, Tang, Dolgui, Battini & Das	127	Researchers' perspectives on Industry 4.0: multi-disciplinary analysis and opportunities for operations management	2021
Holland, Nigischer, Engelmann & Stjepandic	14	Intellectual property protection and licensing of 3d print with blockchain technology	2018
Holland, Nigischer & Stjepandic	58	Copyright protection in additive manufacturing with blockchain approach	2017
Holland et al.	41	Intellectual Property Protection of 3D Print Supply Chain with Blockchain Technology	2018
Mehami, Nawi & Zhong	41	Smart automated guided vehicles for manufacturing in the context of Industry 4.0	2018
Zhong, Xu, Theunissen & Xu	19	Smart AGV System for Manufacturing Shopfloor in the Context of Industry 4.0	2018
Zhong, Xu & Wang	48	IoT-enabled Smart Factory Visibility and Traceability Using Laser-scanners	2017
Fernandez-Carames & Fraga-Lamas	78	A Review on Human-Centered IoT-Connected Smart Labels for the Industry 4.0	2018
Pal & Yasar	28	Internet of Things and Blockchain Technology in Apparel Manufacturing Supply Chain Data Management	2020
Pal	12	Algorithmic solutions for RFID tag anti-collision problem in supply chain management	2019
Lv & Lin	26	Design an intelligent real-time operation planning system in distributed manufacturing network	2017
Ding & Jiang	25	A hybrid-data-on-tag-enabled decentralized control system for flexible smart workpiece manufacturing shop floors	2018
Frankó, Vida & Varga	24	Reliable identification schemes for asset and production tracking in industry 4.0	2020
Pei, Tong, He & Li	23	Research on design of the smart factory for forging enterprise in the industry 4.0 environment	2017

Table 3. List of most cited authors

## 7. Data analysis and Cluster Analysis

### 7.1. SCIMAT Analysis Execution

To analyze the publications collection and the context of articles from the last 10 years, they are segregated into six two-year periods starting from 2012. Table 4, gives the data distributions amongst these periods. As per (Cobo et al., 2012) method, we are required to define analytic parameters by period.

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Years	Nº Periods	Documents
2012-2013	2	7
2014-2015	2	14
2016-2017	2	56
2018-2019	2	106
2020-2021	2	145
2022-2999	1	41

Table 4. SCIMAT 2-year period.

As per (Cobo et al., 2012) method, we are required to define analytic parameters by period. These are shown in Table 5.

Criteria	Analytic Parameters	Explain
Select periods	(Identical to Table 2)	
Selecting the units of analysis	Words: Author's words, Source's words, Added words	This selection, classifies and divides the information according to the selection made.
Selecting the data reduction methods	minimum frequency = 1	frequency limit calculation, by the value within the frequencies of the terms.
Selecting the kind of matrix	Co-occurrence	Reference has been chosen, a document bibliographic coupling network will be built
Selecting the network reduction methods	Edge value reduction = 2	That is, only the edges with a value greater or equal to n in a given period will be taken into account. (COBO)
Normalization	Equivalence index	chooses the similarity measures commonly used in the literature to normalize networks
Selecting a clustering algorithm	Simple centers algorithm: maximum 20, minimum 1	Using a low amount to assemble a cluster, due to low sampling and thus making the relationship denser.
Selecting the document mappers	Core mapper e secondary mapper	intersection mapper which adds the documents that have all the items of the cluster and which adds the documents that have at least k items in common with the cluster
Selecting the quality measures	h-index e sum citations	Base Sample
Selecting the measures for the longitudinal map	Jaccard's index e inclusion index	verification of the sample for its diversity.

Table 5. SCIMAT analytic criteria

## 7.2. Analysis of Overlapping Map

In this analysis, we uncover main connected themes within each period. We give preference to those displaying continuity and greater density as recommended by (Cobo et al., 2012). This will enable understanding the evolution and continuity of the theme throughout. SCIMAT has a tool that monitors the theme variations in periods analyzed. This can also be demonstrated graphically using overlapping map shown in Figure 6. This map presents subsequent periods and the number of shared keywords between them. Arrows shared between periods represent the number of subsequent keywords that persist. The number in each circle represents the number of all keywords used during the period. Arrows above each circle represent the number of keywords of the previous period and the current period respectively.

Figure 6 shows an increasing number of keywords, from 86 in Period 1 to 1319 in Period 5. Period 6 is an anomaly the number decreased, because the dataset was generated until 9/September/2022. By removing overlapping data, we can understand the evolution of themes and their variations. The percentage of the Similarity Index between the periods (the number in parentheses) plotted on Figure 7 shows a constant but discreet evolution. The increased number of keywords the sub periods (2018-2019 and 2020-2021), highlights the increased correlation between themes.

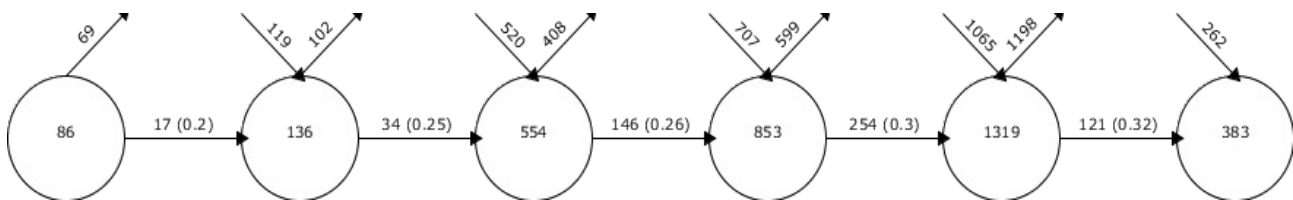


Figure 6. Overlapping Map

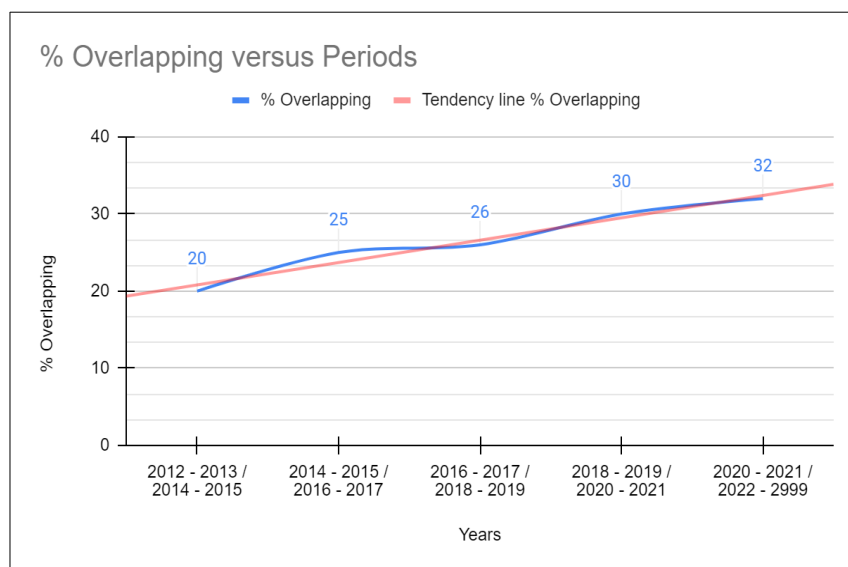


Figure 7. % overlapping

## 7.3. Analysis of Evolution Map

The next analysis is to identify the themes from Evolution Map generated for SCIMAT. The main themes are ordered from top to bottom. Themes with higher density are presented as larger circles. The relationship between the themes can be evaluated by the thickness of the lines, the stronger the relationship the thicker are the lines. As Figure 8 shows, the main themes are strongly connected.

In period (2011-2012), only one theme, “TRACKING-(POSITION)”, appears. The period doesn't have any document related to “INDUSTRY 4.0”, as seen in Table 2. “TRACKING-(POSITION)” has however a

connection to “RFID” in the next period. Later in the paper, we will uncover stronger relations with the theme “RFID”.

In period (2013-2014), “RFID” is the only theme, and has a connection with “MANUFACTURE” in the next period. This theme is a pillar to “INDUSTRY 4.0” and applications to the “RFID” study cases. “SLOT-ANTENNAS” has a relation to this theme being about tools to the application “RFID” and “INTERNET-OF-THINGS” has a stronger connection than the other two. Analysis of the documents (Analysis of data and discussions). “RFID” is considered the “initiation” of the “INTERNET-OF-THINGS”, hence the strong correlation.

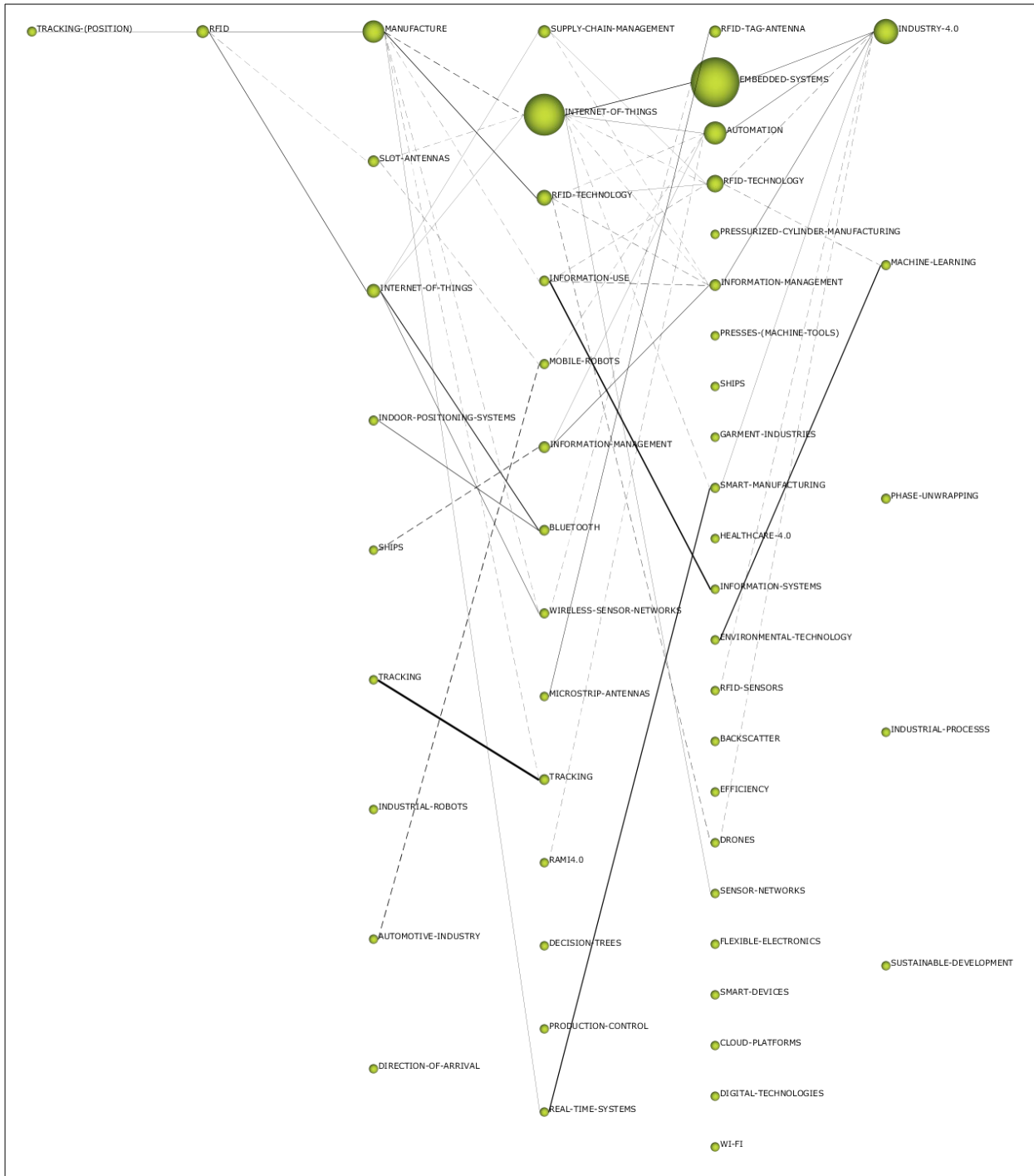


Figure 8. Evaluation map

The themes “MANUFACTURE”, “SLOT-ANTENNAS” and “INTERNET-OF-THINGS”, are the only themes in period thirty (2015-2016), that have a connection with the previous period and are in superior lines, that show importance in an Evaluation map analysis. Observe the connection to the next period (2017-2018), whit another theme that has a continuous connection to another period. “MANUFACTURE” have a connection to “RFID-TECHNOLOGY” for the same reason as the previous connection whit theme “RFID” and the other connection, “INTERNET-OF-THINGS” was the relation to application study cases between these two themes more “RFID”, just as it happened with “MANUFACTURE”, have a connection about application use.

In the fourth period (2019-2020), “SUPPLY-CHAIN-MANAGEMENT”, is connected to “RFID-TECHNOLOGY”, because of the applications used, and “INFORMATION-MANAGEMENT”, has a correlation to the theme “INDUSTRY 4.0” applications, due an information process and system necessary to administer all tools. “INTERNET-OF-THINGS”, to Evaluation map analysis, has a strong relation whit “EMBEDDED-SYSTEM” and “AUTOMATION”, due to a thickness line. In addition, these themes have applications to connect data and manage devices. (Ivanov et al., 2021) and (Neal, Sharpe, van Lopik, Tribe, Goodall, Lugo et al., 2021). “RFID-TECHNOLOGY”, also connected the same theme in the next period, connecting “AUTOMATION” and “INFORMATION-MANAGEMENT”, due to the application of “RFID” in automation process study cases. The last selected theme is “INFORMATION-USE” that connected with “RFID-TECHNOLOGY” to the integration of information and communication technology (Carvalho, Pimentel, Azevedo & Velez, 2018) and connected to “INFORMATION-MANAGEMENT”, for the reason “INFORMATION” applications.

Even though “RFID-TAG-ANTENNA” sits at the top of fifth period (2020-2021), it has only one previous theme and no subsequent theme. Therefore, let’s not delve deeper into this topic, as we are going to cover it again in the next topic analysis (Analysis of data and discussions). “EMBEDDED-SYSTEM” and “AUTOMATION”, have only an important line thickness whit “INDUSTRY 4.0” in the next period. As mentioned earlier in the period (2019-2020), “EMBEDDED-SYSTEM” helps to apply the “INDUSTRY 4.0” concepts. “RFID-TECHNOLOGY” was repeated in this period, due to its relation whit de main theme “RFID” in your applicability. Another important aspect is the connection with “INDUSTRY 4.0” and the theme “MACHINE-LEARNING”, this last, for reason to connect the applicability of data collection from “RFID-TECHNOLOGY”, and “INFORMATION-MANAGEMENT” have connected with the “INDUSTRY 4.0”.

For the visual analysis, drawing tracks to select more upper keywords and that was possible to make a track from 2011 to 2022 and not repeat themes, if possible. Some periods with a low quantity of themes as 2011-2012 and 2013-2014, and some themes are hubs connecting to a lot of themes, like “INTERNET-OF-THINGS” in 2018-2019. The track’s color-line groups the themes which maintain relationships is important to understand the evolution of the theme period by period. As shown in Figure 9, we were also able to delineate some paths that demonstrated the linearity of themes throughout the analyzed period.

The size of the cluster is related to the association documents, observed the Figure 9, the themes “INTERNET-OF-THINGS” (2018-2019) and “EMBEDDED-SYSTEMS” (2020-2021), are expressive and looked by horizontal analysis, “INTERNET-OF-THINGS” is a hub by other themes, as can show in 2017-2018 just one input and four output and 2020-2021, being input and five output. The theme “MANUFACTURE”, like “INTERNET-OF-THINGS”, is another significant hub with one input and six outputs. Transcribing the tracks in Figure 9, we have Table 6, contend themes of the tracks choices.

Figures 8 and 9 analysis, as summarized in Table 6, answer RQ2. The third period (2016-2017) shows an increased number of themes, compared to the first two periods (2012-2013) and (2014-2015). In addition, the third period has “MANUFACTURE” as an important hub of themes, and “INTERNET-OF-THINGS” is a theme that repeats in the fourth periods, but with more relevance. In period six, “RFID-TECHNOLOGY”, is the theme with most connections with origin in important themes like “RFID” “MANUFACTURE” and “INTERNET-OF-THINGS” and then self in the previous period.

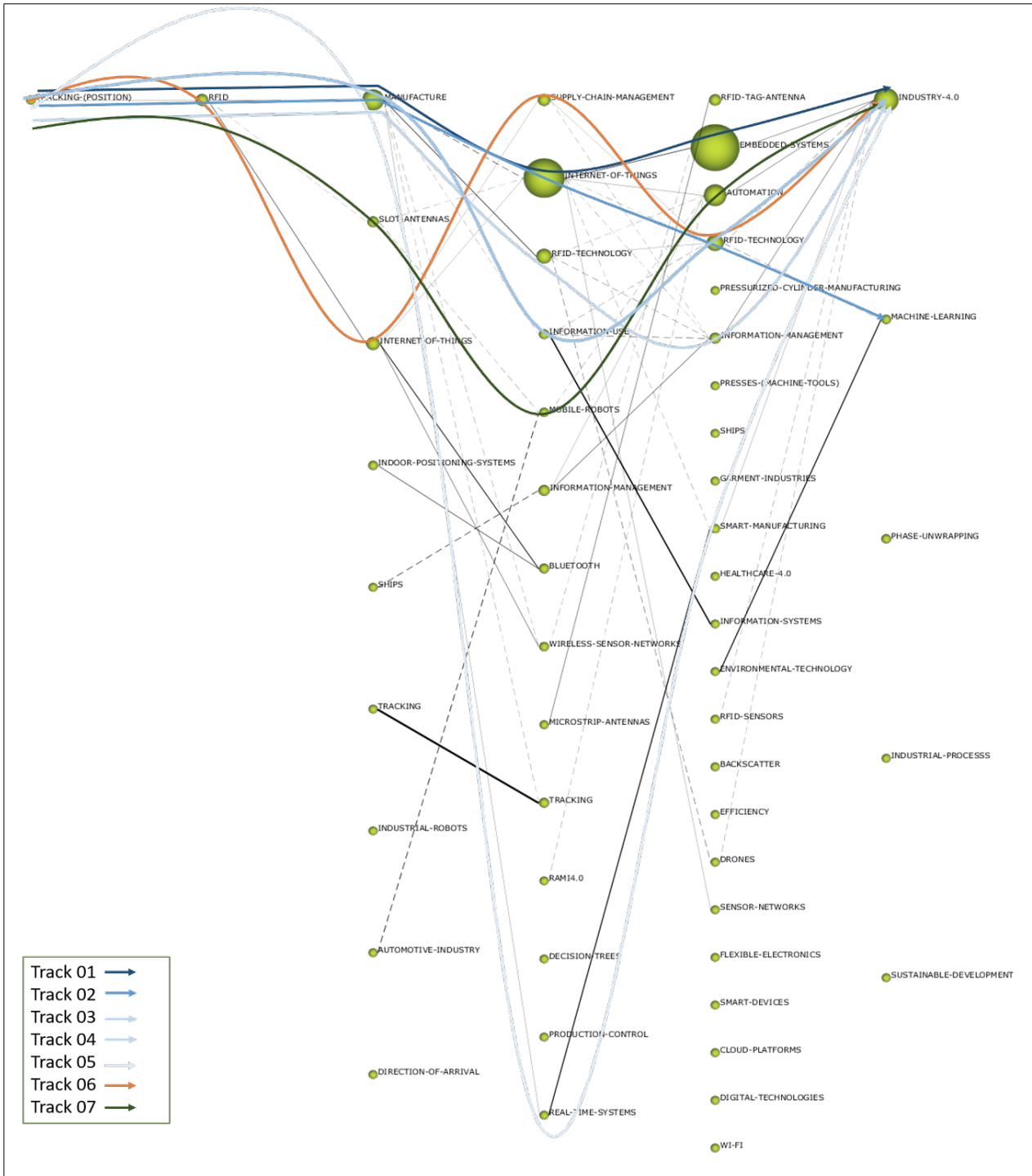


Figure 9. Evaluation map track lines

#### 7.4. Analysis of the Strategic Diagram

As we earlier discussed, the centrality and density position of a given theme uncovers some of their key features and how they relate to other themes in the network of themes. We undertake this for each detected cluster in a given period. Motor Themes or relevance Themes will be considered those of High Centrality. For the themes, we need to understand the strength and their interrelations, to identify the documents to be researched. A systematic tool available in SCIMAT, called “Strategic Diagram”, we were able to create a matrix by the defined period.

Track	2012-2013	2014-2015	2016-2017	2018-2019	2020-2021	2022-2099
01	TRACKING-(POSITION)	RFID	MANUFACTURE	INTERNET-OF-THINGS	EMBEDDED-SYSTEMS	INDUSTRY-4.0
02	TRACKING-(POSITION)	RFID	MANUFACTURE	INTERNET-OF-THINGS	RFID-TECHNOLOGY	MACHINE-LEARNING
03	TRACKING-(POSITION)	RFID	MANUFACTURE	INFORMATION-USE	RFID-TECHNOLOGY	INDUSTRY-4.0
04	TRACKING-(POSITION)	RFID	MANUFACTURE	RFID-TECHNOLOGY	INFORMATION-MANAGEMENT	INDUSTRY-4.0
05	TRACKING-(POSITION)	RFID	MANUFACTURE	REAL-TIME-SYSTEMS	SMART-MANUFACTURING	INDUSTRY-4.0
06	TRACKING-(POSITION)	RFID	INTERNET-OF-THINGS	SUPPLY-CHAIN-MANAGEMENT	RFID-TECHNOLOGY	INDUSTRY-4.0
07	TRACKING-(POSITION)	RFID	SLOT-ANTENNAS	MOBILE-ROBOTS	AUTOMATION	INDUSTRY-4.0

Table 6. Selected themes in Analysis of thematic areas tracks.

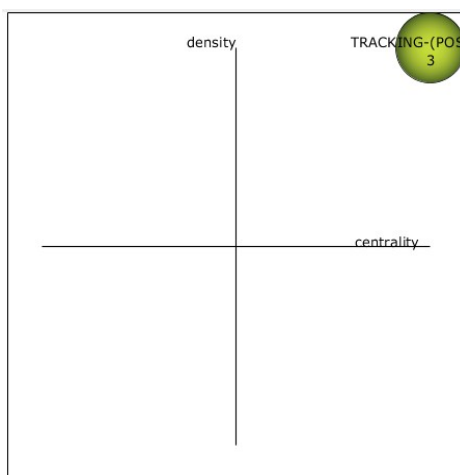


Figure 10. Clusters for 2012-2013

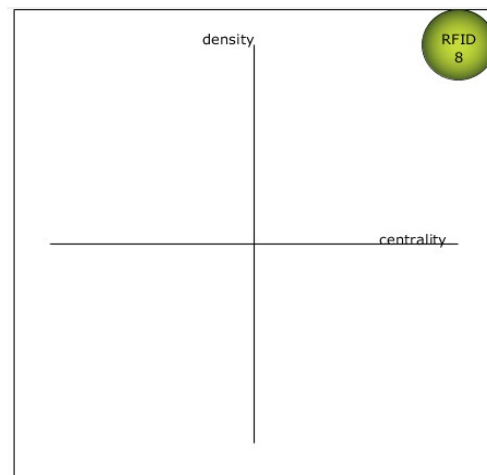


Figure 11. Clusters for 2014-2015

As can see in Figures 10 and 11, just have one theme by period “TRACKING-(POSITION)” by 2012-2013 and “RFID” by 2014-2015. Below in Figure 12 the chosen themes were “MANUFACTURE”, “SLOT-ANTENNAS” “INDOOR-POSITIONING-SYSTEMS” and “SHIPS”. Moving on to the next, Figure 13, the main themes are “SUPPLY-CHAIN-MANAGEMENT” “INFORMATION-USE” and “TRACKING”.

The last two periods analyzed 2020-2021 and 2022-2099, are represented in Figures 14 and 15, chosen for the respective periods “RFID-TAG-ANTENNA”, “EMBEDDED-SYSTEMS”, “PRESSURIZED-CYLINDER-MANUFACTURING” and “INFORMATION-SYSTEMS”, for the last period “AUTOMATION” and “INDUSTRY-4.0 MACHINE-LEARNING”.

Following the bibliometric method and answering RQ3, main themes from the study using Analysis of thematic areas were merged by density. This is shown in for defined the mains themes from the study, that we can see in Table 7.

Selected the main themes, we ask the RQ3, shows the themes most related whit industry 4.0 and RFID, as we can showed up in Table 7. We define documents for themes and periods that will be used for the discussion topic. This matrix can be seen in Annex 01 and will be used to select documents for the themes selected for discussion of the horizontal analysis and strategic diagram.

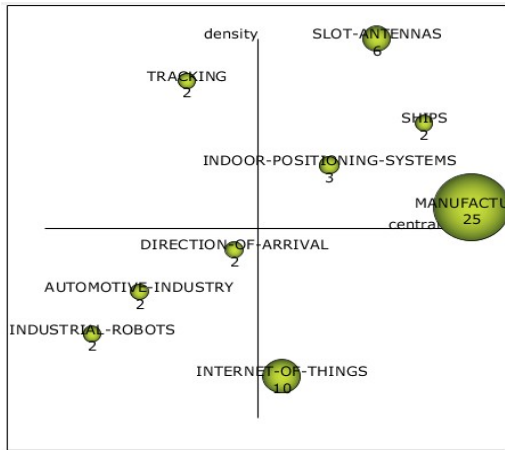


Figure 12. Clusters for 2016-2017

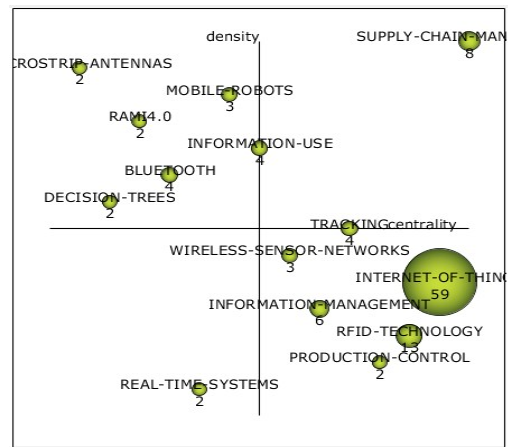


Figure 13. Clusters for 2018-2019

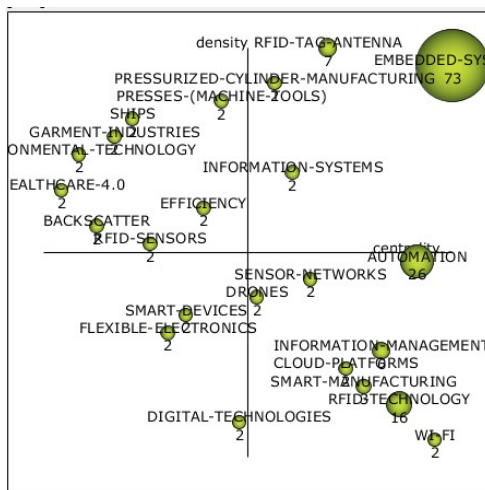


Figure 14. Clusters for 2020-2021



Figure 15. Clusters for 2022-2029

Theme	Analysis of thematic areas	Strategic Diagram	2012-2013	2014-2015	2016-2017	2018-2019	2020-2021	2022-2029
TRACKING-(POSITION)	Yes	Yes	Yes	No	No	No	No	No
RFID	Yes	Yes	No	Yes	No	No	No	No
MANUFACTURE	Yes	Yes	No	No	Yes	No	No	No
INTERNET-OF-THINGS	Yes	No	No	No	Yes	Yes	No	No
SLOT-ANTENNAS	No	Yes	No	No	Yes	No	No	No
INDOOR-POSITIONING-SYSTEM	No	Yes	No	No	Yes	No	No	No
SHIPS	No	Yes	No	No	Yes	No	No	No
INFORMATION-USE	Yes	Yes	No	No	No	Yes	No	No
RFID-TECHNOLOGY	Yes	No	No	No	No	Yes	Yes	No
REAL-TIME-SYSTEMS	Yes	No	No	No	No	Yes	No	No
SUPPLY-CHAIN-MANAGEMENT	Yes	Yes	No	No	No	Yes	No	No



Theme	Analysis of thematic areas	Strategic Diagram	2012-2013	2014-2015	2016-2017	2018-2019	2020-2021	2022-2099
MOBILE-ROBOTS	Yes	No	No	No	No	Yes	No	No
TRACKING	No	Yes	No	No	No	Yes	No	No
EMBEDDED-SYSTEMS	Yes	Yes	No	No	No	No	Yes	No
INFORMATION-MANAGEMENT	Yes	No	No	No	No	No	Yes	No
SMART-MANUFACTURING	Yes	No	No	No	No	No	Yes	No
AUTOMATION	Yes	Yes	No	No	No	No	Yes	No
RFID-TAG-ANTENNA	No	Yes	No	No	No	No	Yes	No
PRESSURIZED-CYLINDER-MANUFACTURING	No	Yes	No	No	No	No	Yes	No
INFORMATION-SYSTEMS	No	Yes	No	No	No	No	Yes	No
INDUSTRY-4.0	Yes	Yes	No	No	No	No	No	Yes
MACHINE-LEARNING	No	Yes	No	No	No	No	No	Yes

Table 7. Themes from horizontal e density analyses

The number of documents collected in each given period (Table 2) is 374. This number, when segregated by themes and periods, is 139. As some documents repeat for different themes or periods, removing repetition documents for all periods, the sample is 120 documents.

### 7.5. Correlation Analysis by Period

Themes identified from the previous analysis will be analyzed in their cluster's theme, and discussed from the perspective of the documents in their corresponding clusters.

#### 7.5.1. Period 1 (2012-2013)

The theme TRACKING-(POSITION) is the only theme identified in this period. But documents in this theme don't relate much to industry 4.0. Their focus is "4.0 W" which is actually a power measure of RFID frequency waves (Liu, Yu & He, 2013) and (Lin, Yeh, Chen & Chang, 2012). But this theme, understandably, becomes quite relevant in later periods (particularly Period 4). Also, is necessary mentioned as we can see in Figure 16, "RFID" has a representative perspective, but we don't have industry 4.0 relationship.

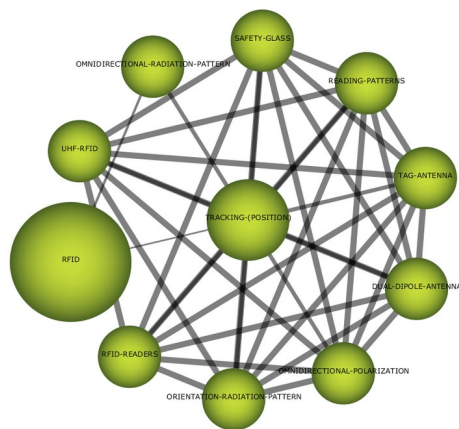


Figure 16. TRACKING-POSITION - Cluster network

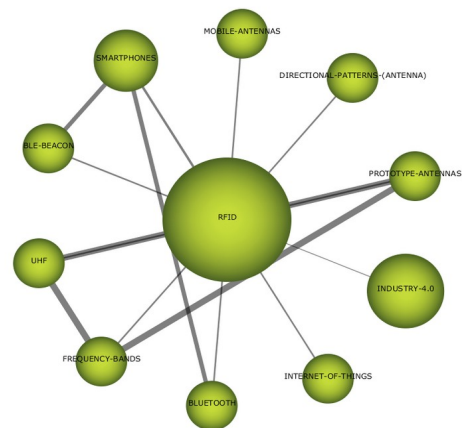


Figure 17. RFID Cluster network

### 7.5.2. Period 2 (2014-2015)

The main theme in this period is “RFID”. As evident in Figure 17, both themes “INDUSTRY 4.0” and “RFID” are related. It is important to highlight this to understand other themes related to industry 4.0 enabling technologies e.g. “INTERNET-OF-THINGS”. In all, 9 documents were listed by SCIMAT as related by in this cluster, and 7 seven documents don't relate to industry 4.0.

As discussed earlier, when analyzing Table 2 and graph by Figure 5, the period with the greatest relevance in terms of document quantity began in 2016. Hence, few documents and themes from periods 2012-2013 and 2014-2015 were relevant. To summarize, all documents analyzed, (Ensworth & Reynolds, 2015) suggests the themes of RFID and the internet-of-things, to apply to the identification of objects in industry 4.0.

### 7.5.3. Period 3 (2016-2017)

Period 3 is composed of four themes, which were selected using a strategic diagram: “MANUFACTURE”, “INTERNET-OF-THINGS”, “INDOOR-POSITIONING-SYSTEM”, “SLOT-ANTENNAS”. “SHIPS” was the only theme selected by the strategic diagram. “MANUFACTURE” was the main theme in this period, because, at this period, SCIMAT shows 9 clusters, but “MANUFACTURE” has 45% of the total number of documents in this period and has the highest centrality (centrality range 1) and Figure 18, shows the relationship with this theme and relevant themes RFID and INDUSTRY 4.0.

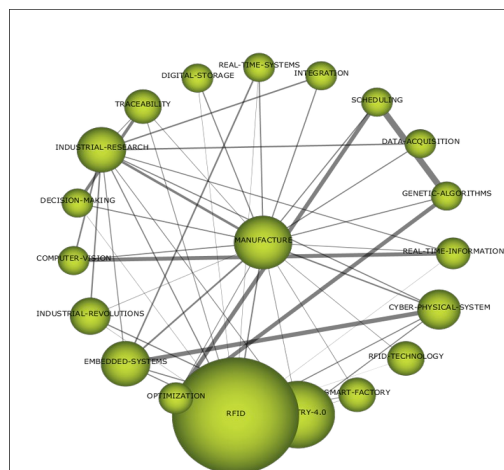


Figure 18. Manufacture Cluster network

Within the scope of RFID and industry 4.0 applications to MANUFACTURE, real-time information is also an important subject e.g. (Zhong et al., 2017) suggests tracking and tracing the real-time status of various managed objects in manufacturing using RFID, making it a key element in IoT used in manufacturing and logistics. This also makes it easy to track the process of manufacture in real-time (Lv & Lin, 2017), using visualization about materials flow, from raw materials to assembling to finished consumer products.

(Pei et al., 2017) comments that RFID technology helps manufacturing in a convenient way for intelligence management. Other authors reinforced “real-time” and tracking system applications to manufacture e.g. (Pei et al., 2017) suggesting RFID also helps to structure enterprise in the real-time tracking system, and Ćwikła & Foit, 2017) suggests smarter manufacture can be achieved using RFID as a tool to real-time managers.

In addition, cyber-physical is another theme for the RFID to industry 4.0 related to manufacture, as (Wang, Jiang & Ding, 2017) suggests RFID helps the cyber-physical systems to store all workproducts. It can help achieve greater efficiency and productivity in all stages of production, work-in-progress tracking, replenishment, and supply chain management (Wang et al., 2017). Both (Holland et al., 2017) and (Ferro, Ordóñez & Anholon, 2017) identify RFID as a tool for managing key workproducts parameters, like product origin, tagging information throughout the process, identifying equipment as needed during the manufacture process. Along similar lines, (Holland et al., 2017)

highlights how RFID can be used to integrate details of how workproducts are manufactured and are intended to be used, creating so called intelligent products. (Ferro et al., 2017) further indicates increase of earnings by “RFID applications, based on real-time information analysis, the decisions taken contributed to a 34% reduction in WIP, a 12% increase in production efficiency, and a reduction of 88% in paper documents at the mill. In this case, 96% of the information was available in real-time. RFID contributed to increasing the speed and efficiency to obtain data”.

Figures 19 and 20 are about “SHIPS” manufacture and “INDOOR-POSITIONING-SYSTEM”. (Fraga-Lamas, Fernández-Caramés, Noceda-Davila, Díaz-Bouza, Vilar-Montesinos, Pena-Agras et al., 2017) and (Fraga-Lamas, Noceda-Davila, Fernández-Caramés, Díaz-Bouza & Vilar-Montesinos, 2016), propose RFID for applications in cyber-physical systems for “SHIPS” manufacture and “INDOOR-POSITIONING-SYSTEM”. (Fraga-Lamas et al., 2017) defines Industry 4.0 as “the aim of increasing the efficiency and the integration of the processes to optimize their life cycle”.

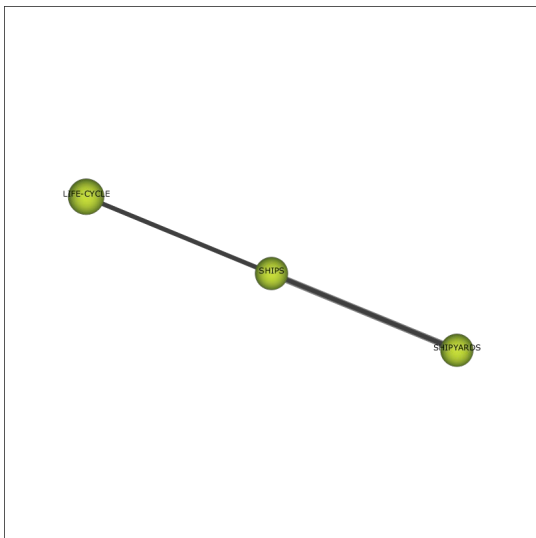


Figure 19. SHIPS Cluster network

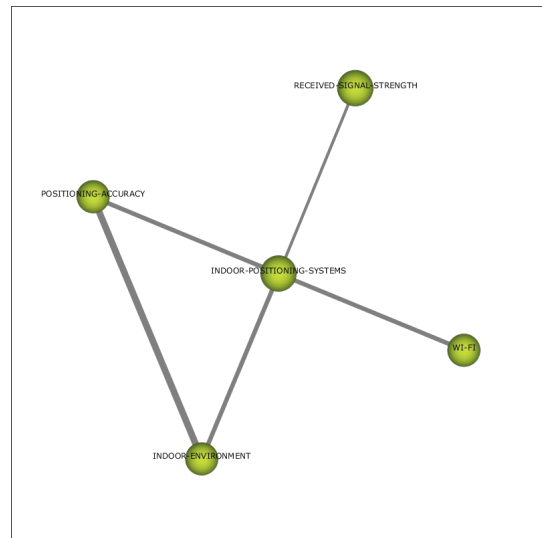


Figure 20. DOOR-POSITIONING

The theme “SLOT-ANTENNAS”, introduced by Figure 21, is directly related to the RFID theme, as it is a critical device used for RFID applications. (Ascher, Lechner, Nosovic, Eschlwech & Biebl, 2017), (Lin, Chang, Chen & Lai, 2016), and (Chang, Chen, Lin, Chen & Chen, 2016) are studies that demonstrate the role of this important device for using RFID.

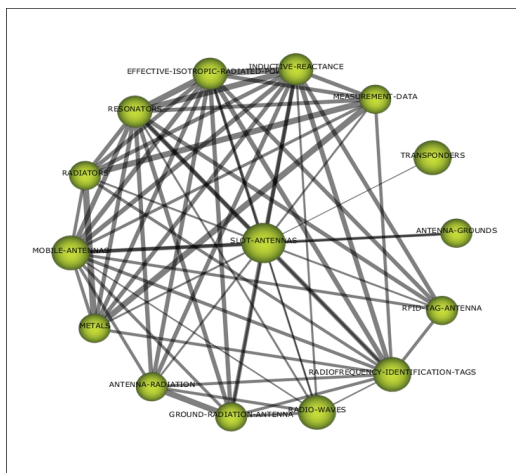


Figure 21. SLOT-ANTENNAS Cluster Network



Figure 22. INTERNET-OF-THINGS Network

The cluster about “INTERNET-OF-THINGS”, represented in Figure 22 is defined by (Valente & Neto, 2017) as “The vision of the Internet of Things (IoT) refers to a growing number of heterogeneous intelligent objects fully interconnected, capable of communicating through the Internet using many different transport protocols”. In Industry 4.0 concepts, “INTERNET-OF-THINGS” is essential, as (Wang, Wang, Sepasgozar & Zlatanova, 2020) suggests that it is a key to industry 4.0, and Cyber-physical systems and Cloud computing, to real-time monitor physical processes in smart manufacturing. In addition, (Tamayo-Segarra, Jammal & Chaouchi, 2017) RFID is a fully developed technology by the industry, however, RFID together with IoT, brings advanced Industry 4.0 to industries. (Nukala, 2016) indicates a strong relationship between RFID and IoT from the very beginning “RFID, the roots of the Internet of Things emerged from Auto-ID labs in 1999 which refers to a network of objects connected using RFID pioneered and IOT like RFID Technology laid the foundation of IoT evolution and is still emerging”. (Suri, Gaaloul, Cuccuru & Gerard, 2017) corroborates as IOTs applications initially appeared with RFID tags and related sensors.

#### 7.5.4. Period 4 (2018-2019)

SUPPLY-CHAIN-MANAGEMENT was one of the most important themes for this period, because of both its high centrality and density, as shown in Figure 23. The work in (Pal, 2019) contributes to understanding supply chain coverage described as a network of businesses that manage materials and information cycle, starting with raw material procurement, transformation, to finished products and distributions. The work in (Hegedus, Franko & Varga, 2019; M'hand, Boulmakoul, Badir & Lbath, 2019) studies the application of RFID to track and monitor products in supply chains. (Hegedus et al., 2019) also emphasizes its role improved operation of logistics in a supply chain management systems. (Fernández-Caramés, et al., 2019) presents RFID as means to collect data towards autonomous applications and big data management. (Carvalho et al., 2018) defines the relation of industry 4.0 with “SUPPLY-CHAIN-MANAGEMENT”, as “SUPPLY-CHAIN-4.0”, that is the application of industry 4.0 in supply chain management. In addition, (Marinagi, Skourlas & Galiotou, 2018) concludes in his study that technology used in Industry 4.0 is propitious to supply chain management activities, creating new business value, due to information disponibility to decision-maker persons.

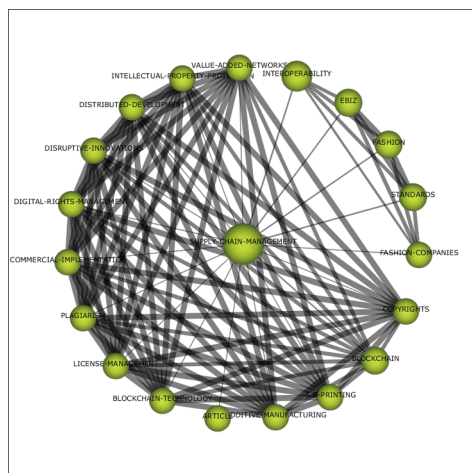


Figure 23. SUPPLY-CHAIN-MANAGEMENT Network

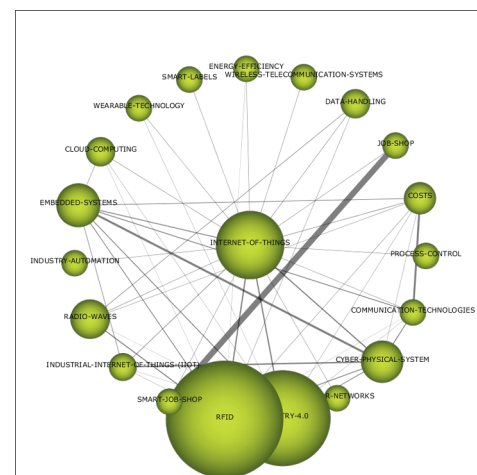


Figure 24. INTERNET-OF-THINGS Network

The theme “INTERNET-OF-THINGS” also appears in the period 2016-2017, but even now with more themes compared to pre-2016. Related applications in themes industrial 4.0, RFID and IOT, appear to converge with emphasis on CyberPhysical Systems and real-time control. For instance, (Fernandez-Carames & Fraga-Lamas, 2018) sees RFID as a Smart label for data collection tightly coupled with IoT and CyberPhysical Systems (CPS). In (Cañizares & Valero, 2018) real-time data collecting underpins IoT with RFID, bringing huge efficiency advantages to the manufacturing process. To summarize, (Ding & Jiang, 2018) shows advantages with the advent of the

Internet of things (IoT), with RFID devices capturing the material flows of manufacturing resources. As Figure 24 shows, the main “RFID” and “INDUSTRY 4.0” themes are strongly relevance in cluster.

In addition, the theme appears in smart manufacturing, as we can see in (Tran, Park, Nguyen & Hoang, 2019) that demonstrates an application of RFID integrated with IoT. This helps to achieve cyber-physical system management in smart manufacturing systems. (ElMoaqet, Ismael, Patzolt & Ryalat, 2018) presents themes of smart production factories and digital transformation, which necessarily needs Industry 4.0, Cyber-physical Systems, and the Internet of Things (IoT). (Ćwikła & Foit, 2017) highlights the role of RFID for industry 4.0 benefits, e.g. a company uses IoT to improve the production process of tool-machines, using RFID technologies and wireless networks, monitoring and managing the data about manufacturing status from each component, and balancing workload for each factory section and each machine. Relating IoT and embedded systems, (Ding & Jiang, 2018) describes objects embedded with the internet of things (IoT) as a physical network of radio frequency identification (RFID) and embedded systems carrying information from cyber-physical systems (CPS).

The theme “RFID-TECHNOLOGY” is quite identical to theme RFID. (Balog, Trojanová & Balog, 2019) utilizes themes that explain RFID as a technology of automatic identification using radio waves from tags (labels, chips) and where the data is stored in a digital form and can then be loaded and rewritten.

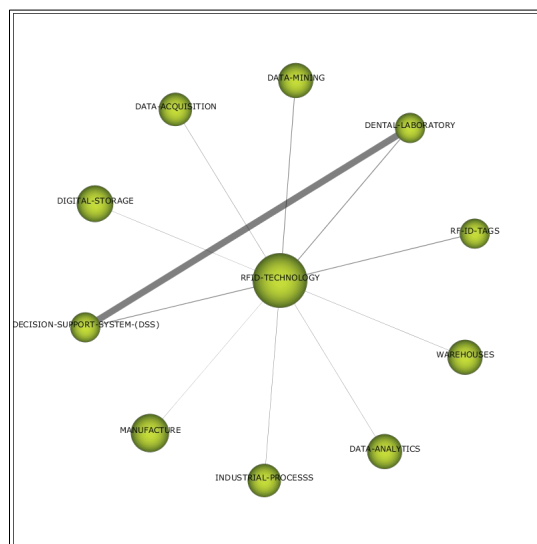


Figure 25. RFID-Technology Network

Figure 25 shows some themes related to “RFID-TECHNOLOGY” deserve attention, like DATA-ANALYTICS, DATA-ACQUISITION – although they are not exclusive from “RFID-TECHNOLOGY”, but also from RFID. These DATA themes interact with industry 4.0. In (Ding & Jiang, 2018) RFID technology is seen as the main way to link data flow and data about physical assets to IoT. (Zou & Zhong, 2018) presents physical processes as information shared from sensors (RFID). (Ding & Jiang, 2018) suggests that RFID allows data storage and data interaction functionalities, extracting this information from physical to virtual in IoT, which improves the transparency, accuracy, and efficiency of production control.

The theme “REAL-TIME-SYSTEMS” does not reveal as much as other themes from this period (Figure 26), but it is still of great importance. (Ding & Jiang, 2018) denotes real-time as one of the principles of Industry 4.0 to collect information from different parts of the value chain. (Pokrajac & Venkatesan, 2019) defines real-time, as technology to provide location information of humans, assets and devices.

The theme “REAL-TIME-SYSTEMS” does not reveal as much as other themes from this period, but it is still of great importance. (Fernandez-Carames & Fraga-Lamas, 2018) denotes real-time as one of the principles of Industry 4.0 to collect information from different parts of the value chain. (Pokrajac & Venkatesan, 2019) defines real-time, as technology to provide location information of humans, assets and devices. Another articulated aspect

of the theme (Ramadan, 2019) as suggested by industry 4.0, is its combined benefits with Radio Frequency Identification (RFID) sensor technologies, leveraging Cyber-Physical Systems (CPS), the basis of the Internet of things (IoT).

The theme resented centrally cluster in Figure 27, is explained for (Schuh et al. 2020) says that the Industry 4.0 core is a relationship with Information systems- when describing the term Industry 4.0 used since 2011 to describe the widespread integration of information and communication technology in industrial manufacturing. (Carvalho et al., 2018) suggests that recent IT developments, such as IoT, Cloud-based, Big Data and Analytics, allow the implementation of Industry 4.0. (Noonpakdee, Khunkornsiri & Phothichai, 2018) highlights that the information progress enterprises increase productivity gains and competitive advantages.

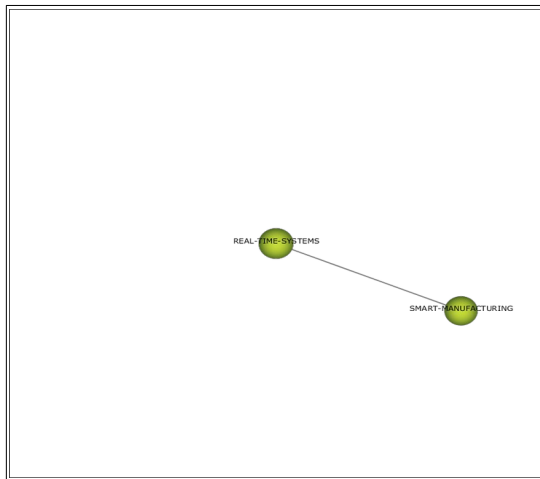


Figure 26. Real-time Systems Network

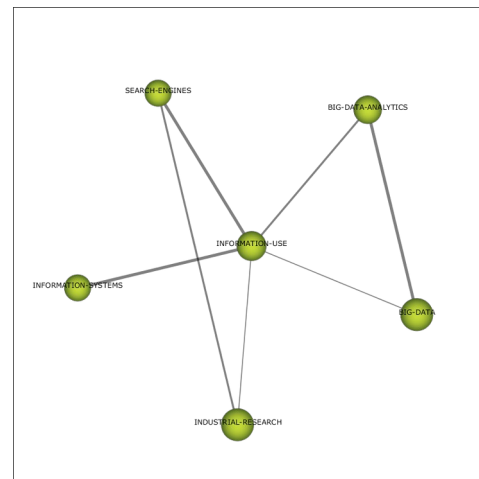


Figure 27. "Information-Use" Network

Figure 28 shows the clusters by the theme "MOBILE-ROBOTS", as determined by (Lee, Goh & Tew, 2018) classify Automated Guided Vehicle (AGV) as mobile robots. In (Mehami et al., 2018), RFID technology is used for guidance or motion control of such mobile robots. (Ramadan, 2019) suggests mobile robots with RFIDs underpins the state of the art for manufacturing. (Mehami et al., 2018) and (Lee et al., 2018) suggest applying RFID to help AGV for localization techniques.

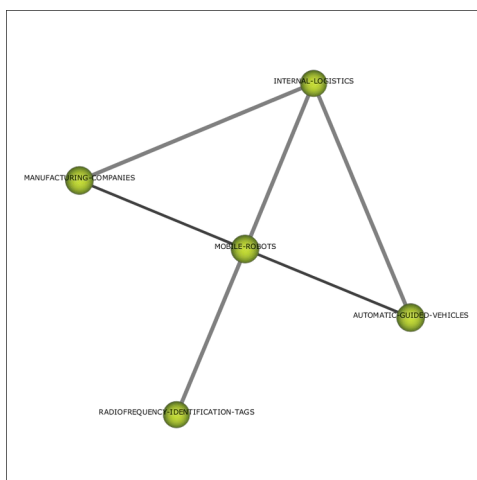


Figure 28. "MOBILE-ROBOTS" network

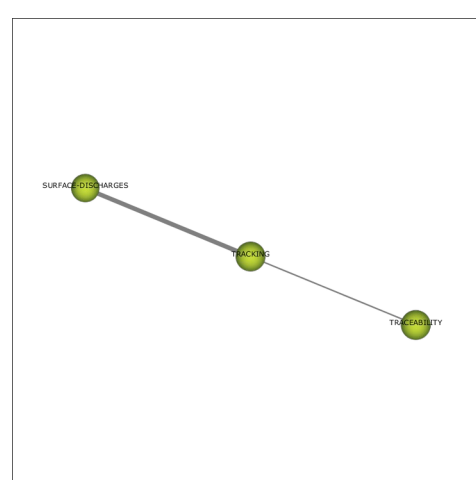


Figure 29. "Tracking" network

As shown in Figure 29 the theme “TRACKING” has not been highly significant during 2012-2013. But it appeared in discussions of relationship with themes like “MANUFACTURE” “SUPPLY-CHAIN-MANAGEMENT” and “INTERNET-OF-THINGS”. For example, (Fernandez-Carames & Fraga-Lamas, 2018) registers RFID as the most popular way for identifying and tracking objects and positioning of products. (Fernandez-Carames & Fraga-Lamas, 2018) applied RFID technologies to track goods. (Fernández-Caramés, Fraga-Lamas, Suárez-Albela & Díaz-Bouza, 2018) suggests tracking using RFID to apply Cyber-Physical System (CPS).

### 7.5.5. Period 5 (2020-2021)

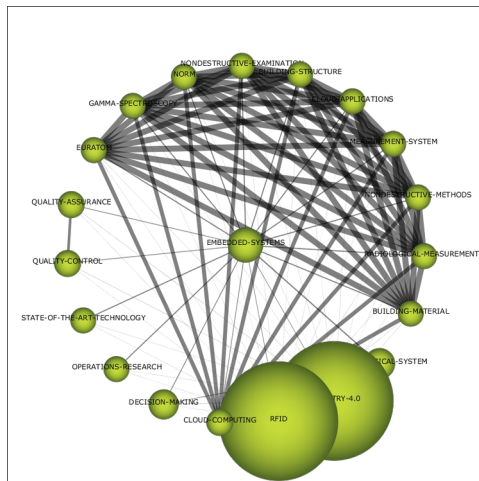


Figure 30. “Embedded-Systems” network

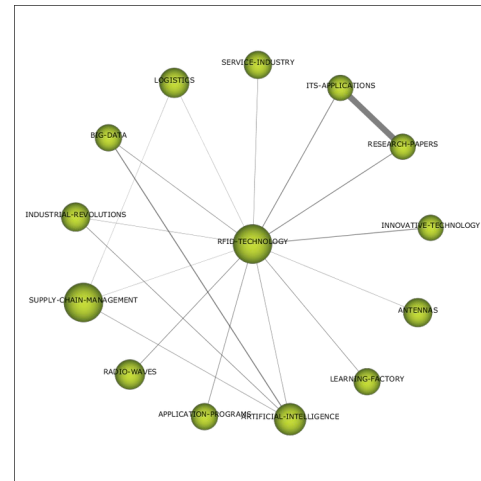


Figure 31. “RFID-TECHNOLOGY” network

During 2020-2021, “EMBEDDED-SYSTEMS” has a centrality range of 1 and is directly linked by the main themes from this study, as possibly seen in Figure 30. Another interesting central theme is “CLOUD-COMPUTING” and, as suggested by (Ivanov et al., 2021) it facilitates technologies such as IoT, big data, electric vehicles, 3D printing, cloud computing, artificial intelligence, and cyber-physical system. Further, (Ivanov et al., 2021) suggests embedded systems to application controls and (Neal et al., 2021) applies embedded systems to monitoring processes using sensors to monitor humidity, temperature, or dust and principally embedding RFID technologies. Other applications are embedded systems to the programmable systems with multiple connectivity interfaces as (Marini, Panicacci, Donati, Fanucci, Fanchini, Peperosa et al., 2021), (Torres, Gomez, Carvallho, Trujillo, Tinjaca, 2020) and (Donati, Marini, Fanucci, Fanchini & Morichi, 2020) are examples and this application is based on industry 4.0.

RFID-TECHNOLOGY appeared in the fourth period too, as shown in Figure 31, but now with more themes and some themes analyzed like “SUPPLY-CHAIN-MANAGEMENT” (fourth period) and new themes like “ARTIFICIAL-INTELLIGENCE” that compare with other themes for this cluster is have more other interactions. Analyze the documents for this period, is not find a direct correlation between RFID and “Artificial Intelligence”, but some applications like (Kumar, Patil, Nath, Rohilla & Sangwan, 2021) applied RFID with a machine-vision application (artificial intelligence) system allowing intelligent tracking and tracing of workpieces in real-time in the value chain and (Konecka & Maryniak, 2020) made a conceptual correlation to RFID and Industry 4.0, to sustainable supply chain, reinforcing the importance of using data from RFID technologies and some apply artificial intelligence.

Aim the main themes, (Colaco & Lohani, 2021) indicates RFID to IoT base applications to be used in Industry 4.0 and (Kanagachidambaresan, Anand, Balasubramanian & Mahima, 2020) suggests de RFID application has powerful capability to identify, trace, and track physical objects, providing real-time data about the relative devices and cheap cust. (Zidek, Pitel, Pavlenko, Lazorik & Hosovsky, 2020) corroborates some benefits of applying RFID to real-time stock situations and Data without delays or human interaction. (Balog & Knapčíková, 2021) uses RFID technologies as a tool to apply concepts from industry 4.0 like Smart Networking

Wireless and wired communication services, to get gains in the industry and ID192 (Centea, Singh & Boer, 2021) completes the RFID application to Industry 4.0 expectations, like cyber-physical systems connected to the cloud computing.

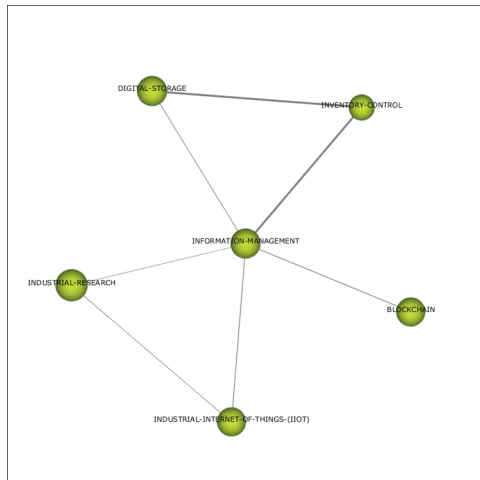


Figure 32. “Information Management”



Figure 33. “Information Systems”

Both themes, in Figures 32 and 33, share the same documents in this period, despite comprehension, of “SYSTEM”, is related to information tools and “MANAGEMENT”, reading the documents, both themes made to understand the “INFORMATION” as an appliance. (Pal & Yasar, 2020) indicates “INFORMATION” as a way to establish an industry 4.0 architecture and applying RFID is to collect information as an IoT. (Yang, Chen, Lin, Cheng & Cheng, 2020) discusses about great results introduced by the information system based on IoT and RFID. Another application of “INFORMATION” is for aiding the application industry 4.0 and RFID as (Musikthong & Chutima, 2020) in the digital transformation of manufacturing and (Yang et al., 2020) used to manage RIFDs to data collection.

The theme “SMART-MANUFACTURING” has appeared first time in the selected themes, however from fourth period, this theme has been read in many documents. In this regard, (Franko, 2020) helped us to understand this relationship when smart manufacturing has been suggested as a main goal of the Industry 4.0 movement. Applying RFID can help transform traditional manufacturing into smart manufacturing, as (Neal et al., 2021) has achieved in their case of study.

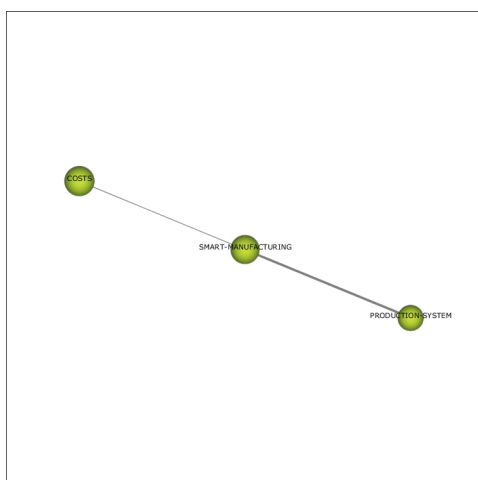


Figure 34. “SMART-MANUFACTURING” network

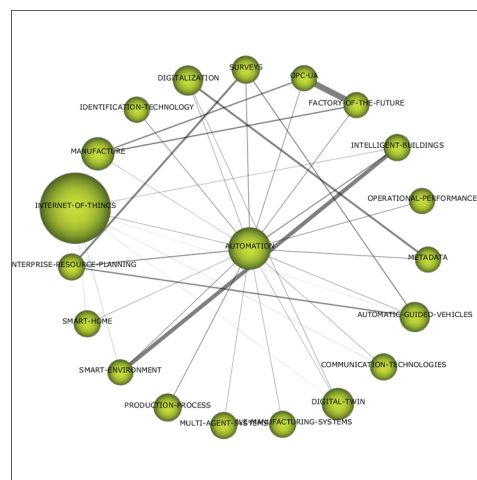


Figure 35. “AUTOMATION” network



Figure 34 presents low density and centrality for SMART-MANUFACTURING theme however the literature highlights its importance for the themes of our study. (Židek, Hladký, Piteř, Demčák, Hošovský & Lazorič, 2021) explains “SMART-MANUFACTURING” as a full digitalization of manufacturing and suggests RFID as a tool for data collection. Moreover, (Konecka, et al., 2020) proposed using RFID application for smart manufacturing and to monitor industrial processes. (Azangoo, Taherkordi & Olaf-Blech, 2020) defines “AUTOMATION” as a way to control manufacturer plants using automation systems of production. Furthermore, the RFID can support automation as a tracking support. (Karabegović, 2020) considers a relationship between industry 4.0 and automation when automation of manufacturing processes has data exchange and data processing. (Karabegović, Turmanidze & Dašić, 2020) presents a study about industry 4.0, applying automation and robots, to understand a new paradigm where automation is not just for efficient manufacturing, but a way to collect data. In addition, the theme “AUTOMATION” related to “RFID”. Knapcikova, Husar and Kascak (2020) applies RFID as a tool in the automation process, allowing readers to monitor the automation.

Figure 35 indicates that the theme “INTERNET-OF-THINGS” has relevance due to density and number of connections. The relationship between themes has been explained in studies such as (Parthiban, 2020) and (Židek, Piteř & Lazorič, 2020) which applied RFID to collect data using IOT devices, allowing manager automation process. Furthermore, (Chatterjee, Shukla, Wanganoo & Dubey, 2021) suggests applying automation in the Supply chain using RFID as an IOT.

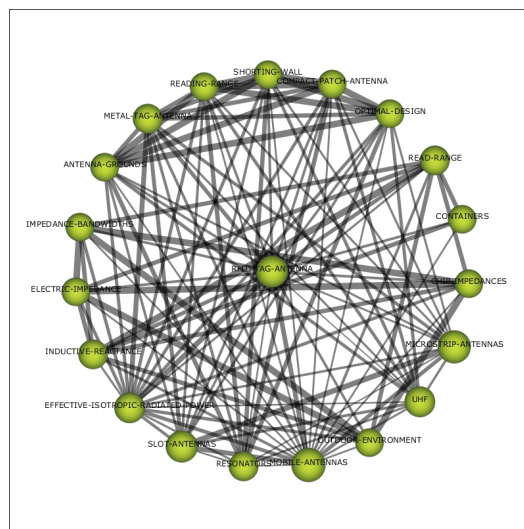


Figure 36. “RFID-TAG-ANTENNA” network

Understanding the RFID application, ANTENNA is a complementary and necessary tool and TAG is the name of RFID chips. To summarize, the theme “RFID-TAG-ANTENNA” is related to technical or engineering applications, as we can see in Figure 36 the relation with themes like “UHF”, and “ELECTRONIC-IMPEDANCE”. Furthermore, the documents selected (Nguyen, Lin, Chang, Chen & Chen, 2021; Tan, Chen, Sim, Chen, 2020; Tan, Lin, Chen, Chang, Tseng & Chen, 2020; Tan, Lin, Chang, Liao & Chen, 2020; Chang, Chen, Tan, Chen, 2021) don’t have any relationship with industry 4.0, just the theme 4.0 W, which is a powerful measure of RFID and not related to industry 4.0. Following the methodology to look at motor Themes or relevance Themes, the theme “PRESSURIZED-CYLINDER-MANUFACTURING”, fit in this context, but analyzing the two documents (Baritto, Billal, Muntasir-Nasim, Sultana, Arani & Qureshi, 2020; Billal, Baritto, Muntasir-Nasim, Sultana, Arani & Qureshi, 2020) the theme is an RFID application, with expected to achieve an industry 4.0 concepts and not a theme.

### 7.5.6. Period 6 (2022-onward)

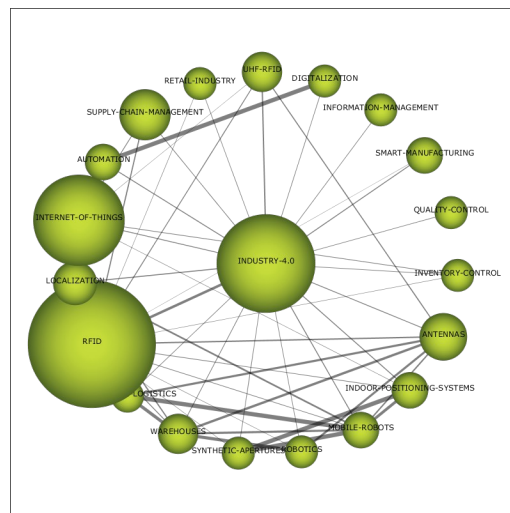


Figure 37. “Industry 4.0” theme network

The Evolution map and Strategic Diagram of the theme “INDUSTRY 4.0” is shown in Figure 37. It is the main theme for this study (with “RFID” too), but “INDUSTRY 4.0” is connected to a larger mix of themes than “RFID”. This is not surprising as industry 4.0 enmeshes and enables a variety of information generation devices and applications as noted in (Dubey et al., 2022). In a study such as this, such interconnections are most noteworthy to highlight (Demčák, Lishchenko, Pavlenko, Pitel, & Židek, 2022). In addition, examining the documents for this theme within this period, we note a marked increase to documents in “SUPPLY-CHAIN-MANAGEMENT” and associated themes such as “LOGISTICS” and “WHAREHOUSE”. Of the 20 documents examined, 9 have those applications: (Unhelkar et al., 2022; Staniec, Kowal, Kubal & Piotrowski, 2022; Tripicchio, D’Avella & Unetti, 2022; Le, Kieu, Nguyen, Nguyen, Ninh, Phan et al. et al., 2021; Smitha & Aslekar, 2022; Angrisani, Arteaga, Bijaya-Ketan-Panigrahi, Kay-Chen, Khamis et al., 2022; Voipio, Elfvengren, Korpela & Vilko, 2022; Kokkonen, Myllymaki, Putaala & Jantunen, 2022).

## 8. Summary of Results

To summarize the results, we go back to the RQs and objective of this work:

### RQ1: For the period with a higher frequency of publications which ones are more relevant?

From total of 374 documents, are 78% is between 2018-2022, and the statistical study, we were able to identify that there is a growing correlation between the Industry 4.0 theme and RFID, if the themes are compared only with the number of documents for the RFID theme for the same period.

### RQ2: Which element has propagated most during the period analyzed?

The overlapping map demonstrated continuity in research-related topics in the analyzed period, on average 20% with a slight evolution period by period. TRACKING-(POSITION), RFID, MANUFACTURE, INTERNET-OF-THINGS, EMBEDDED-SYSTEMS, INDUSTRY-4.0 RFID-TECHNOLOGY REAL-TIME-SYSTEMS and SUPPLY-CHAIN-MANAGEMENT.

### RQ3: Which themes show highest correlation between Industry 4.0 and RFID e correlate to various industry applications?

Figure 38 helps us to answer RQ3 about the staged evolution of research to achieve Industry 4.0 and summarizes the benefits in each stage, from the enabling technologies to start the applications of RFID to Industry 4.0 to achieve. The figure does not use chronological order of the documents, rather it shows the enabling technologies according to their role to achieve Industry 4.0.

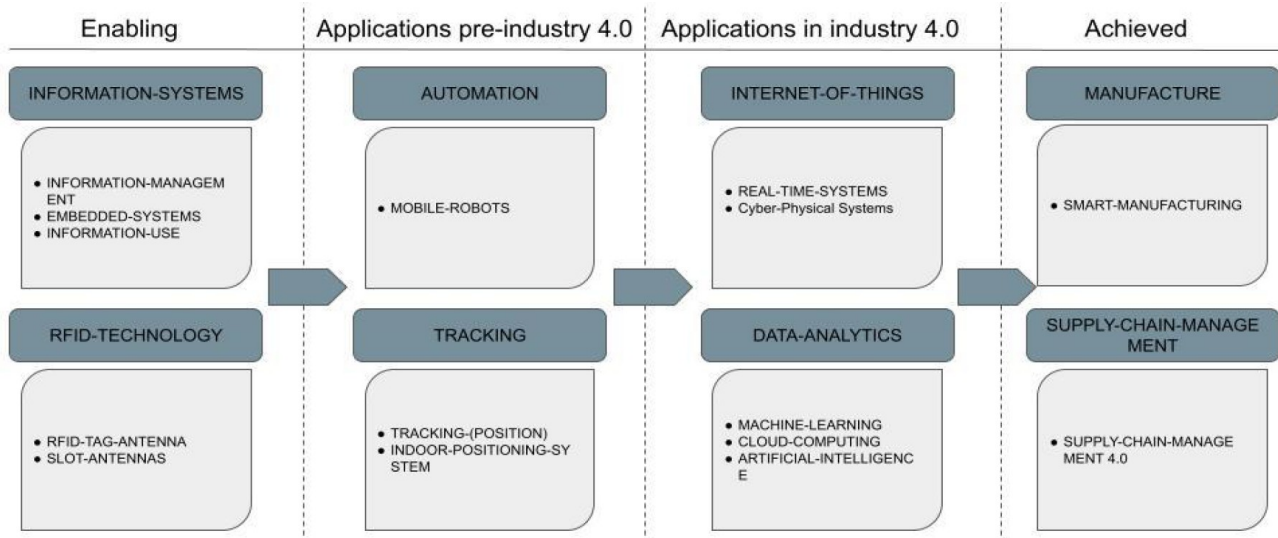


Figure 38. Matrix RFID and Industry 4.0

Although the first stage is ENABLING, it still has principal tools to allow subsequent applications in both of the later stages, of pre and post industry 4.0. Applications, within the second stage of pre-industry 4.0, use information and RFID to track assets and to automate processes (e.g. using robots) within warehouses, but yet without web connectivity. Within the third stage, applications advance beyond tracking and automation using information systems and RFID to include data collection using IoT and this enables applying artificial intelligence to manage processes and to obtain deeper insight. The last stage contains describes ultimate gains and finality for all progress.

## 9. Conclusion

This paper presents a bibliometric review and provides support in understanding the relationship between “INDUSTRY 4.0” and “RFID” and how this evolved. To identify topics for discussion in this field, a list of the most important keywords were used. From a database of 367 documents, we selected sixteen keywords to analyze. The key themes “INDUSTRY 4.0” and “RFID” evolved recently into associated themes such as “ARTIFICIAL-INTELLIGENCE, DATA-ANALYTICS Cyber-Physical Systems, CLOUD-COUPITING and SUPPLY-CHAIN-MANAGEMENT 4.0. These ensuing themes constitute enabling tools for Industry 4.0 and support for “RFID” for this application. Another important objective for this work, is analyzing the support of RFID, as a tool to help Industry 4.0. This was evident not only in increasing number of documents, but too in the analysis of the content of those documents.

## Declaration of Conflicting Interests

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