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Six Sigma vs. Other Quality Improvement Tools: Comparative Analysis of Trends over Period of 1985–present

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Abstract. Six Sigma is a widely adopted method in various industries that is aimed at process improvement and quality management. Understanding the evolving interest and utilization of Six Sigma can provide valuable insights into its current significance and prospects. Using data from Google Trends, Google Books, Web of Science, and Scopus, this study examined the search volumes and interests in keywords and phrases that were related to Six Sigma over a specified period of time. The global analysis revealed the overall direction of interest in Six Sigma worldwide, highlighting periods of peak interest and potential significant shifts in the method's popularity. By identifying those times with the highest concentrations of interest, the article provides a deeper understanding of the adoption and perception of Six Sigma. On top of this, Six Sigma was compared in popularity (by trends) with other known methods such as Lean, Kaizen, PDCA, and TQM. This research contributes to the existing body of knowledge by shedding light on the current trends and future directions of Six Sigma globally. The findings offer valuable insights for practitioners, researchers, and organizations that seek to leverage Six Sigma for process improvements and quality management.

Keywords: Six Sigma, Lean Six Sigma, Lean, DMAIC, Kaizen, TQM, PDCA, trends, Google Trends, WoS, Google Books Ngram Viewer

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1. INTRODUCTION

Six Sigma is a quality-management method that focuses on minimizing errors and defects in production and service processes. It is based on data collection and analysis to identify the root causes of problems, eliminate unnecessary variabilities, and minimize variabilities in manufacturing and business processes. The main goal of Six Sigma is to reduce defects to a level that corresponds to fewer than 3.4 cases per million (Muralidharan, 2015; Sokovic et al., 2005).

The history of Six Sigma began in the 1980s, when Motorola (an American telecommunications giant) made exceptional efforts to improve its manufacturing processes. During this period, Bill Smith (an engineer and quality specialist at Motorola) initiated the concept of Six Sigma as a quality-management strategy that focused on minimizing variations in production. His work in this field led to the introduction of a revolutionary quality-control system based on advanced statistical tools.

Motorola's success in implementing Six Sigma as a method for quality control and process improvement quickly drew the attention of other corporations, resulting in its widespread adoption on a large scale. Over time, Motorola became a symbol of Six Sigma's success, thus contributing to the global popularization of this concept (Eckes, 2001; Watson, 1994).

Six Sigma is mainly applied in large organizations. According to industry consultants, companies with fewer than 500 employees are not suitable for implementing Six Sigma or need to adapt the standard approach in order to make it effective; however, Six Sigma encompasses many tools and techniques that work well in small and medium-sized enterprises. The infrastructure that is described as being necessary for supporting Six Sigma is a result of an organization's size rather than a requirement of Six Sigma itself (Dusharme, 2024).

Six Sigma projects are guided by a couple of project methods (which are presented below). The DMAIC methodology in Six Sigma is a five-step improvement cycle; i.e., define, measure, analyze, improve, and control (Palací-López et al., 2020). Essential components of a DMAIC project encompass team discipline, the structured utilization of metrics and tools, and the execution of a well-crafted project plan (with clearly defined goals and objectives). Lean Six Sigma (LSS) modifies the DMAIC approach by placing an emphasis on speed; this primarily focuses on streamlining a process by identifying and eliminating non-value-added steps. By implementing a lean production process, waste is eliminated. Target metrics include achieving zero wait times, zero inventories, scheduling based on customer demands, reducing batch sizes (in order to enhance their flows), line balancing, and decreasing overall process times. The ultimate objective of Lean Six Sigma is to manufacture high-quality products that fulfill customer requirements as efficiently and effectively as possible. If a process cannot be improved in its current design, another widely recognized problem-solving approach within Six Sigma can be employed. The DMADV process (define, measure, analyze, design, validate) is used for fundamentally redesigning such a process (De Feo & Barnard, 2005; Muralidharan, 2015). Six Sigma offers a quality-improvement and business-excellence roadmap that is inspired by statistical thinking and guided by data-driven techniques (Goh, 2020). In order to be able to benefit from its imple-

mentation, however, a considerable amount of time and resources should be devoted (Uluskan, 2022). There are still companies today that are trying to decide, among other things, whether it is wise or "safe" to embrace Six Sigma after being exposed to various forms of publicity on the subject (Goh, 2020). Among other reasons, this article was prepared in order to shine a fresh light on the current interest in Six Sigma.

This article is structured as follows. First, methods are presented that describe the approaches that the authors of scientific publications have taken to understand the problem. This starts with a keyword selection based on the contents of the bibliographical databases of available publications. Then, the individual data sources are described, with details about the search approach that has been taken by these authors.

Second, our results are presented in the forms of graphs and are typically constructed in the following manner: 1) focusing on Six Sigma-related terms and the method's behavior over time (i.e., terms/phrases such as "Six Sigma," "DMAIC," and "Six Sigma methodology"); and 2) presenting a comparative view on Six Sigma versus other similar methods (i.e., terms such as "Lean," "Kaizen," and "PDCA").

The results section is followed by a discussion where the authors interpret the data, analyze the outcomes, and explain the possible reasons for the given findings. Finally, the conclusion section provides a high-level summary and the outcomes of the study.

2. METHOD

The method that was used to conduct the study can be described as follows. The authors started with a keyword selection using the Web of Science database and 1000 recent publications that were sorted by relevance in order to determine the phrases to be compared in two groups – the first group was focused on quality management and process-improvement tools, while the second compared phrases that were related to the term "Six Sigma."

Once the keywords were determined, the authors conducted searches in four databases – Google Trends, Google Books Ngram Viewer, Web of Science, and Scopus. The first two databases were selected due to their wide reaches (not being limited to academic and scientific publications) – the intentions of the authors was to capture the interest among current or potential Six Sigma users. The final two databases (Web of Science, and Scopus) were reliable and widely used when seeking academic publications – the data that was gathered from these two sources was collected and cross-checked in order to ensure that the authors were correct in their driven conclusions.

The majority of the results are presented in the form of graphs that present the trends over a given time period. The graphs were analyzed, and the conclusions were drawn with regards to the peaks of interest, stability, and inclining/declining trends in popularity.

2.1. Keyword selections

The authors started the research by finding the most popular keywords among the Six Sigma-related publications that could be found in the Web of Science database. The Pareto graph that is presented in Figure 1 shows the frequency of the

keywords that were triggered by the phrase "process improvement." To create the graph, 1000 publications that were dated during the period of 2020–present were selected and then sorted by relevance.

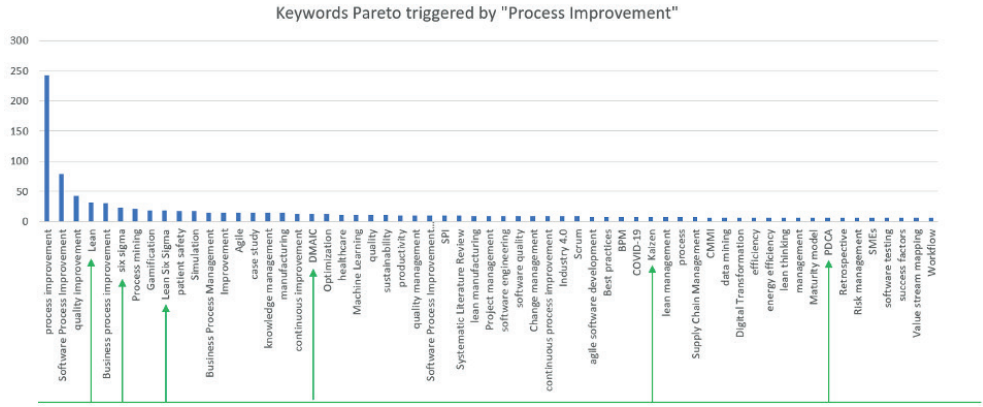

Fig. 1. *Frequency of keywords triggered by phrase "process improvement" (based on Web of Science search)*

Among the key phrases that were proposed by the authors of the publications, there were several phrases that were related to certain methods that were used for process improvement in quality management; those that are pointed out by the green arrows on the graph are Lean, Six Sigma, Lean Six Sigma, DMAIC, Kaizen, and PDCA. These terms are explained below.

The Lean (or lean manufacturing) philosophy focuses on reducing waste and non-value-added activities that do not create value for the customer. Organizations that adopt this philosophy have managed to improve their productivity, product quality, profitability, and competitiveness (Maware & Parsley, 2023).

Lean Six Sigma (LSS) combines Lean manufacturing principles and Six Sigma quality management in order to reduce waste and defects in business processes. LSS builds on the strengths of both approaches by emphasizing the importance of customer satisfaction, process improvement, and data-driven decision-making (Huang et al., 2023).

The DMAIC methodology in Six Sigma is a five-step improvement cycle: define, measure, analyze, improve, control (Palací-López et al., 2020).

Kaizen means "small, incremental, continuous improvement." Kaizen is a philosophy in the Lean system that focuses on both the process and the results; this is a process that, when done correctly, humanizes the workplace, eliminates unnecessarily hard work (both mental and physical), teaches people how to do rapid experiments using scientific methods, and eliminates waste in business processes (Prošić, 2011).

The PDCA cycle is a routinized and standardized way of working; this is a management process that is characterized by a spiraling cycle with large loops and small loops based on the principle of planning (P), execution (or do) (D), check (C), and action (A). The PDCA cycle continuously finds and solves problems in order to improve work efficiency (Zhong et al., 2023). The above phrases are going to be com-

pared with the term "Six Sigma" according to their popularity and trends over the considered time period.

The second search was scoped to find trends among Six Sigma-related terms. In order to find proper keywords, those publications that could be found in the Web of Science database (triggered by the phrase "Six Sigma") were identified. Again, the first 1000 publications that were dated during the period of 2020–present were selected; then, they were sorted by relevance. The obtained results are presented in a Pareto graph (see Figure 2).

For further analysis, the following phrases were used: "Six Sigma," "Lean Six Sigma," "DMAIC," and "Six Sigma methodology." The phrase "total quality management" (TQM) was found among those phrases that appeared relatively frequently. TQM is a systematic management technique for developing a process-driven culture inside an organization in order to achieve quality as well as customer and employee satisfaction (Alawag et al., 2023). TQM was also used to compare Six Sigma with the other methods.

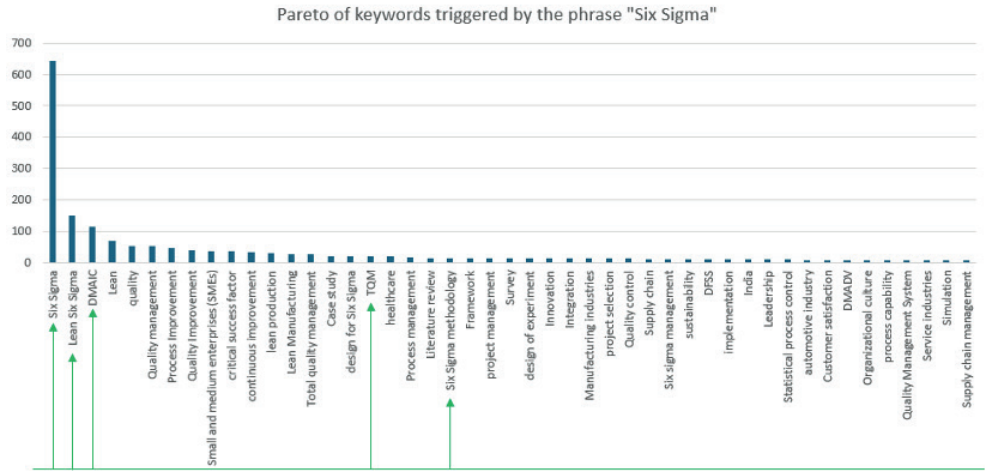

Fig. 2. *Frequency of keywords triggered by term "Six Sigma" (based on Web of Science search)*

2.2. Google Trends

Google Trends is a search-analysis tool that is offered by Google, Inc. (https://www.google.com/trends/); its main purpose is to analyze the behaviors of Google users while mapping human consciousness. This shows how often a specific search term or phrase is entered relative to the total search volume across various regions of the world as well as in different languages. It has been utilized to measure people's interest in a particular topic, displaying related queries and topics that are associated with the searched term/phrase. Google Trends has only been used to identify keyword search frequency since 2004. The keywords that were used to analyze the interest in Six Sigma itself were "Six Sigma," "Lean Six Sigma," "DMAIC," "Six Sigma methodology," and "Six Sigma certification." The keywords that were used to compare the interest between Six Sigma and the other methods were "Lean," "Six Sigma," "TQM," "Kaizen," and "PDCA."

2.3. Google Books Ngram Viewer

Google Books Ngram Viewer is a tool that was developed by Google that allows for an analysis of the frequency of the occurrences of the words and phrases in the language corpus that have been collected by Google Books. This corpus contains a vast number of books, journals, and other textual materials that have been scanned or entered into a database by Google.

Google Books Ngram Viewer enables users to search for words or phrases and presents the results in the form of a graph. The graph represents the frequency of the occurrences of a specific term/phrase over time. Users can customize the time range as well as the language in which the analysis is conducted.

Google Books Ngram Viewer has been used to demonstrate the frequency of the occurrences of words and phrases in the language corpus that has been collected by Google since 1985.

The keywords that were used to analyze the interest in Six Sigma itself were "Six Sigma," "Lean Six Sigma," "DMAIC," "Six Sigma methodology." and "Six Sigma certification." The keywords that were used to compare the interest between Six Sigma and the other methods were "Lean," "Six Sigma," "TQM," "Kaizen," and "PDCA."

2.4. Web of Science

Web of Science (WoS) is an information platform and research tool that provides access to a wide range of scientific publications, journals, and citation indexes. Web of Science enables the searching for and indexing of a significant number of scientific journals, conferences, patents, and other sources of scientific information.

The number of publications that have contained keywords on Web of Science since 1985 was analyzed. The keywords that were used to analyze the interest in Six Sigma itself were "Six Sigma," "Lean Six Sigma," "DMAIC," and "Six Sigma methodology." The keywords that were used to compare the interest between Six Sigma and the other methods were "Lean," "Six Sigma," "TQM," "Kaizen," and "PDCA."

2.5. Scopus

Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books, and conference proceedings. Delivering a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities, Scopus features smart tools for tracking, analyzing, and visualizing research. Scopus is a database that is widely used by academics, business, and governments.

The number of publications that have contained keywords on Scopus since 1985 was analyzed. Just as with WoS, the keywords that were used to analyze the interest in Six Sigma itself were "Six Sigma," "Lean Six Sigma," "DMAIC," and "Six Sigma methodology." The keywords that were used to compare the interest between Six Sigma and the other methods were "Lean," "Six Sigma," "TQM," "Kaizen," and "PDCA."

3. RESULTS

3.1. Google Trends – Six Sigma and related terms

As explained in the method section of this paper, each analysis was split into two areas: 1) focusing on Six Sigma and Six Sigma synonyms to understand the trends over the years; and 2) focusing on comparisons between Six Sigma and other quality-improvement methods. Six Sigma and those terms/phrases that could be considered to be Six Sigma-related are presented on the following graphs.

The graph that is shown in Figure 3 presents the trends in the popularity of the term "Six Sigma" and the terms and phrases that were related to Six Sigma during the period of 2004 through 2024. Google Trends presented the data as time-based results with their relations to the highest achieved results over the given period. In the case of the graph above – the term "Six Sigma" significantly dominated other terms with a similar meaning. The time-based analysis clearly showed a decreasing trend, with a significant drop during the period of 2004–2012. After 2012, a decrease in popularity could also be observed; however, it was not as significant as during the preceding eight years. The data that was obtained for the last six years suggested a certain stability without major drops or increases in the method's popularity.

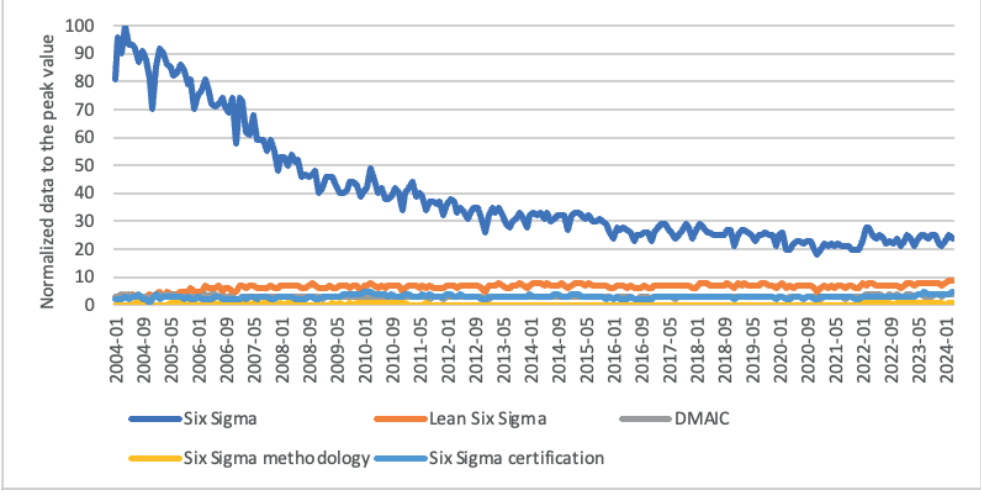

Fig. 3. *Google Trends – Six Sigma and Six Sigma-related terms over period of 2004–present*

Since the term "Six Sigma" significantly dominated the other terms/phrases that were used in the analysis (as was previously mentioned), the authors decided to remove the term from the comparison and focus on the four remaining terms/phrases (see Figure 4). Among the used terms/phrases, the greatest interest could be found with "Lean Six Sigma"; however, the differences between this and the other terms/phrases were not significant. Unlike in the previous graph, no major drop in interest could be observed; all of the terms/phrases seemed to maintain similar levels for nearly 20 years.

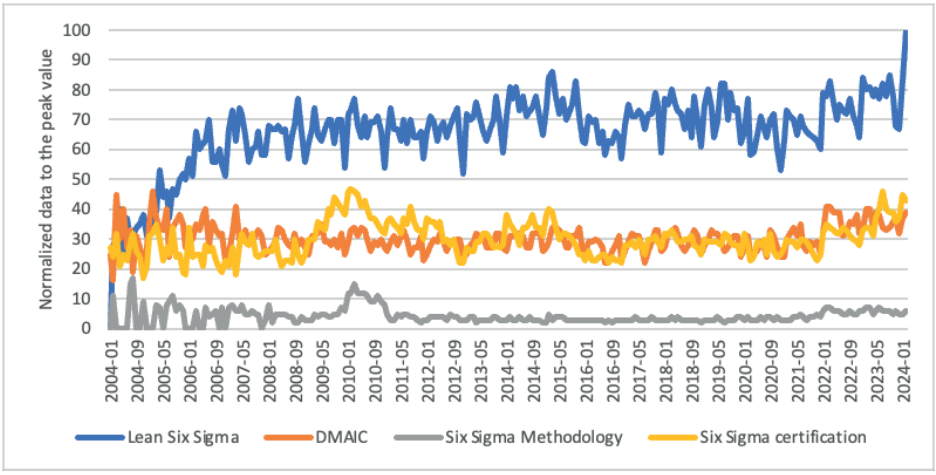

Fig. 4. *Google Trends – Six Sigma-related terms (without "Six Sigma") over period of 2004–present*

A observation was made by the authors while searching for the rationale of the drop of interest during the period of 2004–2012. Similar trends that showed drops of interest within the first eight years of the available data could also be found for other terms and phrases that were related to industry processes; e.g., production, quality, engineering, and manufacturing (see Figure 5). All of these terms/phrases reached their peaks of interest in 2004 (which was similar to the interest in the term "Six Sigma"). Like the Six Sigma trend, the following years featured waning interest for these terms until they finally reached a stable period, at last.

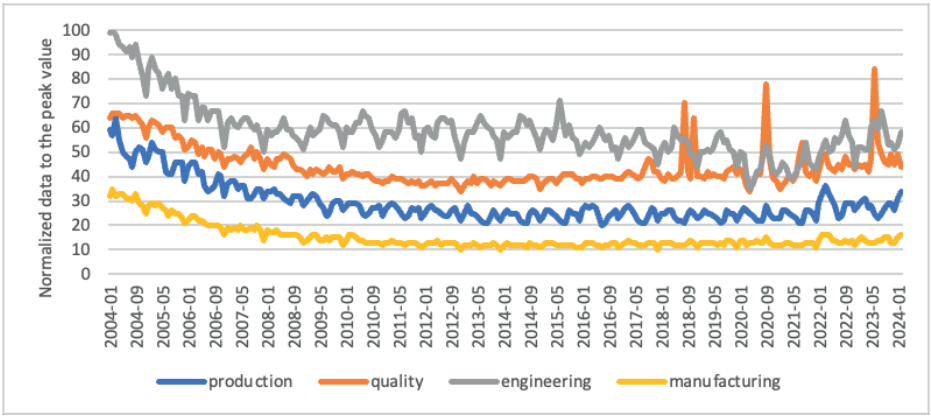

Fig. 5. *Google Trends – industry-related terms over period of 2004–present*

3.2. Google Trends – Six Sigma comparison with other methods

The second analysis focused on comparing Six Sigma with the other methods that were known in the process-improvement area. Among the terms/phrases that were

selected in the analysis were "Lean," "Kaizen," "TQM," "PDCA," and "Six Sigma" (see Figure 6). The data from Google Trends is shown starting in 2004.

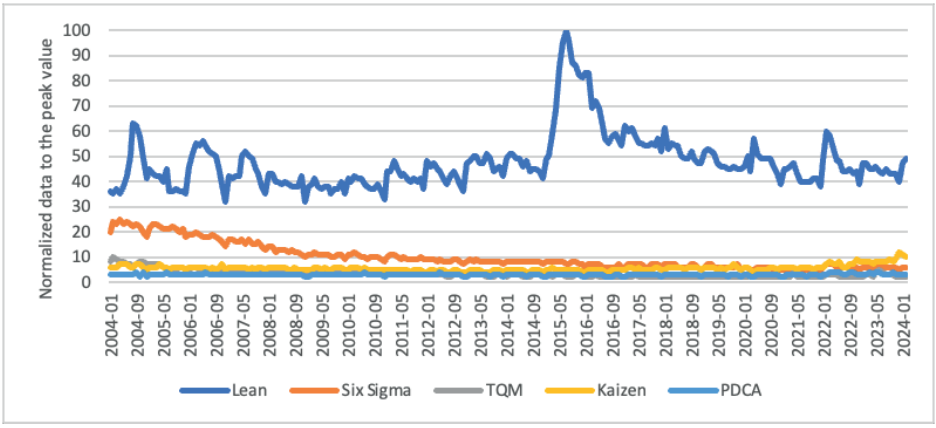

Fig. 6. *Google Trends – Six Sigma versus other process-improvement methods over period of 2004–present*

The dominant term in order of interest within this term selection was "lean." The term was significantly more popular than the others though the whole time range that is presented in this study. "Lean" had stable search results over the analyzed period – with one significant peak of interest around the years of 2015 and 2016. An important note to this search is that the term "Lean" does not have only one meaning; it is likely that the data was affected by searches that were not intended to find process-improvement methods. Since "Lean" significantly dominates on the graph, the authors decided to create another analysis without this term. The obtained results are presented in Figure 7.

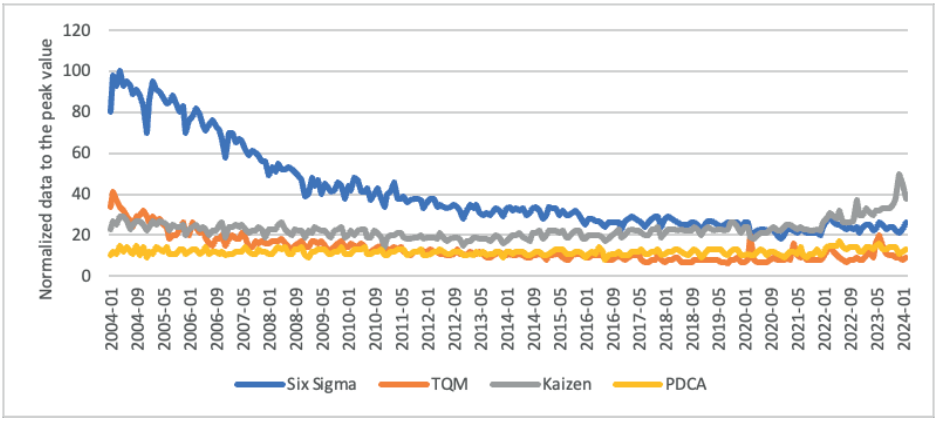

Fig. 7. *Google Trends – Six Sigma versus other process-improvement methods (without "Lean") over period of 2004–present*

The trends in the interest of the search of the term "Six Sigma" were described above. In terms of a comparison, the graph presents a dominating picture of Six Sigma during the first 12 years of the analysis. Since 2016, the terms "Six Sigma," "TQM," "Kaizen," and "PDCA" have been in near proximity to each other with regard to the numbers of registered searches. Over the last two years, the term "Six Sigma" has shown less popularity than term "Kaizen," while "TQM," "Kaizen," and "PDCA" have been stable over the analyzed period (with no major changes in their relative numbers of searches).

3.3. Google Books Ngram Viewer – Six Sigma and related terms

The same methods of research that were utilized in the Google Trends-based analysis were used to analyze the data in the Google Books Ngram Viewer. The first analysis focused on Six Sigma and Six Sigma-related terms over the period of 1985–2019. These results are presented in Figure 8.

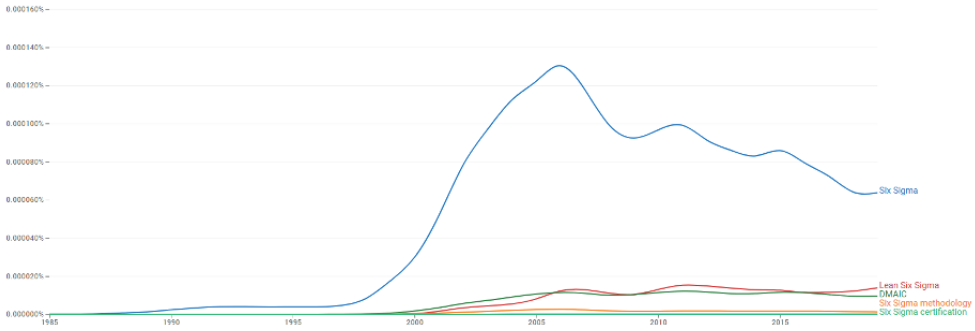

Fig. 8. *Google Books Ngram Viewer – Six Sigma and Six Sigma-related terms/phrases over period of 1985–2019*

Again, dominating on the graph is the term "Six Sigma," with major differences when compared to the terms "DMAIC," and "Lean Six Sigma". Both "Six Sigma methodology" and "Six Sigma certification" represented negligible numbers of results.

In terms of trends in the data, an increase in the number of occurrences of the term "Six Sigma" could be found in the literature between 1996 and 2006; this clearly indicated the rising popularity of the method. Since its peak interest in 2006, this trend has been continuously decreasing; this might suggest lower interest in the method. For the terms "Lean Six Sigma" and "DMAIC," the data indicated stability over the whole time period of 2005 through 2019.

3.4. Google Books Ngram Viewer – Six Sigma comparison with other methods

Similar to the analysis that was done with Google Trends, Google Books Ngram Viewer was used to compare Six Sigma with the other methods. The data from the years 1985 through 2019 is shown in Figure 9.

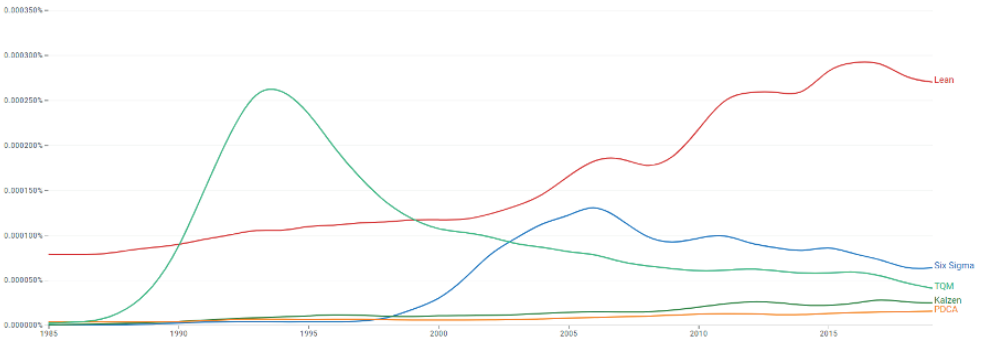

Fig. 9. *Google Books Ngram Viewer – Six Sigma versus other process-improvement methods over period of 1985–2019*

In recent years, the term "Lean" has led in terms of the number of occurrences in the literature that has been covered by the Google database; this term has been significantly more popular than the other terms. "Lean" has enjoyed a continuous rising trend since 1985. One should remember, however, that the word "lean" has more meanings than the one that is used for process improvements; this could have affected the data.

An interesting trend could be observed in the case of the term "TQM." After 1985, the data showed increasing occurrences of the term in publications (reaching its peak in 1994). After this, the data showed a significant decline through 2000; then, it endured a continuous but significant drop over the period of 2000–2019. The data that was related to "Six Sigma" seemed to reflect a similar trend. Data present apparent shift of ten years , however.

3.5. Web of Science – Six Sigma and related terms

The data that was collected from Web of Science was from the years 1985 through 2024. The graph in Figure 10 shows the total number of publications that were triggered by "Six Sigma" and Six Sigma-related terms as a percentage ratio to the total number of publications that were available on Web of Science.

Similar to the findings from the application of Google Books Ngram Viewer, "Six Sigma" showed an increasing number of publications starting in 1995 and growing year by year until its peak of interest in 2007. After 2007, the number of publications slowly decreased through 2023. The data for 2024 cannot be compared with the previous year's as of yet, since the year is not yet completed; this year's trend is similar in its shape to the results from Google Books Ngram Viewer.

In terms of the number of publications, the other Six Sigma-related terms were less popular than the term "Six Sigma." Nonetheless, both "Lean Six Sigma" and "DMAIC" have shown positive trends over the years since their first use (starting in around 2000).

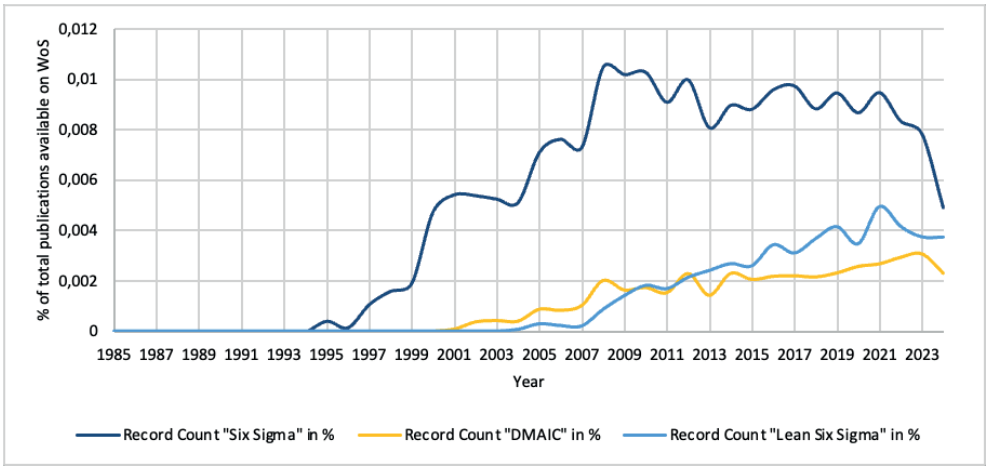

Fig. 10. *Web of Science – Six Sigma and Six Sigma-related terms over period of 1985–present*

3.6. Web of Science – Six Sigma comparison with other methods

The data from 1985 onward was analyzed in order to understand Six Sigma's popularity versus the other process-improvement methods; these results are shown in Figure 11.

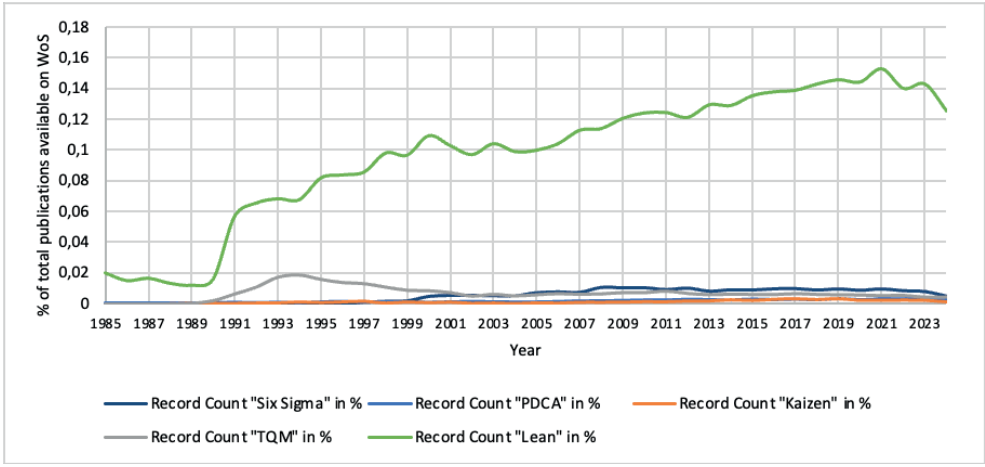

Fig. 11. *Web of Science – Six Sigma versus other process-improvement methods over period of 1985–present*

Like in the other graphs that were previously presented, the data that was available on Web of Science again showed the domination of the term "Lean" among the available publications. The term "Lean" has shown a continuously increasing trend

since 1990. Similar to Google Trends and Google Books Ngram Viewer, the data that was triggered by the word "lean" could have referred to not only the process-improvement method, as the word is frequently used in the other fields. To understand Six Sigma's popularity versus the other methods, a similar graph was created without the term "Lean" (see Figure 12).

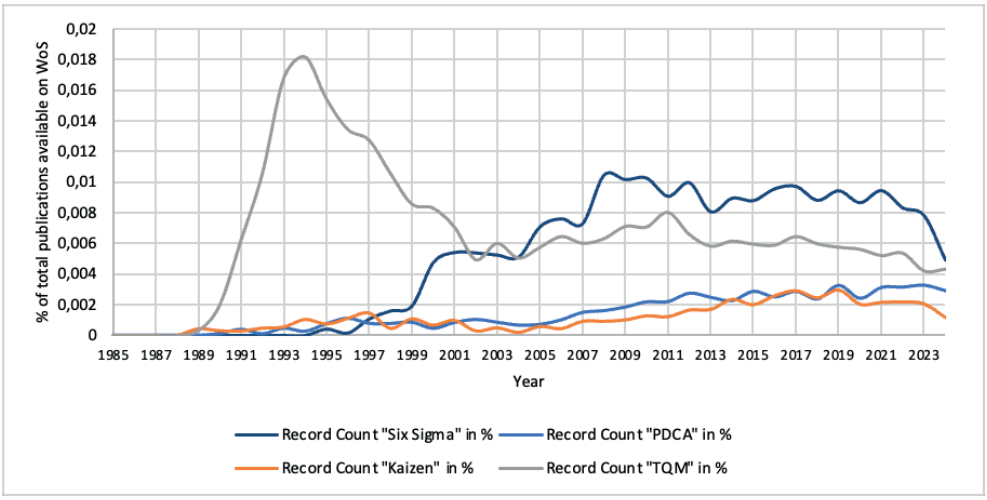

Fig. 12. *Web of Science – Six Sigma versus other process-improvement methods over period of 1985–present (without term "Lean")*

Over the last 20 years, Six Sigma has shown the greatest popularity as compared to the other methods (PDCA, Kaizen, and TQM). Similar to Google Books Ngram Viewer, the term "TQM" showed significant increase over the period of 1989–1994. After 1994, TQM showed drops in its frequency in publications; this trend finally stabilized in 2003.

3.7. Scopus – Six Sigma and related terms

A similar approach was taken to analyze the Scopus database. First, the term "Six Sigma" and its related terms were analyzed, taking those publications that were available during the period of 1985–present into consideration. Figure 13 shows the numbers of publications that were related to the terms "Six Sigma," "Lean Six Sigma", and "DMAIC," as percentages of the total numbers of publications that were available on Scopus.

The early years of Six Sigma's presence among scientific publications was stable and at a low in terms of the total percentage of the publications that were available on Scopus. Starting in 2000, the number of publications rapidly grew to reach its peak in 2006. After 2008, a declining trend could be observed until reaching a stable area in or around 2013. Since then, the trend has been constant up until now.

The other terms that were taken into consideration in this analysis ("Lean Six Sigma," and "DMAIC") showed similar trends, with continuous increases in the numbers of publications from 2000 through 2020. Throughout the whole analyzed time period, there were fewer publications that were related to these terms than those that were related to the term "Six Sigma."

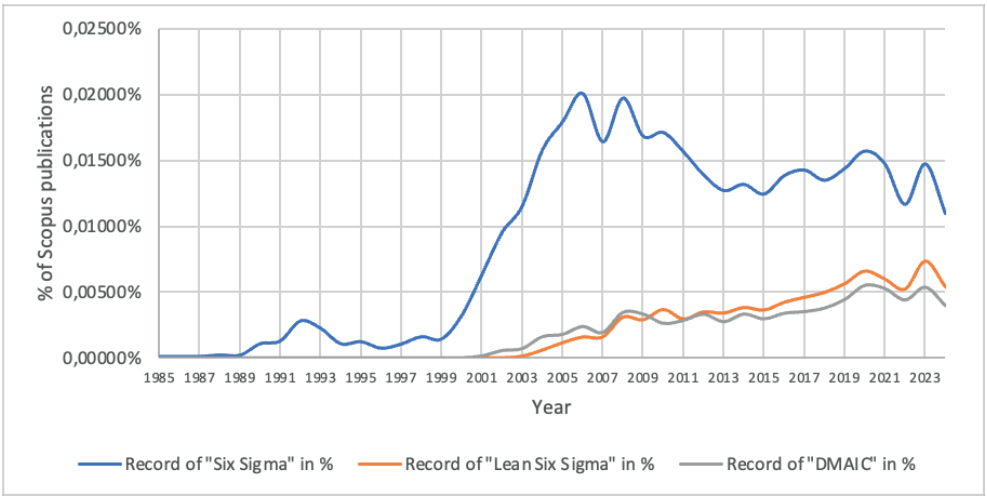

Fig. 13. *Scopus – Six Sigma and Six Sigma-related terms over period of 1985–present*

Besides the numbers of publications, the Scopus database allows us to understand the types of publications that are related to a given term. In terms of Six Sigma, most of the published works were in the forms of articles or scientific papers during the period of 1985–present. The results of the numbers of publications and the percentages of the total numbers of publications are shown in the table below (see Table 1 and Figure 14).

Table 1. *Scopus – Six Sigma during period of 1985–present by publication type*

Document type	Number of publications	Share [%]
Article	4626	48.9
Conference paper	3095	32.7
Review	623	6.6
Book chapter	408	4.3
Conference review	221	2.4
Book	182	1.9
Short survey	85	0.9
Other	219	2.3
Total	9459	100

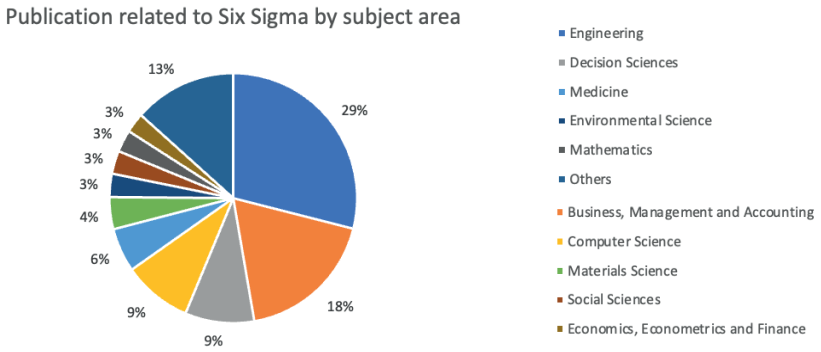

Fig. 14. *Scopus – Six Sigma in publications by scientific discipline during period of 1985–present*

Scopus allowed us to also understand the scientific disciplines that were related to the term "Six Sigma" during the period of 1985–present. The most common discipline to reach for the Six Sigma method has been engineering, followed by business, management, and accounting as well as decision science. A summary of these results are presented in the graph presented in Figure 14.

Scopus – Six Sigma comparison with other methods

Similar to the WoS analysis, the data from Scopus was collected in order to compare Six Sigma with other process-improvement approaches like Lean, Kaizen, PDCA, and TQM. The data from the time period of 1985–present was analyzed; this is presented in Figure 15 as the year-by-year percentages of the total numbers of publications that have been available on Scopus.

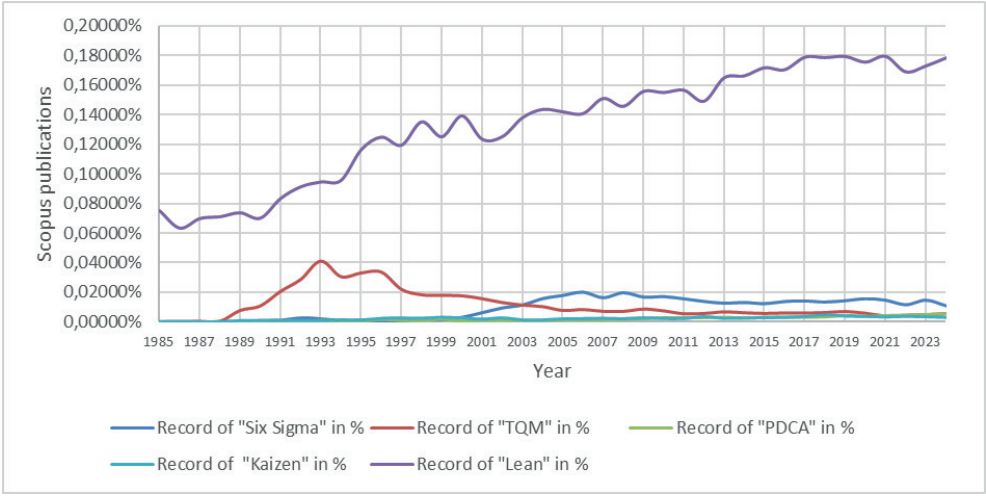

Fig. 15. *Scopus – Six Sigma versus other process-improvement methods over period of 1985–present*

Similar to the WoS results, the dominant position of the term "Lean" can be observed. Since the beginning of the analyzed time period, the trend for this term has increased. Since the word "lean" is used in many different scientific areas (not only those that are related to process improvement), the data was prepared without the term "Lean" in order to better understand Six Sigma's popularity versus the other methods. These results are shown in Figure 16.

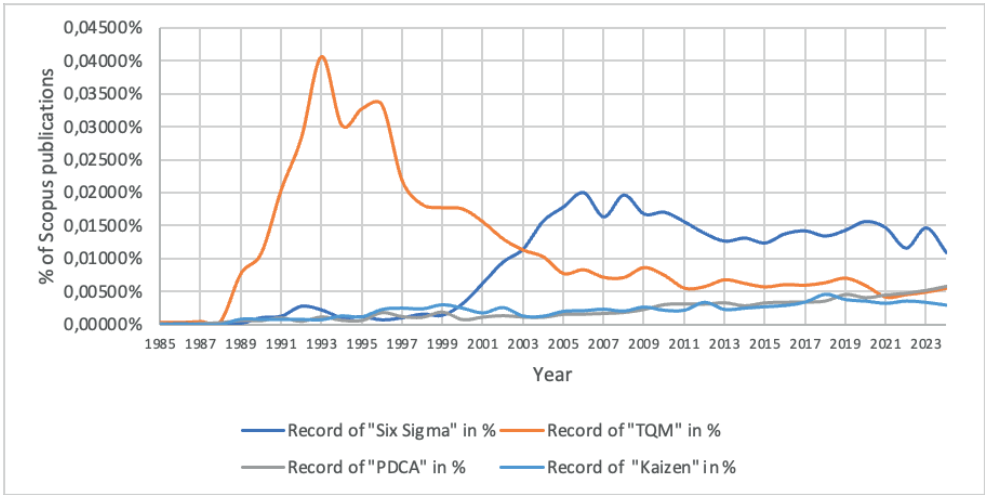

Fig. 16. *Scopus – Six Sigma versus other process-improvement methods over years of 1985–present (without term "Lean")*

The left part of the graph (related to the years before 2000) shows a significant interest in TQM. Starting in 1988 (and reaching its peak in 1993), the term "TQM" was more frequently used than the other terms that are analyzed in this study. After 1993, a decrease of interest could be observed in this term until 2005 (when the stable period began). In 2003, "Six Sigma" surpassed "TQM" in terms of the numbers of publications where these terms were utilized. This trend is similar to the Six Sigma results, where Six Sigma-related publications rapidly grew during the period of 2000–2006 and declined during the period of 2008–2013, finally attaining stability after 2013.

There have been significantly fewer publications that have been related to the terms "PDCA" and "Kaizen" than have been related to "Six Sigma" and "TQM." The trends for PDCA and Kaizen have been growing continuously since 1987.

4. DISCUSSION

4.1. Six Sigma and Six Sigma-related terms

During the study, the authors have analyzed the results of the interest in Six Sigma and Six Sigma-related terms over the years – reaching back as far as 1985. The con-

clusion that came from all three of the analyzed sources was that the method was either on a declining trend in terms of its popularity or in the area of stable interest.

Figure 17 illustrates all of the analyzed trends that came from Google Trends, Google Books Ngram Viewer, and Web of Science (normalized in one graph); the reader should focus on the time scale and the shapes of the curves. The graph was created in order to show the interest in the method over the given time period and check the consistency of the data that came from the different sources.

All of the sources represented similar trends – the popularity of Six Sigma continuously increased starting in 1985 until it reached its peak during the period of 2000–2010. After this, all three of the sources showed decreasing interest, finally reaching a period of stability or slight continuous decrease over the past five years.

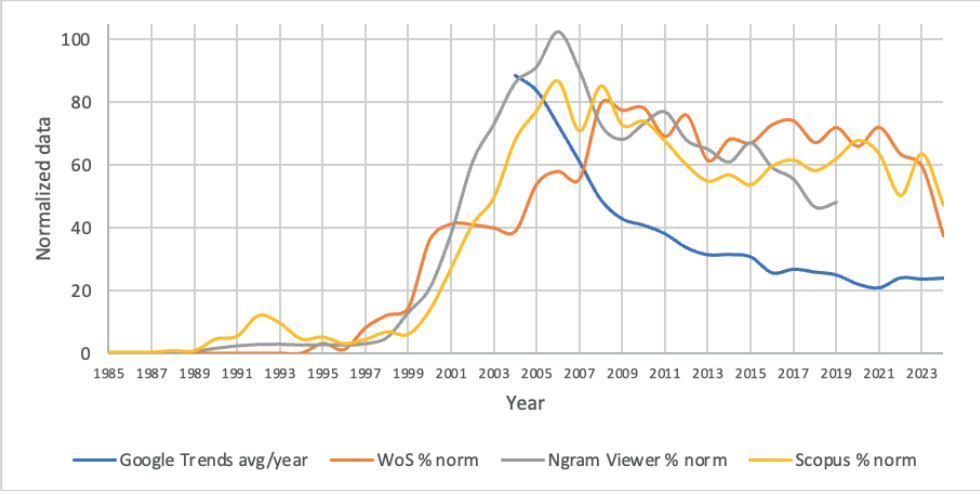

Fig. 17. *Normalized results – data from four sources (Google Trends, Google Books Ngram Viewer, Web of Science, and Scopus) presented on time-based scale during period of 1985–present*

In the shape of the graph that was described above, this analysis is like the typical S-curve of a product's life cycle (see Figure 18). Typically, an S-curve represents a product's life cycle in the following stages: introduction, growth, maturity, and decline; eventually, the product is retired from the market.

Combining the theory that was presented above with the previously shown data about Six Sigma, the following conclusions could be made:

1) *Introduction* phase of Six Sigma (1985–1995) – represented by slow increase in number of publications;
2) *Growth* phase of Six Sigma (1995–2005) – represented by significant increase in number of publications observed on year-by-year basis;
3) *Maturity* phase of Six Sigma (2005–2015) – when data shows peak of interest and slow decrease in numbers of publications;
4) *Decline* phase of Six Sigma (2015–present) – where significant decreases in popularity and numbers of related publications can be observed.

Fig. 18. *S-curve for typical product life cycle (Sanders, 2024)*

Analyzing the S-curve concept of a product's life cycle, it is typical that one product or concept is followed by the next invention while in its decline phase. Among others things, Six Sigma brought about special attention regarding data to industry. Given the common data-driven approaches, it is possible that, following Six Sigma, the concepts that are based on machine-learning or big data are those inventions.

4.2. Six Sigma and other process-improvement methods

Among all of the data that was analyzed from the three sources, the term "Lean" significantly dominated. As mentioned in the previous sections, the word has multiple meanings; therefore, only a fraction of the available publications that were triggered by the word were related to process or quality improvements. Without a deeper analysis (and based on the presented data), a direct comparison between "Lean" and "Six Sigma" cannot be conclusive.

Without the term "Lean" in the picture, Six Sigma has tended to be more popular and featured in more publications than the other methods; however, the differences were not significant. Following the product life-cycle analysis, a conclusion can be made that all of the presented methods reached periods of maturity.

The observation that was made above was especially clear when analyzing the data that was related to the numbers of publications that were triggered by the term "TQM." Here, all four phases of a product's life cycle can be observed: introduction (1985–1990), growth (1990–1993), maturity (1993–1996), and decline (1996–present). The decline phase can be characterized by a long stability period over the past 20 years.

Since the early years of the TQM method occurred before the development of Six Sigma, it was highly likely that Six Sigma would show a similar trend in popularity. This means that the method has already entered its long period of stability and its interest will stay at its current level for the future years.

5. CONCLUSIONS

In this article, the authors studied the trend of Six Sigma's popularity over the years based on the numbers of searches in Google Trends and the numbers of publications or mentions that were available on the Google Books Ngram Viewer, Web of Science, and Scopus databases. The data was analyzed for the period of 1985–present and was analyzed in two ways: looking at the trends over the years for the term "Six Sigma" and other directly related terms in a comparable way, and looking at Six Sigma versus other process-improvement methods.

Based on the conducted research, a conclusion can be made that the interest in the topic of Six Sigma has reached the stable phase at levels that are definitely lower than its peak after years of decline. Given the S-Curve theory of a product's life cycle, this would indicate that Six Sigma is in its decline phase and that industry is already using new methods in process and quality improvements more frequently.

On the other hand, the stable interest over the last few years could indicate that the concept of Six Sigma was (and is still) a strong foundation for process improvements among industries. Following this thought, it can be assumed that Six Sigma's DMAIC data-driven approach and all of the tools that are utilized by the method have become a core asset of knowledge in the field of problem-solving and process improvements.

What is more, emerging trends like Big Data and Industry 4.0 can open new pathways for Six Sigma practitioners, as the integration of Six Sigma with Big Data can provide superior results for many organizations (Antony et al., 2022). Process-mining can serve as an important support technology for process-improvement frameworks such as Six Sigma (Graafmans et al., 2021). In this case, it would be feasible for Six Sigma to show positive inclining trends among searches and publications in the future.

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