

# Mapping the field: Relational study on Six Sigma

**Niñerola, Angels (corresponding author)**

*Business Management Department. Universidad Rovira y Virgili. Reus. Spain,*

*angels.ninerola@urv.cat, Tel. +34977759838*

*ORCID: 0000-0001-5598-1203*

**Sánchez-Rebull, María-Victoria**

*ORCID: 0000-0002-9920-4104*

**Hernández-Lara, Ana-Beatriz**

*ORCID: 0000-0002-8110-9328*

Six Sigma is one of the main approaches to quality management. Its research has produced an extensive literature and the objective of this study is to complement previous reviews by conducting a relational study, which has never been done previously. We analysed 798 articles published prior to 2018 in 392 academic journals using the Web of Science and Scopus databases. Relational techniques were used for mapping the five fields: citation, co-citation, bibliographic coupling, co-author and co-word. The study identifies the most influential journals, papers and authors in Six Sigma research revealing the fields' conceptual, intellectual and social knowledge structures. Results showed that, although Six Sigma literature includes a large number of authors and journals, a small number of these dominate the field. Conceptually, it is noteworthy that seven sub research areas exist in the field, these being related to (1) methodological issues, (2) project and empirical issues, (3) business excellence, (4) training on Six Sigma, (5) Six Sigma process, (6) engineering issues and (7) lean and healthcare issues. The current article provides several starting points for practitioners and researchers when investigating Six Sigma and contributes to broadening the vision of the field.

Keywords: Six Sigma; bibliometric; relational study; science mapping; co-citation; bibliographic coupling

## 1. Introduction

Six Sigma is a business process strategy that combines statistic and management approaches (Kwak & Anbari, 2006). It is based on the principle of measuring, monitoring, and controlling processes and provides an organisational structure for continuous improvement (Schroeder et al., 2008). Its main objective is to achieve business goals and improve company performance through controlling defects, and reducing variation in processes (Andersson et al., 2006). As a consequence of these improvements, costs derived from quality problems are reduced and a quality level of 99.9997% is expected (McClusky, 2000).

Since the mid-1980s, Six Sigma implementation has increasingly been used as a business process management tool in several industries and this is reflected in academic literature. Its study has been a popular topic among researchers and practitioners which has resulted in an extensive literature emerging since 1990.

This literature has focused on different aspects. Firstly, there are theoretical studies to conceptualise and define Six Sigma, its origins, benefits and principles (Klefsjö et al., 2001; Kwak & Anbari, 2006; Linderman et al., 2003).

Secondly, there was an interest in identifying critical success factors for its implementation (Antony & Bañuelas, 2002a; Ismyrlis & Moschidis, 2013; Siddiqui et al., 2016), and the techniques and tools used during the *dmaic* phases (Antony & Bañuelas, 2002b; Klefsjö et al., 2001; Uluskan, 2016).

Thirdly, it is noteworthy that the bulk of literature carried out in the field is through case studies (Reosekar & Pohekar, 2014). These analyse Six Sigma implementation in real life contexts to test its applicability and to provide empirical evidence of its benefits (Ahmed et al., 2019; Benedetto, 2003; Stewart & Spencer, 2006; Su & Chou, 2008; Tong et al., 2004).

To synthesise Six Sigma studies there are bibliometric reviews assessing the evolution of the field and identify gaps and future lines of research (Antony et al., 2018; Brady & Allen, 2006; Niñerola et al., 2019; Nonthaleerak & Hendry, 2006; Patil et al., 2017; Tjahjono et al., 2010). Bibliometrics is a tool used to analyse the evolution of disciplines; organising, classifying and quantitatively evaluating publication patterns. It is recommended in order to fully understand existing research in mature fields with a tradition, to elucidate and classify main topics and conclusions (Gonzales-Bustos & Hernandez-Lara, 2016). Some examples are those focused on identifying critical success factors (Ismyrlis & Moschidis, 2013; Patil et al., 2017), analysing specific sectors or industries where Six Sigma is applied, such as Antony et al. (2018) in healthcare, or general reviews (Brady & Allen, 2006; Reosekar & Pohekar, 2014; Tjahjono et al., 2010). However, none of these studies perform network analysis. They use frequency analysis or basic statistics, specifically for identifying trends of the topic over time in terms of authorships, journals, citations, etc., no bibliometric review using relational techniques has been previously conducted.

Relational techniques delve into the relationships between published research studies, mapping and understanding the structures in the underlying document set (Koseoglu et al., 2016). This proves to be a powerful tool for identifying established and emerging topical areas (Fahimnia et al., 2015). The techniques used are mainly co-citations, bibliographic coupling, co-author and co-word (Zupic & Čater, 2015). Each technique applies a different scope for analysing the research field structures: intellectual, social and conceptual (Cobo et al., 2011). Citation analysis applies two main similarity measures, bibliographic coupling when two works reference a common third work, and co-citation analysis when two works are cited together by a third work (White & Griffith, 1981). Social structure refers to the analysis of co-authorships through their affiliations (Otte & Rousseau, 2002). Finally co-word analysis serves to analyse the conceptual structure of the field and its main research themes (Muñoz-Leiva et al., 2012).

A network analysis of Six Sigma research shows the current structure of the field, and constitutes a starting point for finding potential challenges, gaps and future research

needs. These techniques have not been previously used in the Six Sigma field, so their application is a novel contribution. Network analysis provides different information from the narratives, qualitative or meta-analysis reviews carried out by other authors, adding information about the relationships of previous research and, generally speaking, providing a more comprehensive picture of the state of the art in the field; understanding the relationship between documents broadens our vision. Moreover, this review gathers information from different databases and includes documents up to 2017, representing an extension in breadth and time to previous reviews on the topic. The aim of this study is to answer the following research questions:

RQ1. Which are the most relevant authors and journals in the field?

RQ2. What is the intellectual, social and conceptual structure of this literature?

RQ3. What are the potential opportunities for Six Sigma research?

## 2. Research design

Zupic and Čater (2015) established a guide / workflow for conducting science mapping with bibliometric methods to achieve greater objectivity. We use their 5-steps procedure.

Step 1 (Research Design) we set up the main objectives and the methodology to achieve them: bibliometric techniques like citation, co-citation, bibliographic coupling, co-author and co-word.

In Step 2 (Compilation of bibliometric data) we select databases, apply filters and export bibliographic information for each paper to build our database.

Some authors have used only one database for their review (Brady & Allen, 2006). However, the use of multiple databases is recommended to achieve a more comprehensive review (Gonzalez Aleu & Van Aken, 2017; Keathley-Herring et al., 2016). We chose Web of Science (WOS) core collection (Clarivate Analytics, 2018),<sup>1</sup> and Scopus because they are the most important in Management (Norris & Oppenheim, 2007).

In line with the highly cited Brady and Allen (2006) review, we conducted a systematic search on May 2018 using four keywords or descriptors: “Six Sigma” combined with “quality systems” or “quality improvement” or “quality management”. We included only research articles (including proceedings papers), letters, notes, and reviews (not meeting abstracts, obituaries, corrections, editorials, etc.), written in English, from 1990 (when the first paper appeared) until 2017.

Each article was manually checked to eliminate those that were not related to Six Sigma improvement strategies. Figure 1 shows the search process. It should be noted that there were several motives for the paper exclusion in the last step. Specifically: (1) papers

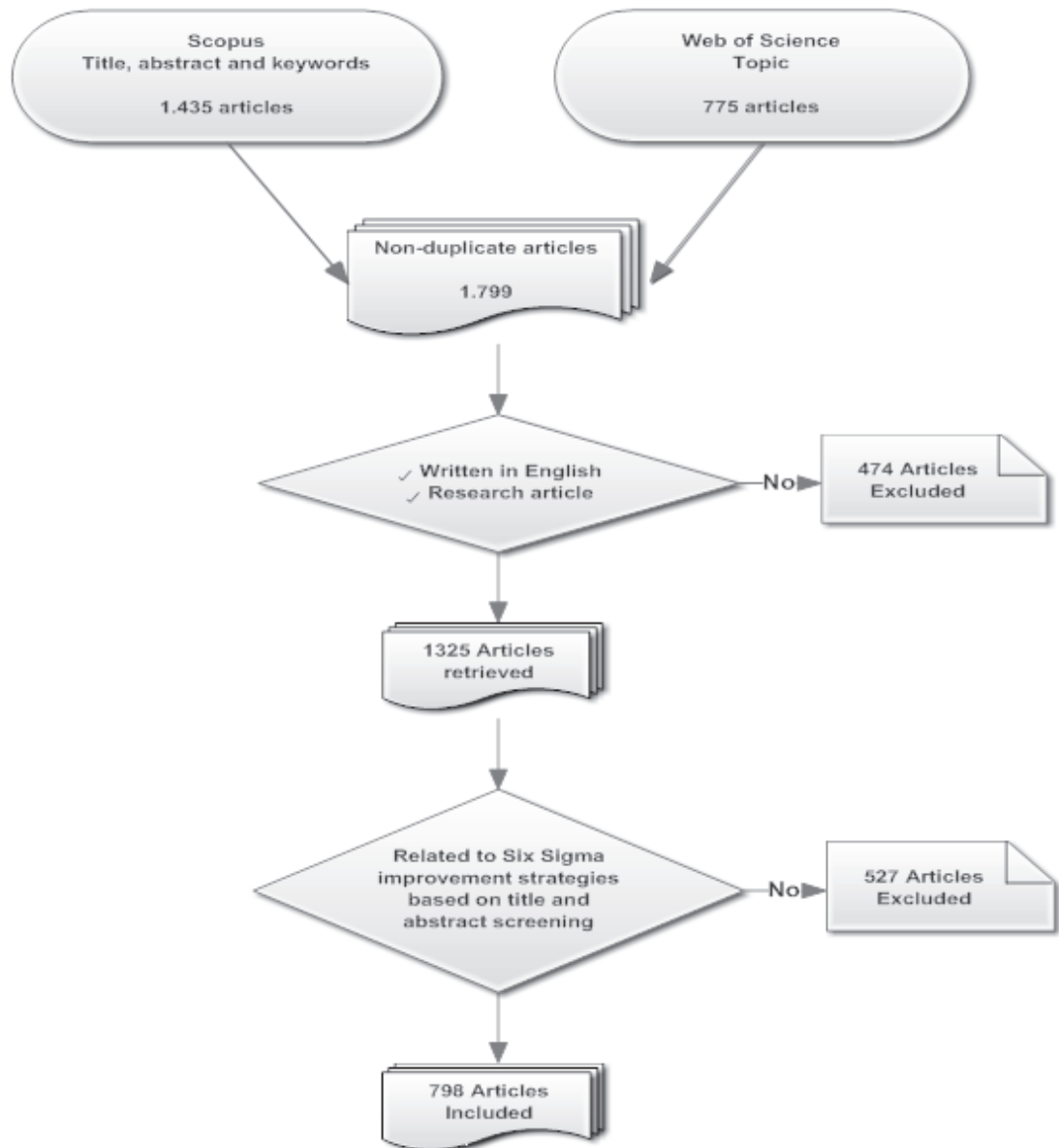
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<sup>1</sup> *Web of Science provides multiple databases cross-searches: Web of Science Core Collection (includes Science, Social Sciences, Arts & Humanities, Book, and Conference Proceedings Citation Indexes), BIOSIS Previews, Chinese Science Citation Database, Current Contents Connect (tables of contents), Data Citation Index, MEDLINE, and Zoological Record.*

*This study used the Web of Science Core Collection to conduct the searches.*

related exclusively to time or waste reduction (related to Lean concepts) rather than efficiency, error reduction, optimisation... (2) papers that mentioned Six Sigma as a list of approaches to improve processes, excluding the improvement of strategies or processes using Six Sigma, and finally, (3) papers related to sigma metrics (not the Six Sigma approach).

Figure 1. PRISMA flowchart



In Step 3 (Analysis), the most appropriate bibliometric software was chosen. We created tables with Excel and network analysis with VOSviewer (van Eck & Waltman, 2010). The decision to use these software tools, instead of others commonly employed in other bibliometric analysis, such as such Pajek, HistCite, Sitkis or Bibexcel (Cobo et al., 2011), was primarily due to our use of two different databases. Most software can work with Scopus RIS or WOS formats separately, whereas VOSviewer and Excel allowed us to work with CSV files and merge data from the two databases.

Before starting data analysis, we carried out an initial homogenisation step to improve the consistency of the results. First, we disambiguated the authors' names. Then, we carried out similar exercises on journal names and keywords. We checked the number of citations obtained from Scopus and WOS independently, to verify that all were included in our sample, and they were not duplicated. Finally, we edited references to put them all in the same citation style to achieve greater accuracy.

Step 4 (Visualisation) and Step 5 (Interpretation) are included in our review results.

### 3. Results

#### 3.1 Exploratory data analysis

The descriptive analysis of the 798 papers reveals some relevant trends. First, we have seen a positive trend in the number of publications since 1990 when the first paper appeared. Like most of the papers until 2003, its author was a practitioner (Table 1). This was expected since the approach started in industry and so it was primarily of professional interest. Subsequently, academics began to focus on this business process management methodology and the literature on Six Sigma increased substantially. We note that 90% of the papers we identified were published later than 2003, and more than 70% of them were written by academics.

We also observe that joint authorship, i.e. co-authorships between academics and industry professionals (labelled as both) has become more noticeable in the last few years. These collaborations provide different perspectives that may help to enrich the work.

Table 1. Publishing trend and Authorship

Year	Absolute frequency	Cumulative frequency	Relative cumulative frequency	Authorship		
				Academic	Professional	Both
1990	1	1	0,13%	0	1	0
1991	2	3	0,38%	0	2	0
1992	1	4	0,50%	0	1	0
1993	2	6	0,75%	1	1	0
1994	1	7	0,88%	1	0	0
1995	2	9	1,13%	0	2	0
1996	1	10	1,25%	0	1	0
1997	2	12	1,50%	0	2	0
1998	2	14	1,75%	0	2	0
1999	4	18	2,26%	2	2	0
2000	4	22	2,76%	2	2	0
2001	8	30	3,78%	3	5	0
2002	16	46	5,76%	8	7	1
2003	29	75	9,40%	14	14	1
2004	35	110	13,78%	17	15	3
2005	38	148	18,55%	22	12	4

<b>2006</b>	61	209	26,19%	38	9	14
<b>2007</b>	34	243	30,45%	23	7	4
<b>2008</b>	66	309	38,72%	44	11	11
<b>2009</b>	51	360	45,11%	44	4	3
<b>2010</b>	57	417	52,26%	45	2	10
<b>2011</b>	60	477	59,77%	46	3	11
<b>2012</b>	60	537	67,29%	43	10	7
<b>2013</b>	40	577	72,31%	33	2	5
<b>2014</b>	51	628	78,70%	42	1	8
<b>2015</b>	47	675	84,59%	34	6	7
<b>2016</b>	67	742	92,98%	49	6	12
<b>2017</b>	56	798	100,00%	37	6	13
<b>Total</b>	798			548	136	114

### 3.2 Citation

Citation is the method most frequently used to measure the influence of an author, journal, or paper (Garfield, 1972; Zupic & Čater, 2015), since it allows quickly identification of important works in the field. We should note that self-citations are not excluded in our analysis.

We identified 392 sources with at least one Six Sigma publication including journals and conference proceedings. Table 2 shows the most cited journals, highlighting the TQM Magazine (Currently published as: The TQM Journal) and the Journal of Operations Management as the main sources of these publications.

Table 2. Top 10 most cited journals

<b>Source title</b>	<b>Citations</b>	<b>Papers</b>
TQM Journal / TQM Magazine	1839	29
Journal of Operations Management	1232	11
Total Quality Management and Business Excellence	767	36
Quality and Reliability Engineering International	704	22
International Journal of Six Sigma and Competitive Advantage	555	45
International Journal of Quality and Reliability Management	514	16
Quality Engineering	340	11
International Journal of Lean Six Sigma	311	24
International Journal of Production Research	302	10
Business Process Management Journal	283	5

Table 3 shows the most cited authors, for example; Antony J. contributed 28 publications related to Six Sigma.

Regarding location, Linderman K., Schroeder R.G. and Choo A.S. are based in American universities, while the rest are from European ones (with the exception of Goh T.N. from Singapore).

Table 3. Top 10 most cited authors

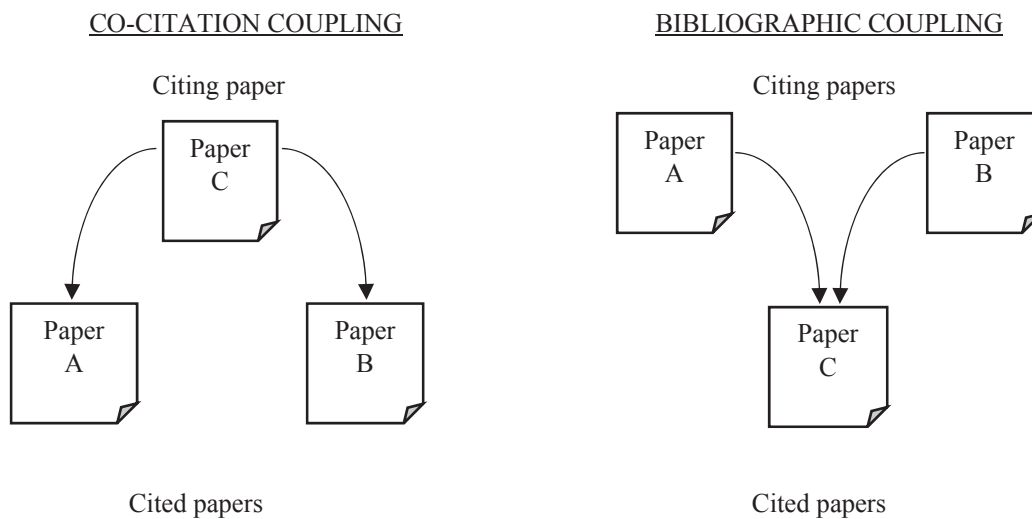
<b>Author</b>	<b>Citations</b>	<b>Papers</b>
Antony J.	1220	28
Linderman K.	1114	9
Schroeder R.G.	958	6
Choo A.S.	929	6
Goh T.N.	475	16
Bañuelas R.	473	5
Does R.J.M.M.	437	12
Kumar M.	354	11
De Koning H.	326	6
Dahlgaard J.J.	325	3

This section answers RQ1: “Which are the most relevant authors and journals in the field?”

### 3.3 Co-citation

Co-citation is defined as the frequency with which two documents are cited together (Small, 1973). Publications are co-cited if they appear together in another paper’s references, i.e. paper A and B are co-cited if paper C cites them both (Figure 2). The basic premise behind this method is that contributions of authors frequently co-cited are likely to relate similar concepts (Nerur et al., 2008). Therefore, co-citation analysis serves as a measure of similarity between documents, authors or journals (McCain, 1990), and may be used to evaluate the intellectual structure of a discipline (Pilkington & Meredith, 2009; White & Griffith, 1981).

Figure 2. Co-citation links and Bibliographic coupling



There are different types of co-citation networks, the three most common being author, document, and journal co-citation analysis (Liao et al., 2018; Nerur et al., 2008; Pilkington & Meredith, 2009).

In this review, we conducted a co-citation network analysis of these three. The results are displayed in Figures 3, 4 and 5. To make these more readable, only the top 50 items are shown in each case.

Nodes represent the number of citations of the unit of analysis, and the distance between them approximates their relatedness. We determined relatedness in terms of co-citation links (van Eck & Waltman, 2017). The more co-citations two documents receive, the greater the relatedness (indicated by the line thickness in the figures). Association strength measure was chosen for normalising the strength of the links between items (van Eck & Waltman, 2009). This technique divides the bibliometric material into clusters, represented by different colours, permitting the visualisation and analysis of a set of items that are cited together by another publication (Skute et al., 2017; Waltman et al., 2010). It should be pointed out that in VOSviewer each item only can belong to a single cluster (van Eck & Waltman, 2017).

A total of 17,269 authors are cited in our database. Considering the 50 most co-cited, the program reveals four principal clusters plotted in Figure 3. Based on number of components, the red cluster with 16 authors is the most important and also in terms of citations and link strength due to the Antony J. As previously noted, besides being the field's most productive and most cited author, Antony J. is also the most co-cited in works related to Six Sigma improvement strategies (861 citations and 17,446 link strength). He is cited with all authors on the map and has especially high link strengths with Kumar M. and Bañuelas R.C., with whom he shares cluster and several papers. It seems difficult to write a paper on Six Sigma and not mention any work of this author. Therefore, this is the central cluster and includes the most cited authors.

The blue cluster, accounting for 10 authors including Schroeder R.G., Linderman K. and Choo A.S. as more co-cited authors, is the second in importance (based on link strengths and citations). The green one is the third in co-citations, and includes more (14) authors, with Hoerl R.W., Harry M. and Snee R.D. as the main members. Finally, the cluster in yellow contains 10 authors and has lower links strengths than the other three.

(Insert Figure 3)

The most co-cited documents, are shown in Figure 4. In this case 14,590 cited references are included in the dataset. The most co-cited (74 times) is "Six Sigma: a goal-theoretic perspective" (Linderman et al., 2003).

These references form three clusters and it is important to mention that papers written by same authors tend to be included in the same cluster. This suggests that anyone who cites one paper of an author is more likely to cite other papers of the same author. The cluster in red contains 25 papers which represent the 50% of the papers shown in the Figure 4. On further investigation, they are related to the business process view of Six Sigma and include most of Antony J.'s research.

The green cluster (13 items) includes classic books or papers related to Six Sigma. Finally, the blue cluster (12 items) includes the Schroeder R.G., Linderman K. and Choo A.S. papers together with some reviews and conceptual studies.

(Insert Figure 4)

Journal co-citation shows the frequency in which two journals are cited together. This evidences similarities between the journal scopes and topics, or their areas of interest (Skute et al., 2017). Journals closer in their areas of interest exhibit higher co-citations and links strengths. Our database contains 5,380 sources (journals, books or proceedings). The TQM journal is the one with more direct citations and co-citations (19,961 total link strength), but the International Journal of Quality and Reliability Management and the Journal of Operations Management present more link strength with other papers (21,917 and 21,351 respectively). These data are displayed in Figure 5.

The 50 more co-cited journals were classified into 3 clusters. The red cluster comprises journals mainly related to TQM and business, and comprises 20 journals. Healthcare journals, focused basically on quality as Quality Progress, Quality Engineering and Six Sigma books, are grouped into the green cluster (16 items). Finally, in the blue cluster (13 items) represents management and strategic journals.

(Insert Figure 5)

### 3.4 *Bibliographic coupling*

Bibliographic coupling complements co-citation analysis by offering another perspective. As opposed to the co-citation analysis carried out in the above section, bibliographic coupling underlies the idea of connection between documents, authors or journals on the basis of the number of shared references, i.e. two documents are bibliographically coupled (paper A and B) if they cite one or more documents in common (paper C) (Figure 2). The more citations they share, the stronger their bibliographic link. Therefore, this is an alternative measure of similarity between documents, authors or journals (Zupic & Čater, 2015).

We analysed the documents of our database in terms of bibliographic coupling (Figure 6). Papers that cited similar bibliographic material are expected to have similar research profiles and be interesting for the same audience, and so should be grouped in the same cluster.

To map the data, we considered a threshold of 10 citations for a document, and display only the 100 most-connected documents in Figure 6. Articles were also excluded if they did not share enough references with others. VOSviewer grouped the documents into four clusters based on their bibliographic similarity: red, green, blue and yellow (with 43, 28, 24 and 5 items respectively).

(Insert Figure 6)

From this Figure, it can be concluded that papers from the same authors shared many references. For example, the red cluster contains several articles of Goh (e.g. Goh (2002a) (2002b) (2010) (2011) ...), the green cluster works of Kumar (e.g. Kumar (2018a) (2009) (2011) ...), and so on. Works of the same author tend to belong to the same cluster. Moreover, Six Sigma has been used in several research areas, so this also has a strong influence, i.e. papers from the medical area are more likely share references with other medical papers rather than with business ones (and vice versa). This is clearly seen in the yellow cluster, as its five items are related to Six Sigma in healthcare.

### 3.5 *Co-author*

Co-authorship is one of the most tangible forms of scientific collaboration. Co-author analysis examines scientific social networks through co-authorships (Glänzel & Schubert, 2004; Newman, 2001). Analysing collaborations allows one to establish the social structure of a field (Newman, 2001), the main groups of research, and their relationships with other groups or institutions.

We review co-authorships using network analysis to identify the degree of collaboration and knowledge exchange. Figure 7 indicates that research in this field is carried out by groups of authors, hence the different clusters that are observed in the map (each node colour represents a group of authors collaborating). The most relevant are the most cited and co-cited authors, as mentioned in previous sections.

(Insert Figure 7)

Those authors who normally work together, tend not establish relationships outside their group. Figure 8 shows graphically that, of the 1,768 authors who constitute the database, only 106 have some connection outside their working group. Furthermore, we can observe a thin link strength between them (except for Antony J. and Kumar M). Therefore, it is suggested that research collaborations in this field are endogenous and weak.

(Insert Figure 8)

### 3.6 *Co-word*

Co-word analysis is a content analysis that can use words included in abstracts, titles of papers or even the keywords of a document to glimpse the conceptual structure of the field (Callon et al., 1991).

The authors use keywords to characterise their work. We analyse the words most frequently used as keywords by them (Table 6). In Figure 9, the sizes of the nodes and words represent their weight (keywords) i.e. occurrences. The distance between two nodes reflects the strength of the relationship between them, a shorter distance meaning a stronger relation. The network connections show the keywords that appear together more frequently in the analysed papers, a line between two keywords indicates their co-occurrence. The thicker the line, the greater the co-occurrence frequency. Finally, the colour of the nodes indicates that they belong to the same cluster (van Eck & Waltman, 2017).

We found 1,294 keywords in the database but, to make the plot readable, only the top 50 are shown (Figure 9). Using this threshold of 50 implies that each keyword has to appear more than five times, i.e. at least six papers use it. Unsurprisingly, the largest node, i.e. the most frequently used keyword, is *Six Sigma* (Table 4). More surprising may be the fact that its main link strength is with *dmaic* as most empirical papers apply this define-measure-analyse-improve-control methodology.

Table 4. 10 most co-occurring keywords

<b>Keyword</b>	<b>Occurrences</b>	<b>Total Link Strength</b>
Six Sigma	480	901
Dmaic	100	244
Quality Management	100	214
Tqm	95	225
Quality Improvement	81	165
Lean	74	214
Quality	52	135
Lean Six Sigma	46	101
Process Improvement	39	84
Critical Success Factors	33	78

(Insert Figure 9)

Keywords are grouped into seven clusters according to the association strength normalisation method used by VOSviewer (van Eck & Waltman, 2009) (Table 5).

Table 5. Keywords cluster analysis

<b>Cluster</b>	<b>Colour</b>	<b>Items</b>	<b>Keywords</b>	<b>Theme</b>
#1	red	9	control chart; dmaic; dpmo; India; patient safety; pdca; quality improvement; statistical process control; taguchi method	Methodological issues
#2	light green	8	automotive industry; case study; higher education; innovation; process management; project management; quality assurance; quality management systems	Project and empirical issues
#3	dark blue	8	business excellence; critical success factors; iso 9000 series; literature review; quality programs; smes, survey; tqm	Business excellence
#4	yellow	7	black belts; customers satisfaction; education; improvement; process; quality; training	Training on Six Sigma
#5	purple	7	cause and effect analysis; continuous improvement; doe; integration; process capability; process improvement; six sigma	Six Sigma process
#6	light blue	6	construction industry; dfss; knowledge management; quality control; quality engineering; quality management	Engineering issues
#7	dark green	5	healthcare; hospital; lean; lean six sigma; service quality	Lean and healthcare issues

Abbreviations: dmaic= define, measure, analyse, improve and control; pdca= plan, do, check and act; smes= small and medium enterprises; tqm= total quality management; doe= design of experiment; dfss= design for Six Sigma.

In accordance with the conceptual (keywords co-occurrence) analysis of the Six Sigma literature we can draw some conclusions. As seen in Cluster 1, some of this literature is based on methodological aspects. It is a steps approach (dmaic) that uses different statistical tools e.g. control charts, consequently some keywords are related to statistical or methodological issues. On the other hand, it has a project approach (#2) that uses mainly a case study research methodology. The cluster analysis also reveals that Six Sigma is mainly focused on different sectors or industries including: engineering (#6), higher education (#2), automotive (#2), construction (#6), healthcare (#7), as well as general business (#3). Therefore, different clusters contain keywords applicable to each sector. We can see that *Lean approach* is more used in healthcare than in any other sector, as it belongs to Cluster 7. The complexity of Six Sigma implementation requires training on its principles. *Black belt* is one of the certifications that guarantees its achievement for this reason it is in Cluster 4. Finally, in the Six Sigma process cluster (#5), we see some of the words used to define it, as *continuous improvement* or *process improvement*.

These results, and those from the last sections where we have applied relational techniques, answer RQ2: “What is the intellectual, social and conceptual structure of this literature?”

#### **4. Discussion and conclusions**

We conducted a bibliometric analysis and visualisation of Six Sigma publications. Its objective was to identify the field structures and opportunities for further research.

We found a steadily growing literature on Six Sigma research as mentioned in previous reviews (Brady & Allen, 2006; Tjahjono et al., 2010). Moreover, the growth rate increased once academics began to conduct studies using this approach (Reosekar & Pohekar, 2014; Tjahjono et al., 2010), our disaggregation of papers by authorship makes this evident. This differentiation was also made in several previous works, especially following the highly cited Brady and Allen (2006) review.

Regarding authorship, we underline the low degree of collaboration between the authors found, as was already suggested in Reosekar and Pohekar (2014). These authors found that 22.9% of the articles they reviewed were single author and, by definition, had no have collaboration. A further 38.5% had two authors and the remaining 38.5% more than two. We have also seen that even if a research group exists, it works endogenously, without relating to other groups. It has been argued that, as well as collaborative research between academics and industry professionals, inter-group collaborations are also needed (Reosekar & Pohekar, 2014).

Many journals have been outlets for this research. We found that, and in line with previous reviews (Reosekar & Pohekar, 2014), over the period the TQM Journal (previously The TQM Magazine) has been the most prolific. But we also found journals

indexed in different research domains not purely focused on quality issues or on process management. When compared to other topics, Six Sigma is a cross-cutting theme that interests many areas of research: engineering, business, medicine... (Reosekar & Pohekar, 2014). Its literature shows that it is very much in use within the manufacturing sector (Reosekar & Pohekar, 2014) but is growing in the service sector (Tjahjono et al., 2010). Brady and Allen (2006) also found a large audience in medical journals.

We cannot compare the analysis of co-citations and bibliographic coupling with previous studies, since they have not been previously carried out in this field.

On the other hand, several of the results of the keyword analysis are supported by what we observed in the literature (such as, for example, the analysis of the tools used in the different Dmaic phases c.f. Ismyrlis & Moschidis, 2013; Tjahjono et al., 2010). These have been analysed in empirical articles, but have also been deeply studied in Uluskan (2016). In the present review, some Dmaic tools appeared as main keywords in the field and are included in Cluster #1, methodological issues.

Another part of the Six Sigma is focused on the analysis of the success and failure factors of its implementation (Ismyrlis & Moschidis, 2013; Nonthaleerak & Hendry, 2006; Patil et al., 2017). Here, critical success factors appear as the tenth most used keyword. These success factors have been analysed in general business and also in some specific sectors. The reviews carried out for construction (Negi et al., 2017; Siddiqui et al., 2016) and healthcare (Ahmed et al., 2013; Antony et al., 2018; Dellifraime et al., 2013) already foresaw these as two relevant sectors. This is also highlighted in the keyword analysis since they appear among the most repeated keywords.

Some authors argue that, as compared to large companies, less attention has been given to the application of Six Sigma in SMEs (Nonthaleerak & Hendry, 2006; Tjahjono et al., 2010). They therefore suggested that more research is needed to understand Six Sigma adoption within SMEs, i.e. how to adapt the framework for companies with smaller investment budgets. Our analysis shows that some research is already being done in this regard, since we see that *SMEs* is among the 50 most used keywords.

This review represents an extension of previous reviews carried out in the field. It covers all the publications regarding Six Sigma improvement strategies in Scopus and Web of Science from its first occurrence, up until 2017.

The main contribution of this research is regarding the methodology. Bibliometric relational techniques had not been used before in the field and complement the existing literature. Previous bibliometric reviews were limited to showing the quantitative change over time of the articles published on this topic, their relevance through citations, the journal that published most of the papers, etc. By analysing the relationships between publications, authors and words, the techniques used in our research allow elucidation of the different structures of the research field. This is particularly useful for classifying the literature on subtopics, collaborations, and research areas. It may also be useful for beginning researchers wishing to identify subtopics or activity sectors where Six Sigma is applied, the main works, and literature groups. It may also be useful for finding potential opportunities or gaps to cover, for example, we found that research

collaborations in this field are endogenous and weak so authors might look to establish new collaborations that broaden their point views.

## **5. Future directions of Six Sigma research**

By mapping the Six Sigma field through its literature analysis we are able to answer the RQ3 regarding the opportunities for Six Sigma research. We see some aspects that researchers should consider addressing. The first one concerns the application of Six Sigma in other areas. We have seen that, identified through keyword analysis, research in the area is especially related to specific activity sectors as healthcare (Ahmed, 2019), engineering or automotive (Surange, 2015), however this methodology could be applied to other sectors since it can improve any process, whether production or service.

The second opportunity is relative to authorship. There is a group of authors who dominate the research publications in regard to cites and co-cites. These are the authors of reference on this topic. Nevertheless, up to 1,768 authors appeared in our dataset, so there are many other authors, both academic and professional, who are interested in the field. In addition, from the co-authorship analysis, it is noted that there is little collaboration between different research groups; working with other authors, instead of constituting closed groups lacking external contacts, might serve to improve the quality of their work.

Through the years Six Sigma has been blended with Lean technologies creating a sophisticated set of tools that are the essence of Operational Excellence. In this sense, the implementation of Six Sigma in the future will probably require a lot of process innovation to meet future industry demands or the introduction of the Industry 4.0 for further advance in the field (Arcidiacono & Pieroni, 2018). Therefore, the third opportunity will be related to methodological innovation.

On the other hand, Six Sigma methodology has been applied to a diverse set of non-manufacturing related issues giving excellent results. It is not a methodology focused only on production as it has also been successfully applied in services sector (Furterer, 2016; Sunder et al., 2018) or even in the public sector (Antony et al., 2016). Despite the difficulty of implementing Six Sigma in public institutions, the improvement of their efficiency and in the transparency of their decision processes could suppose an improvement for the whole community. Therefore, it is a challenge for the future to get Six Sigma to institutional levels. So, the fourth opportunity, is in terms of non-traditional domains of research and journals in the field of business, management, engineering, health, and education which may be willing to publish related papers. Their availability should encourage authors to continue providing empirical evidence on the improvements that this approach can bring to projects or to companies as a whole.

Finally, it has been a clear the advantage of Six Sigma to employees, customers, managers, and shareholders, however, the benefits of Six Sigma have not really reached to the majority of people. The fifth opportunity is to change this fact. That is to say that the use of Six Sigma to solve global challenges, like environmental issues (Chugani et al., 2017), should to be the centre of the attention of our leaders. Climate change is a reality affecting all planetary systems hence all humans living on the planet. The

projection of population growth sees the world reaching 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion by 2100. Therefore, one global challenge is to improve the decision-making process so that takes into account global foresight in an unprecedented accelerating change. Six Sigma methodology is probably the best tool to ensure that decisions are taken based on data and facts and that the influence of geopolitical factors is diminished to more tolerable limits in order to ensure that decisions are made to improve the lives of the majority of people reducing the inequality level of today. Another global issue where Six Sigma could be applied is the growing energy demand and the access to fresh water.

In order to achieve these objectives, Six Sigma should not be limited to a few schools and universities around the globe and it needs to become a formal subject as a tool for making decisions based on data instead of belief. The current article provides several starting points for practitioners and researchers when investigating Six Sigma and contributes to completing the vision of the field by complementing previous literature reviews through the network analysis.

Nevertheless, it has some limitations that we should mention. Firstly, we established a threshold to visualise a part of the dataset in a more readable way, instead of working with the whole dataset. Therefore, only a subset of the quantitatively most important items is represented. Secondly, since we used author's keywords for the analysis of the conceptual structure of the field, if these do not well describe the papers, our research may omit relevant information. Thirdly, we use a limited number of databases, we consider two of the most important, WOS and Scopus, but we could have considered others, such as Google Scholar, to increase coverage. Fourth, we only consider articles as academic outputs, not taking into account books or book chapters, reports or other types of documents. Finally, we downloaded documents written in English. This leads to underestimation of researchers who use other languages.

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Figure 4

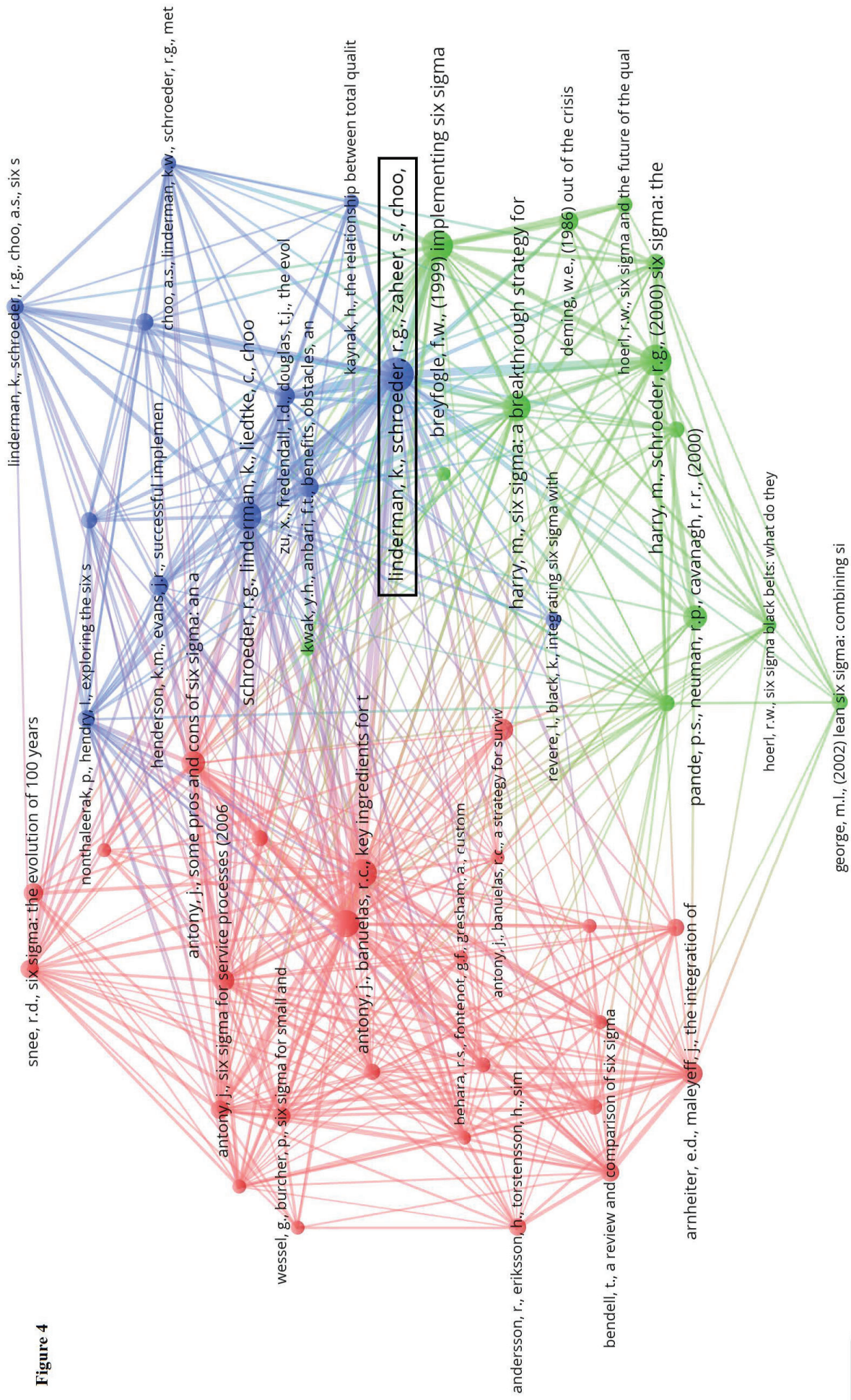








Figure 8

