

Six Sigma Literature: A Bibliometric Analysis

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Abstract

Six Sigma is business management strategy used by many industries for quality improvement. The aim of the study is to conduct a bibliometric and relational study on Six Sigma research indexed in two well-known databases: Scopus and the Web of Science. Data collection involved 798 articles published in 392 academic journals between 1990 and 2017. Studies were classified based on research type (methodology used), authorship (type and country of affiliation), research field and keywords (co-occurrence and trend). Results show that literature on Six Sigma is dominated by the field of business and management followed by engineering and medicine. United States is the leading country in this topic in terms of documents, cites and co-authorships. Case studies and conceptual papers are clearly the most used methodologies, although there is a noticeable upward trend in surveys in the business and management area. Based on the articles' keywords, it appears that Lean Six Sigma, the combination of the two management approaches, has recently become one of the most common terms, outpacing traditional terms such as Total Quality Management or continuous improvement. For the field to advance, further survey studies are needed as conceptually it has been deeply researched.

Keywords: Quality management; Six Sigma; Literature review; Bibliometric

1. Introduction

The term *Six Sigma* was introduced as a business process management in the mid-1980s by Bill Smith, an engineer at Motorola (Brady & Allen, 2006) in response to the growing competitiveness of products from Japan. At that time, Japanese companies in electronic industry offered lower price and higher quality, so American companies needed to improve their products to successfully compete in global and domestic markets (Raisinghani et al., 2005).

From a business point of view, Six Sigma is a powerful strategy that enhances the efficiency of business processes and significantly reduces product defects (Antony, 2006; Kwak & Anbari, 2006). From a statistical point of view its goal, as its name suggests, is the reduction of variability in business processes (Kwak & Anbari, 2006; Linderman et al., 2003). Specifically, what is sought is to achieve a level quality of 99.99966% which corresponds to 3.4 defects per million opportunities (DPMO). An opportunity is defined as a chance for non-conformance, or not meeting the required specifications (General Electric, 2013).

Six Sigma quickly became popular in other organisations after 1988 when Motorola received the Malcolm Baldrige National Quality Award for its Six Sigma implementation (Raisinghani et al., 2005). Many organisations launched Six Sigma initiatives from that moment achieving greater success, but it is especially noteworthy the case of General Electric (GE). GE played a very significant role in the development of Six Sigma as a methodology because they decided to add a “define” step at the beginning of the MAIC process (*measure, analysis, improve and control*) to clarify the problem addressed (Antony et al., 2017). As shown in Table 1, DMAIC phases allow Six Sigma to be a systematic, data-driven approach.

INSERT TABLE 1

Unlike other Business Management Systems approaches such as TQM (Total Quality Management) or Lean, Six Sigma focuses on savings and costs (Andersson et al., 2006). By offering reliable products / services (without failures) Six Sigma improves the profit margin and ultimately allows the producer achieve customer satisfaction (Karout & Awasthi, 2017; Raisinghani et al., 2005).

Due to its benefits, Six Sigma has been widely researched in operations management literature and a considerable number of reviews have been carried out. Brady and Allen (2006) first and Tjahjono et al. (2010) later, tried to answer the question “what is Six Sigma” and Prabhushankar et al. (2008) conducted a comprehensive review of the principles of Six Sigma. By analysing various definitions provided in the literature, they proposed a new holistic definition for Six Sigma. According to these authors, Six Sigma is “a highly disciplined, organised, systematic, proactive, powerful and multifaceted problem-solving or continuous and/or breakthrough business/process improvement strategy that seeks to find and eliminate the sources of error or the causes of customer-defined mistakes or defects, drive out wastes in business processes, and reduce variation, thereby improving the efficiency and effectiveness of organisational operations, and

strives to reach a level of 3.4 DPMO using extremely rigorous data gathering and statistical analysis, thereby meeting or even exceeding customers' needs and expectations with a focus on financially measurable bottom-line results”.

Some these literature reviews have sectoral nature, in the fields of construction (Negi et al., 2017; Siddiqui et al., 2016) and health care (Antony et al., 2018; DelliFraine et al., 2013). Six Sigma has had a considerable impact in the medical as is evidenced by the many conceptual articles and case studies that focus on hospitals and medical processes. However, most reviews are generic, not related to a sector, and focus on specific aspects of Six Sigma, such the importance of project selection to achieve successful implementations (Padhy, 2017; Shanmugaraja et al., 2012), critical success factors (CSF) (Brun, 2011; Chakrabarty & Chuan Tan, 2007; Ismyrlis & Moschidis, 2013; Nonthaleerak & Hendry, 2006; Patil et al., 2017) or the DMAIC toolbox (Ismyrlis & Moschidis, 2013; Uluskan, 2016).

Therefore, besides the varied perspectives from which Six Sigma can be analysed, we have three additional motivations for carrying out this bibliometric review. Firstly, the number of related academic has made a quantum leap in recent years. It can be noted the comprehensive reviews conducted by Brady and Allen, (2006), Reosekar and Pohekar (2014) and Tjahjono et al. (2010) covered different periods, but only up to 2011. They retrieved 201, 179 and 167 papers respectively, which gives an indication of the volume of published material. Secondly, it would be interesting to update the highly cited review made by Brady and Allen in 2006, which included publications from 1990 to 2003 in the Web of Science, with publications until 2017 and considering multiple databases. And thirdly, we consider that a network and bibliometric analysis of publications would represent a significant contribution to the literature.

Six Sigma has been applied to manufacturing/industrial sectors but also in services (Chakrabarty & Chuan Tan, 2007). As it is a methodology that can be applied to any field, our aim is to apply Six Sigma to conduct a literature review on this topic. In the following paragraphs, we describe how we use the DMAIC methodology to the creation of the current paper.

Our Introduction is the *definition* phase, which defines the objectives we pursue. Our Methodological section corresponds mainly to the *measure* phase as it identifies, selects or excludes the articles we consider. The articles selected will be *analysed* in the next phase, constituting our Findings section. The *improve* phase corresponds to our Conclusions and Implications where we present the contributions. Finally, the *control* phase has two aspects: on the one hand, a periodic search for new articles to be included and, on the other, the supervision conducted by experts on the different parts of the revision process. Using this methodology of systematic review and supervision we hope to optimise the search and analysis of the papers.

The aim of the paper is to systematically review academic papers related to Six Sigma using the methodology itself. Through the identification and analysis of some aspects such as authorship, country of affiliation, journal of publication, research field, research methodology, etc. we expect to offer a rigorous and up-to-date synthesis of prior insights into Six Sigma.

2. Methodology

A systematic literature review seeks to systematically search for, to appraise and to synthesise research evidence (Grant & Booth, 2009). It is characterised by being objective, systematic, transparent and replicable (Kitchenham & Charters, 2007).

Tranfield et al. (2003) proposed a design for systematic literature reviews in the management field based on three stages with different steps or phases in each. These phases include planning the review, conducting the review and reporting / dissemination. We adapted Table 2, developed by Tranfield et al. (2003), for the DMAIC analysis carried out in this paper.

INSERT TABLE 2

STAGE I, called “planning the review”, corresponds to the *Define* phase of DMAIC. Identification of the need for the review and preparation of the review proposal, Phases 0 and 1 respectively, are motivated and justified in the article introduction and, Phase 2, development of a review protocol, is explained in the methodological section. We will detail which databases were selected for article searching, which keywords were chosen for this purpose and which criteria were used for inclusion/exclusion in the review. Only studies that meet all the inclusion criteria specified in the review protocol will be incorporated into the review. Furthermore, we establish a set of descriptors for article classification, some of them based on Brady and Allen (2006).

STAGE II, “conducting the review” includes Phases 3 to 7. They correspond to the *Measure*, *Analyse* and *Control* phases of DMAIC. All but the last of these serve to identify, select, evaluate and monitor articles from the selected databases. Phase 7 is related to data synthesis, as part of the analysis phase of DMAIC.

Finally, STAGE III, “reporting and dissemination”, corresponds to *Analyse* and *Improve* functions of DMAIC. This part of the systematic review constitutes the goal of the study as it provides an overview of the state-of-the-art, and comments regarding further research.

It should be noticed that the phases in stages II and III, have implicit control tasks, both during the literature review process and at the end, in the reporting and dissemination stage.

2.1 Selecting databases

The relevance of a review depends on the relevance of its methodology and on the items included. For this reason, we selected two databases on which to implement the review: Web of Science (WOS), core collection, and Scopus. These consist of the best, peer reviewed, scientific journals and are generally used by academic community due to their quality (Cobo et al., 2011). Journal coverage differs substantially among disciplines in each database and, in consequence, the results of bibliometric analyses may vary

depending on the database use (Mongeon & Paul-Hus, 2016). For this reason, like many authors, we used more than one search platform or database in order to achieve a more comprehensive review including multiples sources (Chakrabarty & Chuan Tan, 2007; Gonzalez Aleu & Van Aken, 2017; Keathley-Herring et al., 2016; Patil et al., 2017; Uluskan, 2016).

The Web of Science (WOS) is a world leader among citation database and is produced by Clarivate Analytics. It is multidisciplinary (Science, Social Sciences and Arts and Humanities) and consists of over 90 million records (Clarivate Analytics, 2018). The Scopus database is offered by Elsevier; it also is multidisciplinary (Life Sciences, Social Sciences, Physical Sciences, Health Sciences) and has over 69 million records (Elsevier, 2018).

In order to collect comprehensive data from both databases, we used a two-step approach. First, we selected relevant keywords to search (Subsection 2.2), and second, we did a content analysis of the articles in order to “cross-check” if the databases identified the right articles for our analysis (Subsection 2.3).

2.2 Selecting keywords

The systematic search was conducted using the four keywords or descriptors: “six sigma” and “quality systems” or “quality improvement” or “quality management” in line with Brady and Allen (2006). These needed to occur in the Title, Abstract or Keywords for Scopus, and in the Topic for WOS.

2.3 Selecting criteria for inclusion

We collected information on journal articles written in English only and published before 2018.

We considered as publication types ‘research articles’: articles (including proceedings papers), letters, notes, and reviews (but not meeting abstracts, obituaries, corrections, editorials, etc.) (van Raan, 2003).

Each article was manually checked to eliminate those that were clearly not related to Six Sigma improvement strategies.

Figure 1 graphically represents the steps done during the review process using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2010). As can be seen, the first search phase, identification, produced 775 items in WOS database and 1.435 in Scopus. Many of them appeared in the two databases so, after removing duplicates, the number of articles included amounted to 1,799.

After applying the criteria mentioned above (texts in English, period 1990-2017 and, typology of document: article, proceedings, review, letter and note), 474 articles were excluded, and 1.325 remained eligible. In the next step, after screening their titles and abstracts, 517 articles were removed because they were not exactly related to Six Sigma. The motives for exclusion were:

- They were related to waste reduction (Lean concept) rather than efficiency, error reduction, optimisation...
- They only mentioned Six Sigma as a list of approaches to improve processes, but the article was not about improving strategies or processes using Six Sigma
- They were related to sigma metrics (not Six Sigma approach)
- They were related to Six Sigma training

The final sample consisted of 798 articles after remove those with not available data.

INSERT FIGURE 1

Although it is always possible that some relevant articles may have been missed, two authors worked independently, and studied the articles in detail to minimise this possibility. Only articles commonly agreed between them were included in the review on the basis that, to be included, it must address a theoretical or an empirical issue concerning Six Sigma improvement strategies.

2.4 Selecting descriptors for analysis

Descriptors were identified in each article, these were used to classify the articles, and are then used as analysis variables in the following section. These descriptors, and the justification for the choice of each, is as follows:

- Year of publication. Counting the number of papers per year serves for establishing publication trends and checking whether the topic is still interesting for both academic and professional audiences;
- Authorship (this variable is used in twofold analysis: (1) type of authorship in terms of Industrial (professional), Academic or Both as in Brady and Allen (2006), and (2) country analysis, considering authors' country of affiliation). Identifying authors and their countries allowed us to establish a ranking of the most cited, those that have more contributions (papers) and other aspects such as co-authorship by country, as well as the approach (professional or academic) of their works;
- Name of the publication (publication source). Identifying the reference journals for the topic based on the number of papers published;
- Keywords. Adding keyword analysis to the review helped us find the main descriptors used in Six Sigma research (keyword co-occurrence frequency) and the links between them, i.e. keywords that often appear together;
- Research field (Keathley-Herring et al., 2016). Four categories were used to label each paper according to the field of the journal which they belong. The Scopus classification was used as most of the papers were in this database. These categories or research areas were: 1. Business, Management and Decision Sciences, 2. Medicine and Nursing, 3. Engineering and Computer Sciences and 4. Others (education, environment ...). We decided to use these broad groupings

because journals are sometimes classified into several categories and this classification amalgamates areas commonly shared by journals. Therefore, these four groups correspond to different areas related to (1) decisions, (2) medical, (3) technology and (4) other;

- Research methodology (labelled as Case Study, Conceptual, Survey and Secondary data (Jiang et al., 2007)). In Case Studies, data reflected the specific situation of one or more companies; Conceptual included literature reviews or papers without data processing; Survey involved questionnaires administration; and, Secondary Data used data from secondary sources, such as government reports or industry-wide.

2.5 Data processing

Before starting with data analysis, we carried out an initial homogenisation step to improve consistency of the results. First, we disambiguated the authors' names. Then, we did similar exercises on journal names and keywords. Finally, we checked the number of citations obtained from Scopus and WOS independently, to verify that all were included in our sample and were not duplicated.

We used different software for statistical and graphic processing. We did graphs and tables with Excel, network analysis with VOSviewer (van Eck & Waltman, 2010) and finally, geographical analysis with mapchart.net. In addition, to conduct a descriptive analysis of data, we took advantage of bibliometric tools provided by VOSviewer for analysing citations (excluding self-citations), co-authorships, geographical distribution and word frequency (keywords) to draw some conclusions.

The decision to use these software tools instead of others such as Pajek, HistCite, Sitkis or Bibexcel (Cobo et al., 2011; Kumar et al., 2015) often used in bibliometric analysis was primarily due to our use of two different databases. Most software reads Scopus RIS or WOS formats separately, whereas VOSviewer and Excel allowed us to work with CSV files and merge data from the two databases.

3. Findings and Discussion

Review results are detailed in the next five subsections. Analysis of the author, journal, country, year, research field, research methodology and keyword variables, indicates the state-of-the-art for Six Sigma improvement strategies.

3.1 Initial data statistics: top journals, top authors

The first results are focused on analysing the journals and main authors with publications on Six Sigma. The total number of journals or proceedings with at least one article related to Six Sigma and improvement strategies is 392. This result is very high compared to previous reviews, Brady and Allen (2006) contains 63 journals/proceedings and Reosekar and Pohekar (2014) 52 reputable journals. Because we found such a wide spread of

sources, we display only those having 5 or more documents in Table 3. Using this threshold, the list is reduced to 27 sources, representing 42% of the articles covered.

INSERT TABLE 3

As expected, all journals on the list are related to quality management and control issues. We identify three large fields of research where Six Sigma has been analysed, business, engineering and health care.

From Table 3, it is clear that there are two journals (International Journal of Six Sigma and Competitive Advantage and International Journal of Lean Six Sigma) dedicated almost exclusively to Six Sigma and therefore they accumulate most of the documents and citations. On the other hand, TQM Magazine has published the articles with the greatest impact since this journal has more than a thousand citations, e.g. Arnheiter and Maleyeff (2005) and Dahlgaard and Dahlgaard-Park (2006).

A total of 1,786 authors have published articles related to Six Sigma and their improvement strategies during the period analysed.

Using citation counts solely may include an author with only a single, but highly-cited, article. For this reason, we decided to analyse the most relevant authors according to their H index in their Six Sigma papers included in our database (Table 4). The H index developed by an American scientist, Hirsch, quantify an individual's scientific research output by comparing papers and citations.

“A scientist has Index H if h of his or her N_p papers have at least h citations each and the other (N_p-h) papers have $\leq h$ citations each” (Hirsch, 2005).

INSERT TABLE 4

3.2 Literature trends

It is interesting to analyse the publishing trend to see how the research field evolves over time (Garfield, 1994). Besides counting the number of articles per year, in this review we identify the authorship of papers in order to provide additional information. So, we can see if interest in the topic is professional or only academic, as well as its evolution over time. Figure 2 shows the trend in numbers of article published, disaggregated by the type of authorship.

INSERT FIGURE 2

Six Sigma is a process management approach of considerable publication interest, with a substantial and growing number of papers being published annually. The number of articles has increased much over the period reviewed, with an upward trend (dashed line). Current interest, as measured by authorship, appears to be more academic than professional unlike the Brady and Allen (2006) findings. At the beginning, when Six Sigma was conceived and began to be applied, authors with an industrial background were remarkably more prolific (see Brady and Allen (2006)). This trend has changed substantially, and academics predominate for the last 15 years (2003–2017). Of the total 798 articles, 548 (69%) have academic, 136 (17%) professional, and 114 (14%) joint authorship. It seems that, in the first stage of Six Sigma research, industry professionals were those who contributed most to this literature probably because its roots were in the industrial / business world. Like Reosekar and Pohekar (2014) we find that recent papers by authors from universities and other educational centres are at least triple those from industry authors. On the contrary, in their review from 2004 to 2009, Tjahjono et al. (2010) find the numbers of publications per year from industrial and academic authors to be approximately equal. This, perhaps, is because they made several interpretations of Six Sigma and, in addition to considering it, as we do, to be an operational philosophy of management, they also understand the methodology as a set of statistical tools. Therefore, they used keywords in their search strategy such as “tools” or “techniques” that retrieve papers with a more industrial character.

Regarding joint collaborations (co-authorships) between academics and professionals (labelled as both), it should be noted that, according to our data, they basically occur in the Medical field due to practitioners in this field being more likely to be involved in research and academic activities. Figure 3 shows that 48 of the 114 joint authorship papers (42%), were in the medical area.

The nature of joint collaboration was not previously studied, and we consider it would be interesting to explore from different points of view Six Sigma organisational benefits. So other fields, besides Medicine, should take advantage of the synergies of academics and practitioners working together.

INSERT FIGURE 3

3.3 Geographic distribution and multinational collaborations

Using authors' country of affiliation, we note that interest of Six Sigma is worldwide, because there are some 61 countries that have published at least one article related to the topic. According to Figure 4, the United States is the country where more papers have been written (more than 100 papers), followed by India and the United Kingdom (both with more than 75) and China (more than 50).

INSERT FIGURE 4

The world map in Figure 5, shows which countries receive most citations. The United States with 6,622 citations dominates both indicators. It is followed by United Kingdom (2,048) and India (934). It is worth highlighting the rise of India in terms of

both citations and papers in recent years. Of the 64 papers we found in 2017, 17.2% have Indian authorship, 32.8% American with other countries (including the United Kingdom) each being less than 5%.

The increase in the number of papers (53) in relation to Six Sigma in China is remarkable, even though in terms of citations (only 74) they are well below the top three. However, our sample suggests that countries such as India or China will have more presence in the future Six Sigma publications, although the United States will undoubtedly remain the leader.

INSERT FIGURE 5

In this section we will focus especially on multinational collaborations. Co-authorship is one of the most tangible forms of scientific collaboration and we analyse these using network analysis to identify the degree of collaboration between countries. As in Merigó et al. (2016), we consider author affiliation, not their nationality, to carry out the analysis.

Of the 61 countries we found, 35 of them are connected in the sense that they have co-authors from different countries of affiliation. The size of the nodes of Figure 6 represents the number of papers published by a country, and the arcs are the connections between countries. The colours represent different groups or clusters. The normalisation method used was the default option of association strength (van Eck & Waltman, 2017). A cluster is a set of closely related nodes and each node in a network is assigned to exactly one cluster (Waltman et al., 2010). Our 61 countries form 32 clusters which means that they have few similar attributes to be grouped, only 14 clusters consist with more than one country. They are disaggregated in Table 5 and displayed in Figures 6 and 7.

INSERT FIGURE 6 AND FIGURE 7

INSERT TABLE 5

Co-authorships analysis has shown the importance of linguistic and territorial affinities in the network analysis clusters. Cluster 8 (Croatia, Montenegro and Slovenia) might be explained by their proximity and their historical relationship, Cluster 9 (Argentina, Mexico and Spain) and Cluster 11 (Portugal and Brazil) by their cultural and linguistic proximity, and Cluster 13 (Greece and Macedonia) or Cluster 4 (Croatia, Montenegro and Slovenia) by geographic proximity. However, it is remarkable that co-authorship has an international character. Countries from the first three Clusters, belong to *three* different continents. And those belonging to Clusters 4, 5, 6, 7, 9, 10 and 11 are from *two* different continents.

On the other hand, our results are in line with those of Reosekar and Pohekar (2014) who found that multiple country authorships are infrequent (only 12.3% in their

study). We have verified that collaborations between countries in relation to Six Sigma are not common, since our sample of 61 countries are grouped into 32 clusters implying little affinity between them and only 35 countries have any connections with others.

We can check in Figure 6 that there are some countries (Hong Kong, Norway, Tunisia ...), that have no collaborations with others and consequently have no links. On the other hand, among countries with some multinational collaboration (Figure 7), we see some aspects that would have been expected, such as the link between Mexico, Spain and Argentina (countries sharing a common language), that the United States is the most productive country in terms of papers and is also the one with the most relationships with other countries. The connections between Asian countries such as China, Singapore and Taiwan are also noteworthy.

3.4 Keywords analysis of Six Sigma improvement strategies literature

Co-occurrence is the term used to describe the frequency and proximity of keywords appearing on scientific papers, as well as the relationship between them (Cobo et al., 2011). Co-occurrence considers that two keywords often simultaneously appear in different articles under the same topic and is used to illustrate literature hot spots.

Several maps of keywords based on co-occurrence data (see van Eck and Waltman (2010) for further detail) can be built by VOSviewer. We built three maps to analyse the co-occurrence of keywords relationships and trends.

3.4.1 Co-occurrence keywords relationships

The aim of this subsection is to identify the most common keywords that the authors have used to characterise the paper. From this analysis, it is possible to identify the most frequently occurring topics in the field. The co-occurrence keywords network of Six Sigma constructed by VOSViewer is shown in Figure 8. The size of the nodes and words represents the weight of the nodes (keywords) i.e. occurrences. The distance between two nodes reflects the strength of the relation between them, i.e. shorter distance means 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 is, the greater the co-occurrence frequency. Finally, the color of the node indicates that they belong to the same cluster (van Eck & Waltman, 2017).

In our sample (798 papers), we obtained 1,294 keywords. Of these, 1,007 (77.8%) appeared only once. Figure 8 shows the result of running the VOSViewer algorithm restricted to a minimum number of 5 occurrences of a keyword.

INSERT FIGURE 8

A total of 54 keywords fulfilled this restriction, and they were grouped in 6 clusters. The first cluster (in red - labelled as Six Sigma strategy), whose main weight is on Six Sigma, consists of 12 items, including case study, cost reduction, quality management among others. The second cluster (green - labelled as Quality) consists of 11 items and, their main keywords are other quality approaches as Lean, Lean Six Sigma and ISO. The third cluster (dark blue - labelled as Management) is formed by 11 items. Its biggest nodes are TQM (Total Quality Management), DOE (Design of Experiment) and SMEs (Small and Medium Enterprises). The main component of the fourth cluster (yellow – DMAIC tools) is DMAIC and most of these 9 items are related to this methodology. The fifth cluster (purple - labelled as Process Control) include 6 items. Among them there are keywords related to process control like CTQ (critical to quality) or FMEA (Failure Mode Analysis and Effects). Finally, the sixth cluster (light blue - labelled as Health Care) include 5 items related basically to quality improvements in health care (for example, patient safety or health services).

Authors tend to identify their research with the field of study, so it is unsurprising that the highest frequency keyword is Six Sigma (464 occurrences and 791 link strength). This is followed by DMAIC and quality management, with 100 and 99 occurrences respectively.

The node Six Sigma has thicker lines, which implies higher link strengths, with DMAIC (the steps to undertake a Six Sigma approach), quality management, TQM (Total Quality Management) and quality improvement. This means that those keywords often appear together with Six Sigma when an author characterises their paper. Six Sigma is a quality management system, so it is likely to be related to concepts such as TQM, quality management and improvement. On the other hand, DMAIC is the methodology used in most of case studies applying Six Sigma, and it is well-known that most of the literature about this approach relates to case studies.

3.4.2 *Co-occurrence keyword trend*

Here, we examine in some detail changes over the period analysed (1990–2017). Figure 9 uses a colour scale to show the average number of publications per year in relation to each node.

INSERT FIGURE 9

In the Figure 9, it can be seen that the term Six Sigma is in the middle of the scale (green) due to the repetition of this keyword across the period analysed. On the other hand, interesting keyword trend results can be extracted in terms such as DFSS (Design for Six Sigma), continuous improvement or quality programs have become obsolete in the relevant literature (dark blue), while others like Lean or DMAIC are used more recently. In addition, it is observed that the mix of these two approaches, Lean and Six Sigma is the most popular term among recent papers (orange).

It is also clear that higher education and quality assurance (red colour) are recently used keywords as they have a higher average per paper closer to 2014. From this data, one sees Six Sigma extending out of its traditional health and management fields.

3.5 Research field and research methodology

Publications on Six Sigma are distributed basically across three research fields and the changes are observed in Figure 10. Business, Management and Decision Sciences are the main fields where Six Sigma is applied as it is a Business Process Management method. Therefore, journals on this area are highly interested in papers related to this topic. It can be seen that in Medicine and Nursing, with the exception of 2014, the interest in Six Sigma has been growing. On the contrary, in Engineering the number of publications in recent years has decreased.

INSERT FIGURE 10

We also classified articles according to their data source. In general, the case study is the most common methodology (439 out of 798), while 281 papers are conceptual (they do not analyse data). Finally, 44 are survey (6%) and only 34 papers used secondary data (4%).

This result can be explained by the difficulty of gathering crucial industry data such as costs or the manufacturing process where a company's competitive advantage may lie. In addition, each company has its particularities and it requires a detailed study of its functioning for the application of this method which makes its generalisation complicated. For these reasons, case studies often appear as the option chosen to do research on Six Sigma.

Table 6 shows the changes over the period analysed of the data source of our sample of publications. It highlights that, in the last two years, there has been a strong increase in the number of papers using secondary data (although, at about 4%, from a low base). We expect that this source will continue growing relative to the conceptual or overview papers which were more numerous at the beginning of the period.

INSERT TABLE 6

Combining research field and data source information, we note that there are 31 of 44 surveys papers which indicates that these are used mainly in the fields of Business, Management and Decision Sciences (see Table 7). Second, almost all papers with secondary data are observed in the fields related to Business or Medicine (18 and 12 documents, respectively). Another relevant aspect is the importance of case studies in the Medicine and Engineering fields. Although Business, Management and Decision

Sciences are the fields with most papers, in relative terms we see the proportion in Medicine and Engineering is close to 70% of the total number of publications in this field (Figure 11). Finally, conceptual papers or overviews are more frequent in Management (159 out of 281 items).

INSERT FIGURE 11

INSERT TABLE 7

4. Conclusion

This review carries out a bibliometric and visualisation/network analysis on Six Sigma improvement strategies until 2017. This work considers multiples databases instead of a single one and provides an extension of previous reviews by covering the recent fruitful period of academic literature related to Six Sigma.

Despite authors like Brady and Allen (2006), Chakrabarty and Chuan Tan (2007), Nonthaleerak and Hendry (2006), Patil et al. (2017), Prabhushankar et al. (2008), Reosekar and Pohekar (2014) or Tjahjono et al. (2010) have contributed to the topic by carrying out some reviews, to the authors' best knowledge none of these authors conducted network analysis and this represents our main original contribution to the literature.

The most relevant results regarding network analysis of keywords are regarding the evolution from Six Sigma and continuous improvement, to Lean Six Sigma in recent years and, the broadening out of this approach to non-traditional of Six Sigma research fields. Health care and Management have been the primary areas of research (Nonthaleerak & Hendry, 2006) and we have evidence that it is making its way to new areas such as Higher Education. This highlights the usefulness of Six Sigma and its cross-curricular approach which allows it to be adapted to a wide range of industries.

From an academic perspective, research into Six Sigma improvement strategies has mainly been done conceptually and through case studies. However, we verify that, in recent years, there has been an increase in surveys, especially in the Management field. This fact is explained by maturity cycle of the research field (Malhotra & Grover, 1998). At early stages research is exploratory or descriptive and later on is focused on hypothesis testing with a quantitative scope. Therefore, in the future, we expect an increase in the number of studies where secondary data and surveys is used to consolidate and generalise results found at research early stages.

From a managerial perspective, it would be interesting to apply the Six Sigma approach in new research areas such as Education, Environmental studies or the Hospitality industry in addition to its traditional sectors of Construction, the Automotive industry or Health Care. The importance of these areas (environmental and education) is crucial to bring the benefits of implementing Six Sigma to the majority of people and not just at a business level. More and more Six Sigma methodology has been applied to a

diverse set of non-manufacturing related issues giving excellent results. Despite the increasing interest in Six Sigma and the enormous amount of information available, the use of Six Sigma to solve global challenges seems not to be in the focus of our leaders and political groups that are making critical decisions affecting our present and future lives. If we look at the present issues that our planet and humanity are facing, we clearly see that inequality and poverty are growing in the world. Six Sigma needs to be taught at schools and universities becoming a formal subject as it is probably the best tool to ensure that decisions are taken based on data and facts.

Six Sigma attracts both academics and practitioners as we have seen. On the one hand, it is clear that practitioners need to increase their results and improve their processes for this reason they use the method. On the other, academics explore the environment to shed some light into areas that are not clear or that are of a global interest. Therefore, Six Sigma results interesting for both as it is a very structured way to see problems and to emit reasoned opinions based on evidences rather than personal opinions or beliefs.

Finally, for those seeking to do research in the field, the identification of “core” journals and authors may prove a good starting. On the other hand, for authors specialised in the topic we identify some opportunities for further research. Previous research is lacking of authorship collaborations and these would enrich future works. Moreover, Six Sigma is cross-cutting theme that may be of interest to different fields of knowledge, we encourage scholars from different areas to apply the DMAIC steps for quality improvement and share their results. In this way, the applicability of the method to any field would be demonstrated. Seeing the number of publications in recent years and, the need to establish a systematic improvement method to continue competing, we hope that Six Sigma will continue to expand as management philosophy worldwide.

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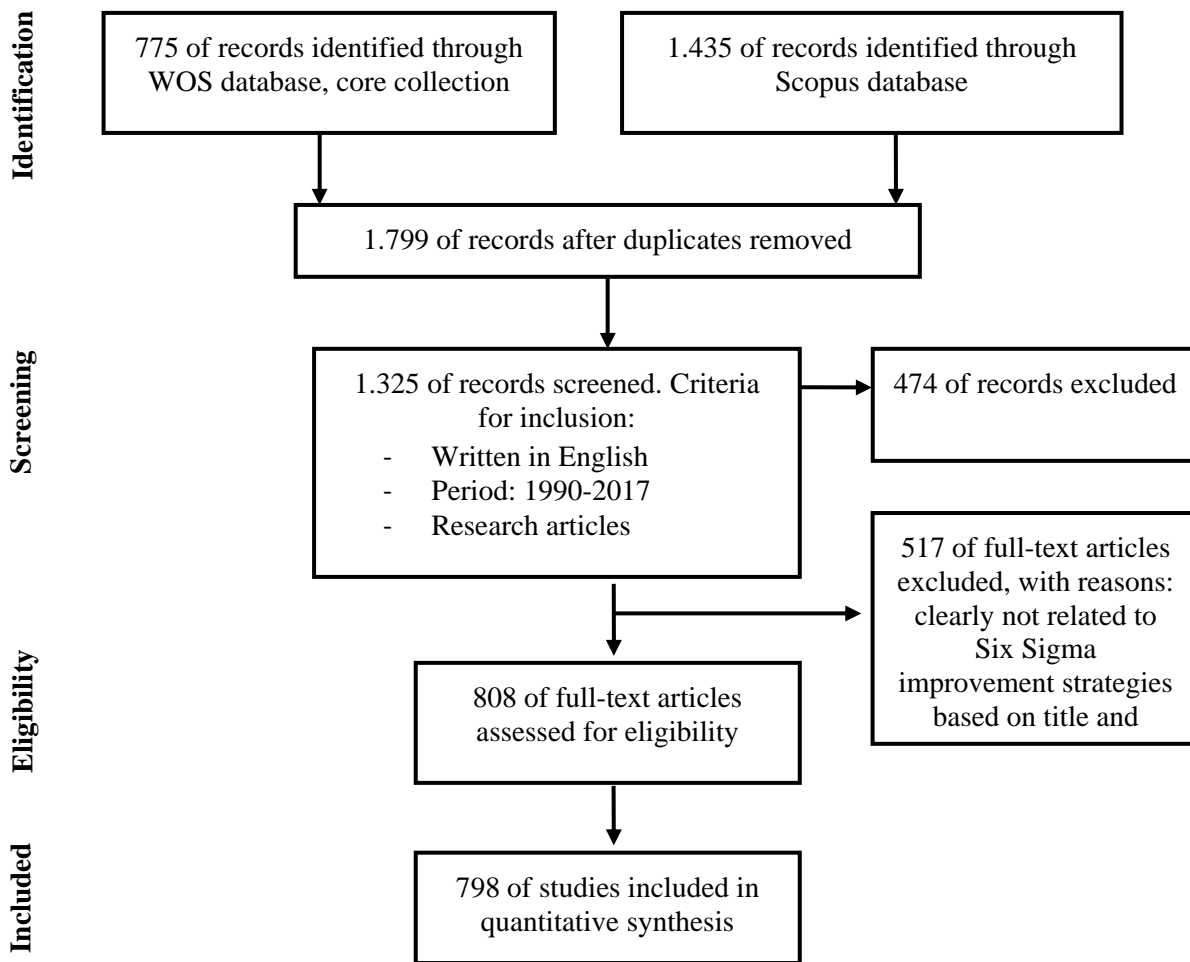
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Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).



Source: Adapted of Moher et al. (2010)

Figure 10. Publishing trend by research field

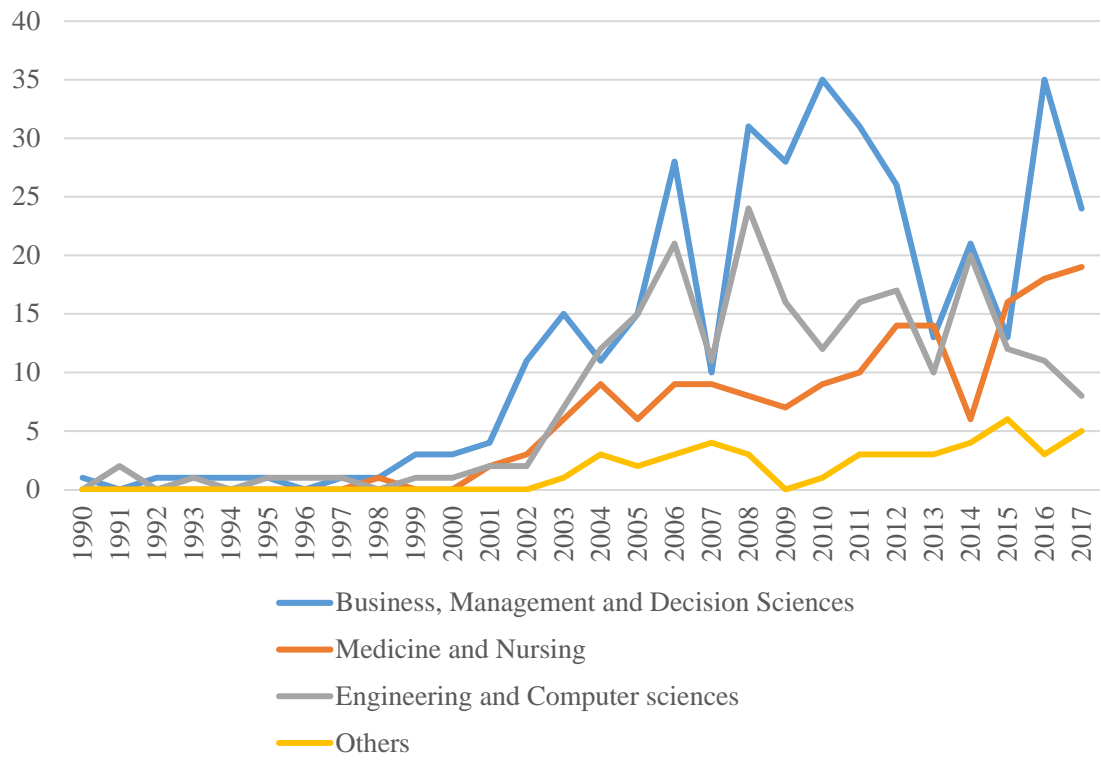


Figure 11. Data source by research field (100% stacked bar)

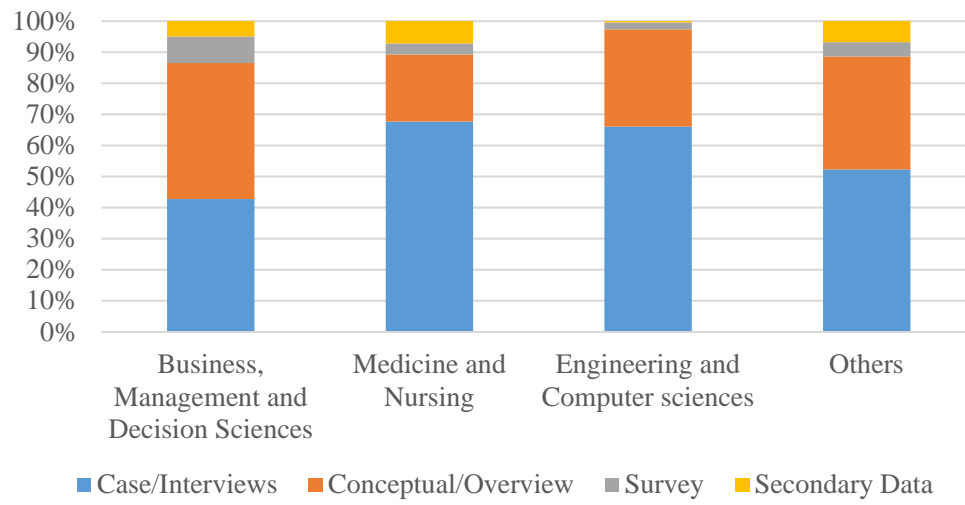


Figure 2. Publishing trend in the area of Six Sigma related to improvement strategies by type of authorship

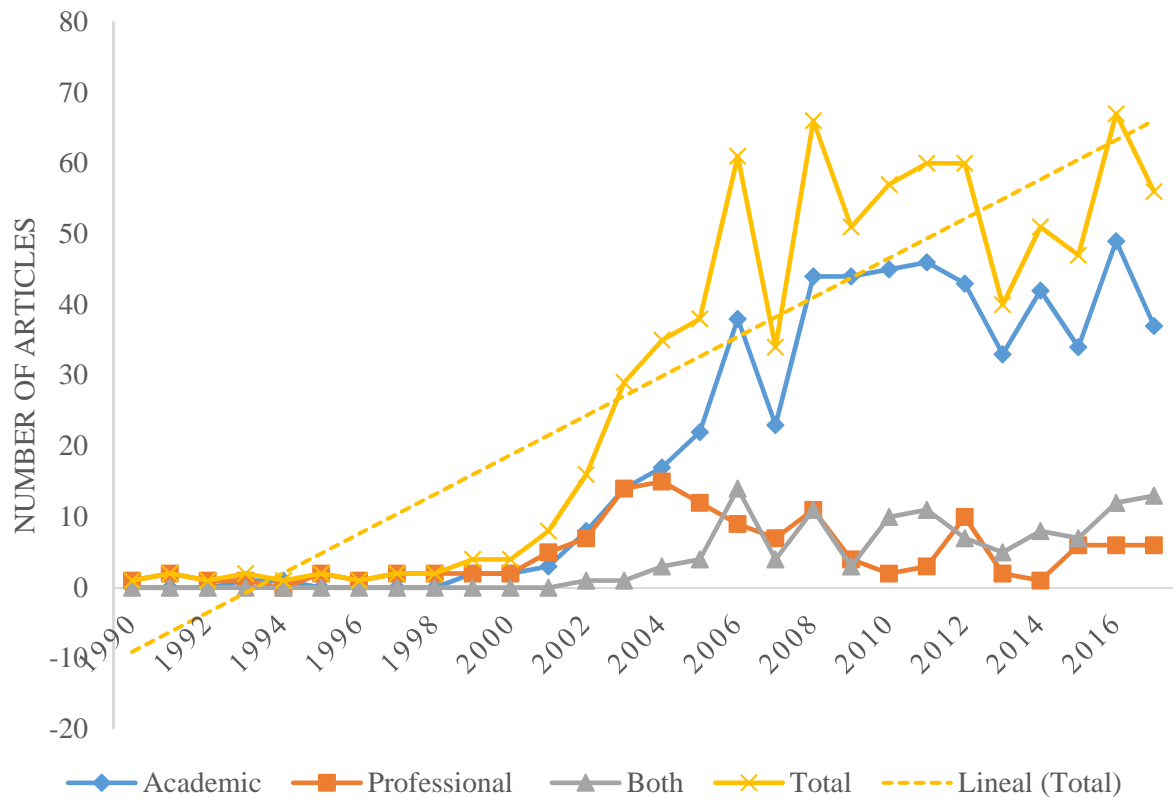


Figure 3. Number of articles by authorship type and research field

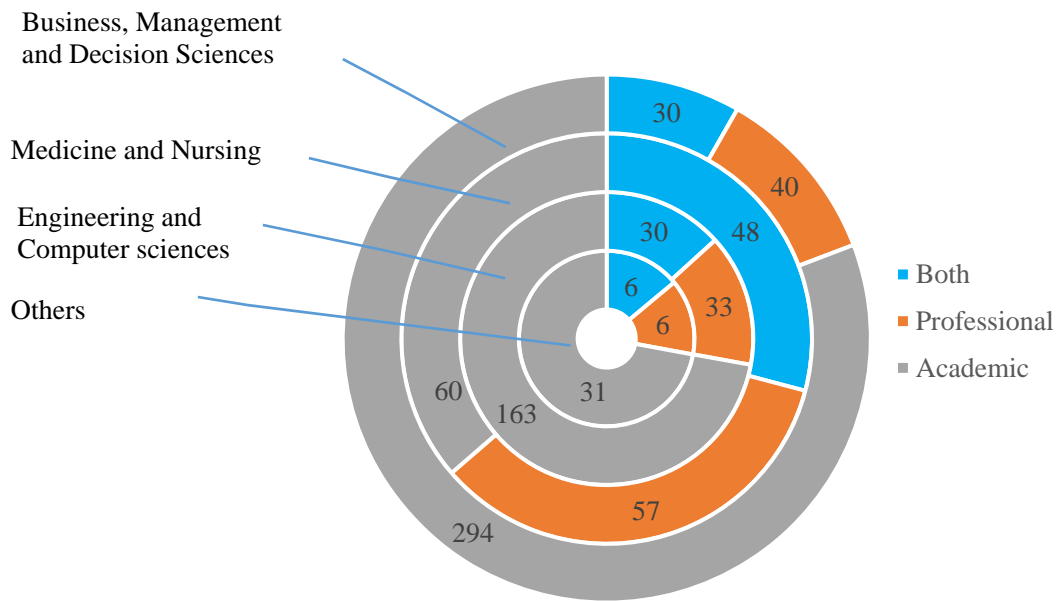


Figure 4. Geographic location of all contributing authors on Six Sigma.

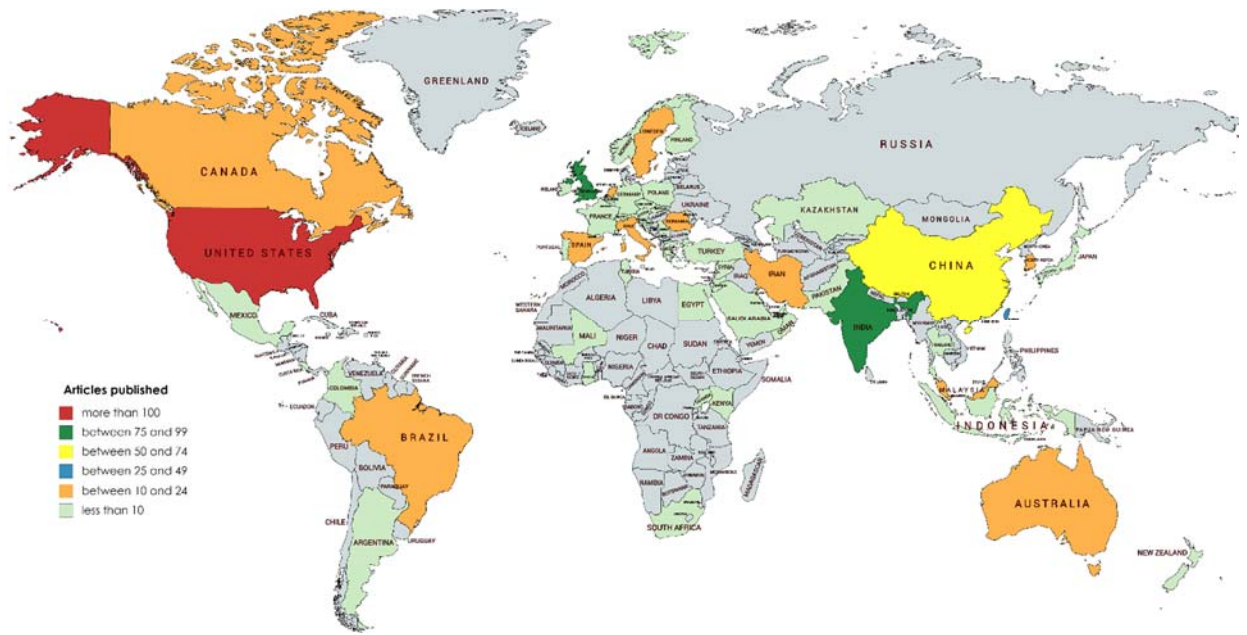


Figure 5. Geographic location of all received citations of papers of Six Sigma.

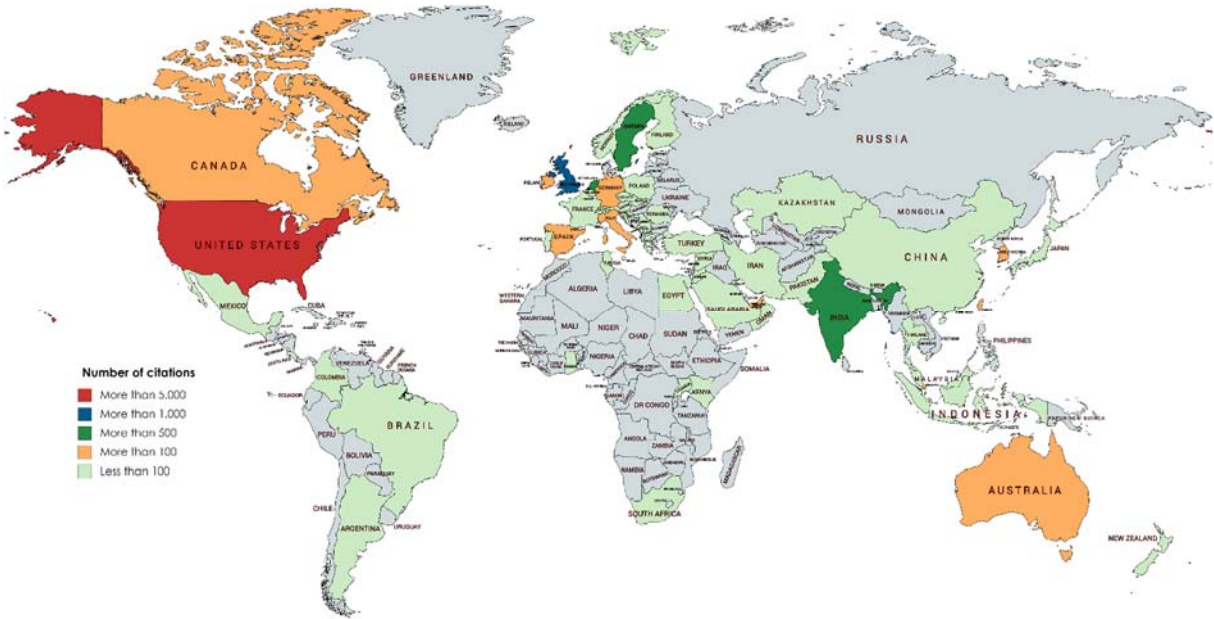


Figure 6. Country co-authorship network of Six Sigma improvement strategies related papers

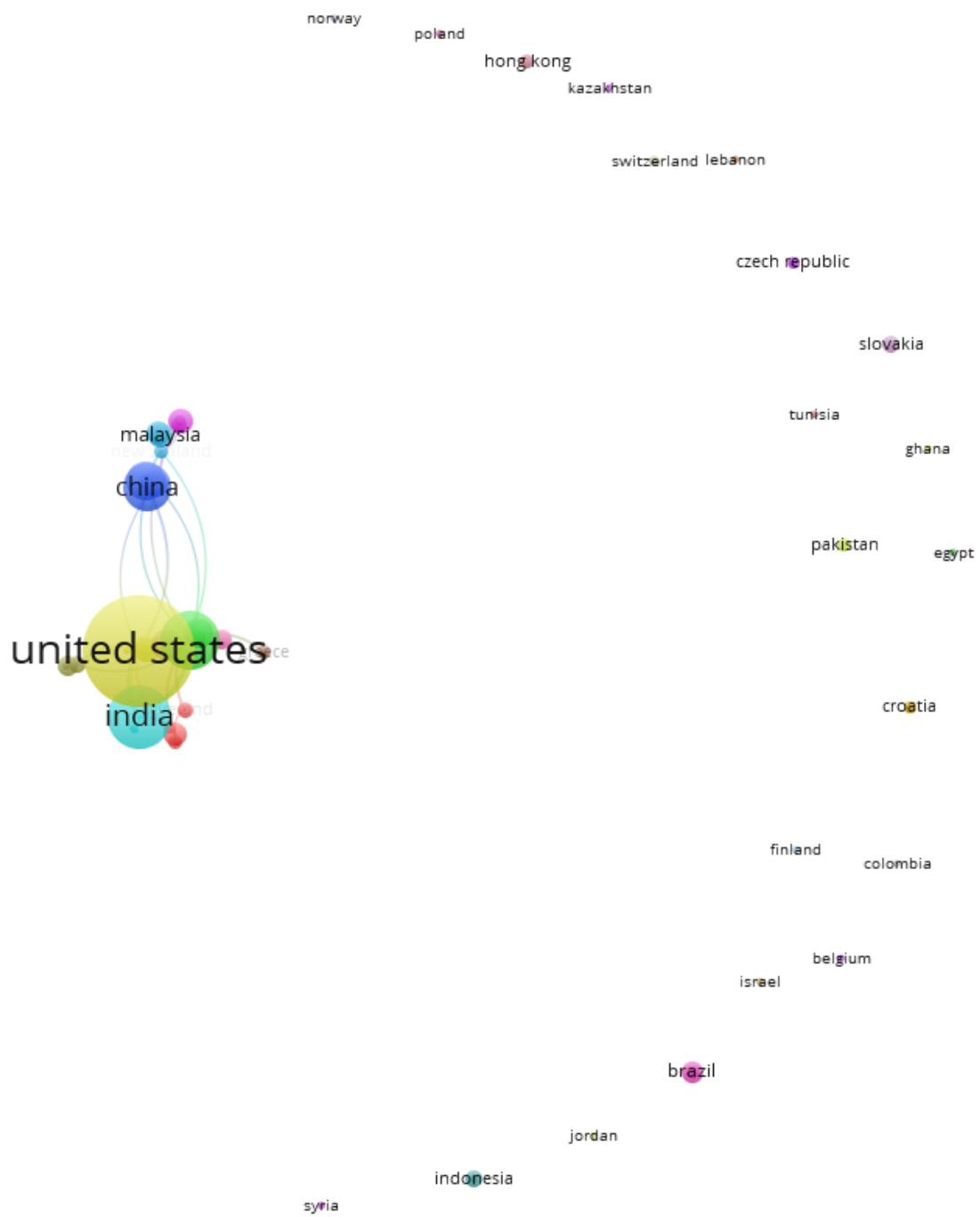


Figure 7. Enlargement of Figure 6 (Countries with some co-authorship link)

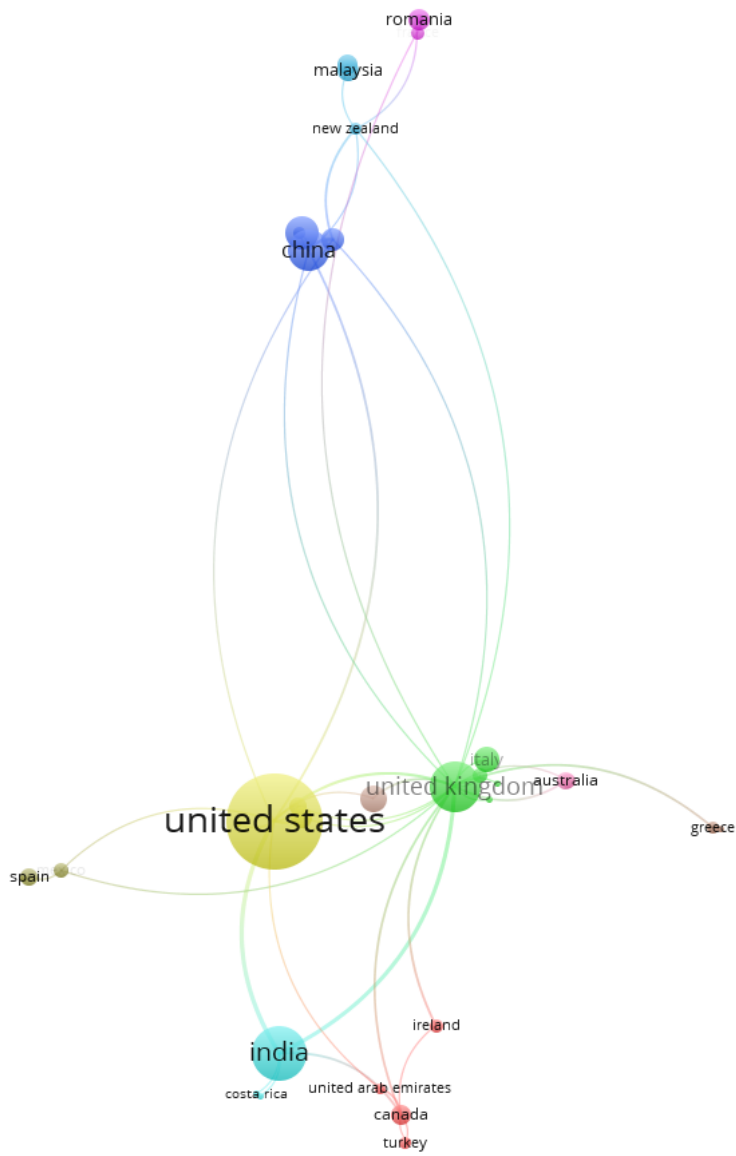


Table 1. Steps of Six Sigma using DMAIC process.

D	Define	Define the requirements and expectations of the customer. Define the project boundaries. Define the process by mapping the business flow.
M	Measure	Measure the process to satisfy customer's needs. Develop a data collection plan. Collect and compare data to determine issues and shortfalls.
A	Analyze	Analyze the causes of defects and sources of variation. Determine the variations in the process. Prioritize opportunities for future improvement.
I	Improve	Improve the process to eliminate variations. Develop creative alternatives and implement enhanced plans.
C	Control	Control process variations to meet customers' requirements. Develop a strategy to monitor and control improved process. Implement the improvements of systems and structures.

Source: Kwak and Anbari (2006)

Table 2. Systematic Literature review with DMAIC methodology.

		DMAIC
Stage I	PLANNING THE REVIEW	
Phase 0	Identification of the need for the review	D
Phase 1	Preparation of a proposal for a review	D
Phase 2	Development of a review protocol	D
Stage II	CONDUCTING THE REVIEW	
Phase 3	Identification of research	M C
Phase 4	Selection of studies	M C
Phase 5	Study quality assessment	M C
Phase 6	Data extraction and monitoring progress	M C
Phase 7	Data synthesis	A C
Stage III	REPORTING AND DISSEMINATION	
Phase 8	Report and recommendations	A I C
Phase 9	Getting evidence into practice	I C

Source: Adapted of Tranfield et al. (2003)

Table 3. List of journals and proceedings that provided at least five relevant articles (number of articles and citations).

	Total articles	Total citations
1 International Journal of Six Sigma and Competitive Advantage	45	555
2 Total Quality Management and Business Excellence	36	767
3 International Journal of Lean Six Sigma	24	311
4 Quality and Reliability Engineering International	22	704
5 International Journal of Productivity and Quality Management	21	208
6 TQM Magazine	18	1609
7 International Journal of Quality and Reliability Management	16	514
8 International Journal of Health Care Quality Assurance	14	255
9 Journal of Operations Management	11	1232
10 Quality Engineering	11	340
11 Quality Management in Health Care	11	242
12 TQM Journal	11	230
13 International Journal of Production Research	10	302
14 Advanced Materials Research	8	1
15 International Journal of Services and Operations Management	8	57
16 Production Planning and Control	8	130
17 Quality Progress	8	115
18 Joint Commission Journal on Quality and Patient Safety	7	106
19 International Journal of Operations and Production Management	6	159
20 Journal of Healthcare Management	6	204
21 Annual Quality Congress Transactions	5	10
22 Applied Mechanics and Materials	5	0
23 ASEE Annual Conference Proceedings	5	7
24 Business Process Management Journal	5	283
25 Journal for Healthcare Quality	5	192
26 Proceedings of the International Conference on Industrial Engineering and Operations Management	5	0
27 SAE Technical Papers	5	2

Table 4. Authors with H-Index of 5 considering only their papers related to Six Sigma

	Author	H index	Articles	Citations
1	Antony J.	17	28	1220
2	Goh T.N.	11	16	1114
3	Does R.J.M.M.	10	12	958
4	Kumar M.	10	11	475
5	Linderman K.	8	9	473
6	De Mast J.	8	9	437
7	Devadasan S.R.	6	11	929
8	Schroeder R.G	6	6	295
9	Choo A.S.	6	6	291
10	De Koning H.	6	6	102
11	Van den Heuvel J.	6	6	88
12	Kumar S.	5	9	354

Table 5. Clusters of co-authorship by countries (clusters with more than 1 item)

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Canada Ireland Kuwait Turkey United Arab E.	Italy Kenya Thailand Uganda United Kingdom	Austria South Korea Sweden United States	China Singapore South Africa Taiwan	Costa Rica India Oman
Cluster 6	Cluster 7	Cluster 8	Cluster 9	Cluster 10
Iran Malaysia New Zealand	France Romania Saudi Arabia	Croatia Montenegro Slovenia	Argentina Mexico Spain	Australia Germany
Cluster 11	Cluster 12	Cluster 13	Cluster 14	
Brazil Portugal	Indonesia Japan	Greece Macedonia	Czech Republic Serbia	

Table 6. Data source evolution

	Case/ Interviews	Conceptual /Overview	Survey	Secondary Data	Total
1990	1	0	0	0	1
1991	1	1	0	0	2
1992	0	1	0	0	1
1993	1	1	0	0	2
1994	1	0	0	0	1
1995	1	1	0	0	2
1996	1	0	0	0	1
1997	1	1	0	0	2
1998	1	1	0	0	2
1999	0	4	0	0	4
2000	1	3	0	0	4
2001	6	2	0	0	8
2002	2	14	0	0	16
2003	11	17	0	1	29
2004	19	16	0	0	35
2005	19	19	0	0	38
2006	26	29	6	0	61
2007	16	16	2	0	34
2008	50	16	0	0	66
2009	29	22	0	0	51
2010	34	18	4	1	57
2011	34	21	5	0	60
2012	38	14	6	2	60
2013	28	10	2	0	40
2014	32	14	4	1	51
2015	29	9	7	2	47
2016	34	16	4	13	67
2017	23	15	4	14	56
TOTAL	439	281	44	34	798

Table 7. Data source by research field

	Case/ Interviews	Conceptual/ Overview	Survey	Secondary Data	Total
Business, Management and Decision Sciences	155	159	31	18	363
Medicine and Nursing	113	36	6	12	167
Engineering and Computer Sciences	148	70	5	1	224
Others	23	16	2	3	44
	439	281	44	34	798