WHAT AHP/ANP CAN DO FOR SIX SIGMA? A SHORT LITERATURE SURVEY

Marcin Nakielski[1]
Grzegorz Ginda[2]
Chellappa Vigneshkumar[3]

Highlights

- AHP/ANP proved is a universal and reliable tool support tool for Six Sigma.
- The tool is mainly applied to support Six Sigma-related external tasks.
- AHP/ANP support helps to widen areas for Six Sigma application.
- Questionable ways of expressing the imperfections information are overused.

ABSTRACT

Six Sigma provides a robust and universal methodology for solving practical decision—making problems in diverse industries. AHP/ANP methodology, on the other hand, provides universal decision making services for any application. The methodologies fit perfectly into one another, therefore. It is unclear, however, if this perfect fit is fully utilized in the practice of Six Sigma and derivative methodologies. This is why a literature survey is applied in the paper to reveal actual state of Six Sigma users' interest in AHP/ANP application. Survey results are finally utilized to draw conclusions about present trends and gaps in the utilization of actual AHP/ANP potential in Six Sigma.

Keywords (3-6): AHP/ANP, Six Sigma, DFSS, Lean, application, potential.

1. Introduction

Six Sigma is a data-driven methodology aimed at significantly improving process quality and product outcomes by reducing variability and defects. It comes from the mid-eighties

[1] Marcin Nakielski, MSc. Eng., PhD Student, AGH Doctoral School, AGH University in Krakow, al. Mickiewicza 30, Krakow, Poland, e-mail: nakielsk@agh.edu.pl (ORCID: 0009-0007-3793-8050).

[2] Grzegorz Ginda, DSc PhD MSc Eng., Associate Professor, Faculty of Management, AGH University of Krakow, ul.Gramatyka 10., 30-067 Krakow, Poland, e-mail: gginda@agh.edu.pl (ORCID: 0000-0003-2153-1858).

[3] Chellappa Vigneeshkumar, PhD, Postdoctoral Fellow, School of Design, The Hong-Kong Polytechnics University, Kowloon, Hong-Kong, PC, e-mail: vkumar.chellappa@polyu.edu.hk (ORCID: 0000-0002-1278-9606).

of the twentieth century. The methodology is widely applied in practice across industries (Tengtarto et al., 2022). In fact, it is a universal methodology that takes advantage of merits of diverse tools which cover concrete needs of the methodology that depend on actual character of a decision making problem at hand.
It offers a robust framework for reducing defects and variability, the complexity of modern business environments often calls for more sophisticated decision-making tools. This is where the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) can complement Six Sigma, providing a structured approach to complex problem-solving.
A short literature survey is presented in the paper to reveal actual range of Six Sigma user's interest in AHP/ANP methodology application and to provide some hints that would help the users to utilize full potential of the methodology.

2. Six Sigma and AHP/ANP

The name "Six Sigma" refers to six standard deviations from the mean in a normal distribution, indicating a very low defect level.
Core Principles of Six Sigma include:

1. Customer Focus: All efforts are centered around meeting and exceeding customer needs and expectations.
2. Data-Driven Decision Making: Every decision is backed by statistical data analysis.
3. Continuous Improvement: Quality improvement is an ongoing process, not a one-time project.
4. Cross-Functional Teams: Problems are solved by multidisciplinary teams.

The most commonly used tool in Six Sigma is the DMAIC process perfection cycle, which consists of five phases:

1. Define: Identify the problem, project goals, and customers.
2. Measure: Collect data and determine key performance indicators (KPIs).
3. Analyze: Analyze data to identify the root causes of the problem.
4. Improve: Develop and implement solutions.
5. Control: Establish control procedures to prevent the problem from recurring.

There are several variations of Six Sigma methodology available e.g. DFSS (Design for Six Sigma (DFSS), Lean Six Sigma etc. DFSS Focuses on designing new products and processes with high quality in mind from the outset. The DFSS process perfection cycle is often described as DMADV (Define, Measure, Analyze, Design, Verify). On the other hand, Lean Six Sigma combines the principles of Six Sigma with Lean philosophy, which emphasizes eliminating waste. Lean Six Sigma enables the achievement of both high quality and process efficiency.
The application of Six Sigma usually brings several benefits. The benefits deal with improved product and service quality by means of reduction of defects and increased customer satisfaction, reduced costs thanks to the elimination of waste and process optimization, shorter lead times due to improved efficiency and productivity, increased competitiveness thanks to the differentiation in the market through high-quality products and services.
The implementation of Six Sigma is nevertheless often threatened by challenges. The challenges include: employee resistance, implementation costs due to a need for investment in training, software, and employee time, time consumption and a need for improved consistency due to a need to achieve lasting results.

Despite some minor drawbacks, Six Sigma ought to be seen as a powerful tool that can bring significant benefits to organizations seeking to improve the quality of their products and services. However, successful Six Sigma implementation requires commitment from top management, adequate resources, and a culture of continuous improvement.
On the other hand, AHP and ANP (Saaty & Vargas, 2012; Saaty & Vargas, 2013) are multi-criteria decision-making methods that allow for the hierarchical breakdown of complex problems and the evaluation of various alternatives. By assigning weights to different criteria and comparing alternatives pairwise, these methods enable decision-makers to make more informed choices. When integrated with Six Sigma, AHP and ANP can enhance the effectiveness of various phases of a basic Six Sigma process perfection cycle.

3. Research Methodology

Scopus bibliographical database https://www.scopus.com for providing data about publications covering joint application of Six Sigma and AHP/ANP. In particular '("Six Sigma" OR "Lean Six Sigma" OR "DFSS" OR "Design in Six Sigma") AND ("AHP" OR "ANP")' search phase is applied for 'Search within Article title, Abstract, Keywords' inquiry box on main Scopus service webpage. It turned originally out that there are 109 literature entries which span a period 2003-2024 (Fig.1). However, an introductory analysis resulted in the reduction in the number of entries. The excluded entries covered one retracted paper and 10 conference reviews. Finally, 98 essential entries were qualified for a detailed bibliographical analysis.

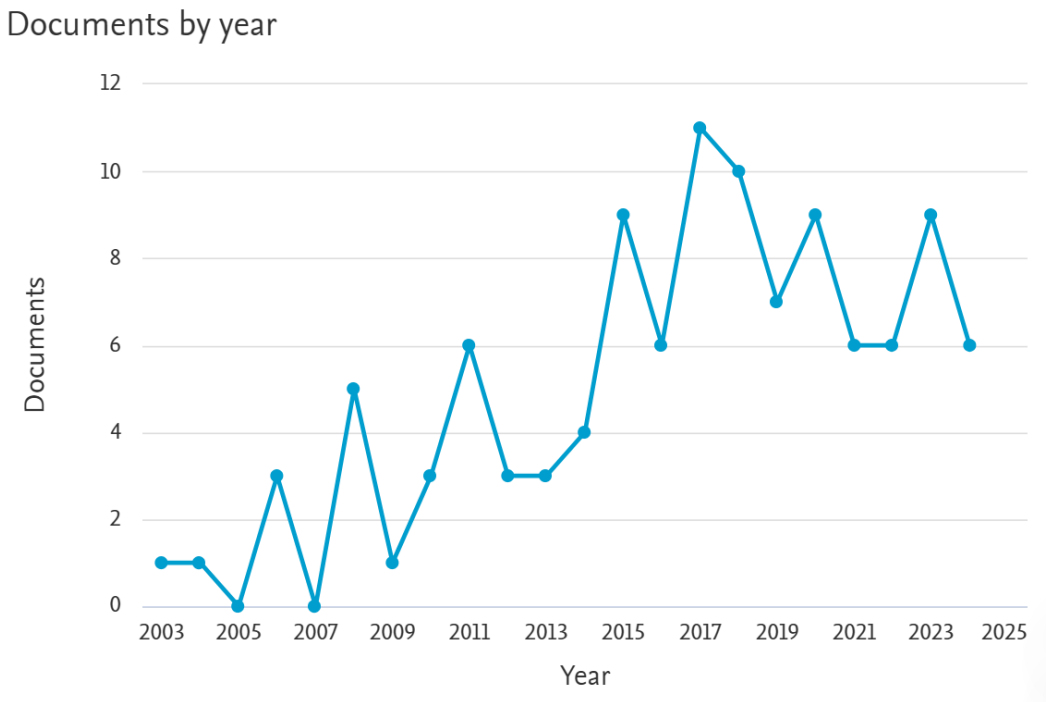
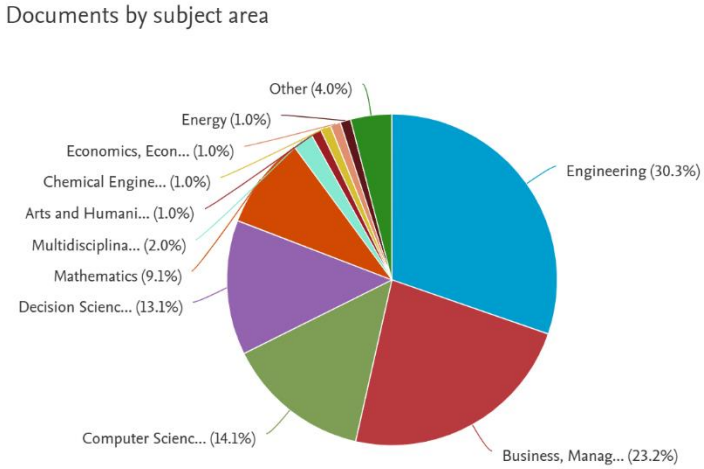


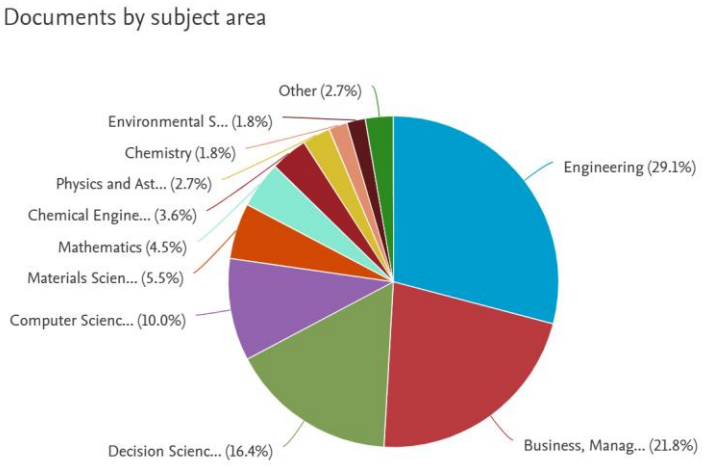
Figure 1. Number of publications per year as for 2024-11-15
(Source: Scopus bibliographical database).

4. Objectives

Detailed bibliographical analysis is conducted to reveal actual role AHP/ANP plays in supporting Six Sigma applications, as well as, the range and ways of this support. The results of the analysis are expected to provide detailed knowledge of actual state of AHP/ANP support for various Six Sigma flavors. Thus, necessary information that would allow to facilitate future development in AHP/ANP potential utilization with regard to Six Sigma-related support.



a. Upward phase (2003-2017)



b. Flat phase (2018+)

Figure 2. Structures of the area of AHP/ANP-Six Sigma applications in different development phases (Source: Scopus bibliographical database).

5. Results

Fig. 1 reveals that the development of scientific bibliography related to analyzed topic may be divided into two distinct phases. The first one is upward phase. It starts in 2003 and lasts up to 2017. The second one starts from 2018 and is rather flat. It deals with a yearly number of publications about 8. One should be also aware that despite shorter span the second phase covers the majority of, namely 53 out of 98, publications. The flat character of the

second phase may testify for reaching the state of maturity by AHP/ANP and Six Sigma interactions. Other general results of literature analysis are presented in Figs. 2-5.
For example, it appears there are several dominant areas of Six Sigma-related applications of AHP/ANP. They cover engineering, as the main Six Sigma application domain, as well as, Business and Management, Decision Science, and Computer Science. However, Fig.2 shows that the development of AHP/ANP and Six Sigma connections results in continuously increasing share of other areas which tend to be far away from traditional Six Sigma application.

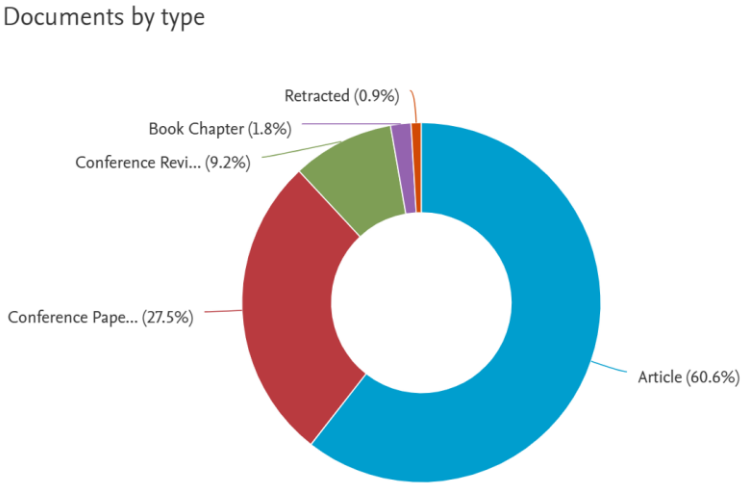


Figure 3. The share of different publication types
(Source: Scopus bibliographical database).

Fig.3 confirms that journal articles play dominant role in the dissemination of scientific research which addresses AHP/ANP and Six Sigma interconnections. They are followed strictly followed by conference papers. Book chapter seem to have a tiny share in all publications, only.

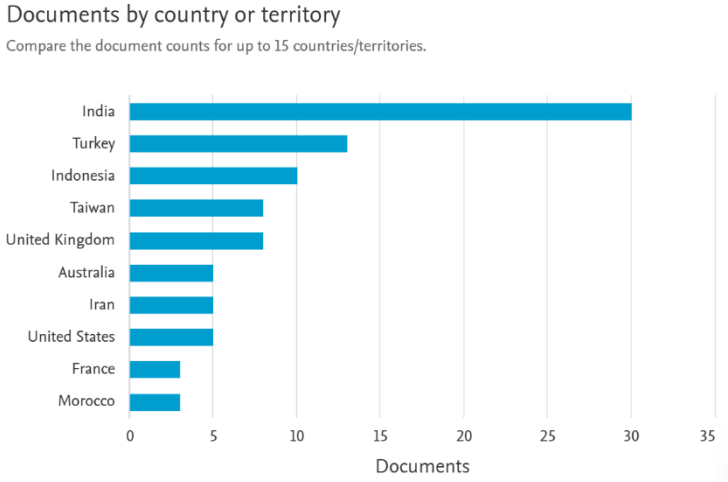


Figure 4. Geographical share of publications (Source: Scopus bibliographical database).

The results also show that the majority of publications come from Asian authors (Fig.4). On the other hand, the research about AHP/ANP-Six Sigma interactions spans amongst a

lot of different sources with a slight exception of *International Journal of Lean Six Sigma* which proves to be a leader with a share almost equal to 10% (Fig.5).

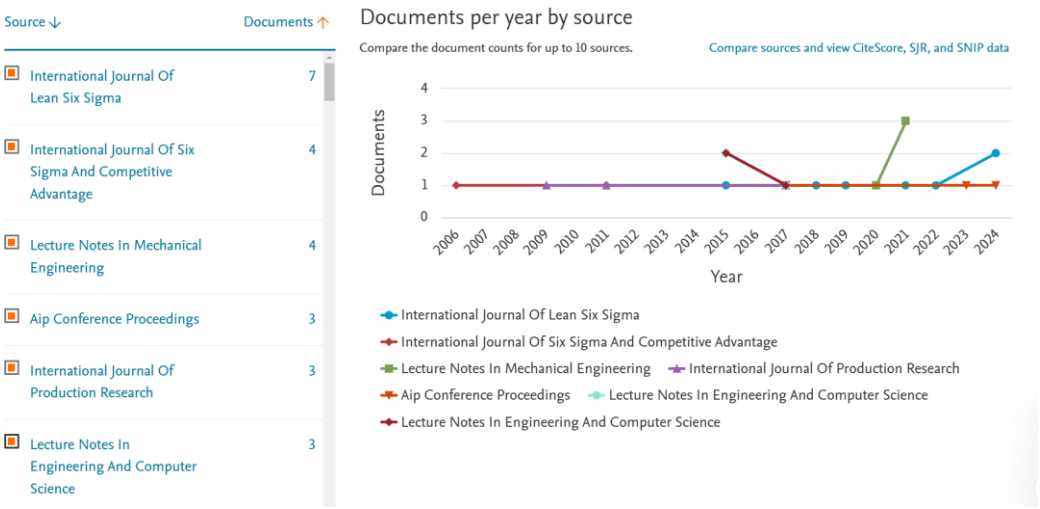


Figure 5. Leading sources (Source: Scopus bibliographical database).

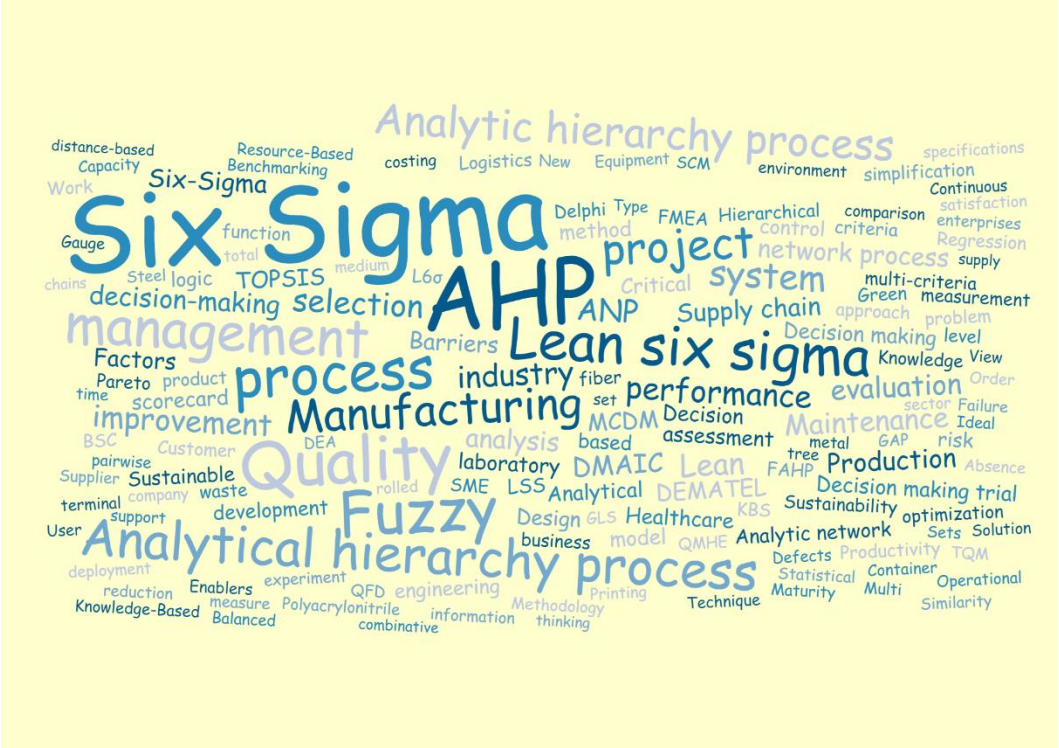


Figure 6. A wordcloud (Source: Scopus bibliographical database).

Analyzed publications present diverse detailed topics. Fig. 6 presents a wordcloud obtained for data, namely the entities of author keywords. One can see that the keywords mainly cover typical range of both Six Sigma and AHP/ANP methodologies. However, with a slight supplement of several decision analysis and typical Six Sigma application areas,

only. Note the presence of 'fuzzy' term which is relatively often applied. This fact contradicts with the good habits of avoiding it in the case of AHP/ANP application.
The publications differ in the number of citations obtained. There are only a few publications that outstand from others with regard to the number of overall citations. Such publications were delivered in particular by Su and Chou (2008), Büyüközkan G., Öztürkcan (2010), Yadav et al. (2018) who were cited more than 100 times. Other, extraordinarly cited publications were proposed by Bañuelas R. and Antony (2003), Yadav et al. (2017), namely Yadav et al. (2018a), Vinodh S. and Swarnakar (2015), Kuei et al. (2011), and Pandey et al. (2018).
However, when it comes to number of citations per year nothing beats Yadav et al. (2018), Yadav et al. (2018a), Pandey et al. (2018), Singh and Rathi (2022) with 10 or more citations yearly.
The above mentioned facts show also that this is a research team of Yadav et al. that is responsible for the highly acknowledged and cited publications about coupling of AHP/ANP and Six Sigma methodology.
It is also very meaningful that most cited publications mainly deal with the application of AHP/ANP for the evaluation and selection of Six Sigma project alternatives or Six Sigma methodology components (often with the help of other decision support tools) , as well as, the identification of barriers for the adoption of different Six Sigma flavors. In particular, Lean Six Sigma is often addressed with this regards.
The rest of publications also cover other topics. They nevertheless repeat relatively rarely.

6. Conclusions

General results of conducted analysis show that AHP/ANP methodology is utilized in Six Sigma application support context mainly to solve some external problems like evaluation, prioritization and final choice of Six Sigma projects or the identification of enablers and barriers for Six Sigma methodology adoption. In our honest opinion the potential of AHP/ANP has a lot more to offer for Six Sigma. In particular, its ability to deal with intangibles may be wider utilized within a full DMAIC or similar perfection cycle to provide means for reliable valuation of intangibles.
Moreover, Six Sigma-related application of AHP/ANP in Six Sigma is often directly based on questionable and unnecessary representation of imperfect information e.g. fuzzy sets, without any rational explanation, for example, by means of a kind of sensitivity analysis based on the application of crisp judgement scales. By the way the potential of alternative judgements scales isn't applied at all while supporting Six Sigma.
Results of bibliographical analysis nevertheless show the evident positive effect of AHP/ANP application on widening range of Six Sigma application areas.

7. Limitations

It is clear that the relying on the application of a single bibliographic database isn't good. Thus, future analyses should be based on the application of .other bibliographical databases e.g. local national-level databases. More detailed analysis, that wasn't possible in such short format of conference proceeding is also welcome. It will be possible, however, in a post-conference publication.

8. Key References

Bañuelas R., Antony J. (2003). Going from six sigma to design for six sigma: An exploratory study using analytic hierarchy process. *TQM Magazine*, 15(5), pp. 334 - 344, DOI: 10.1108/09544780310487730.

Büyüközkan G., Öztürkcan D. (2010). An integrated analytic approach for Six Sigma project selection. *Expert Systems with Applications*, 37(8), pp. 5835-5847. DOI: 10.1016/j.eswa.2010.02.022.

Kuei C.-H., Madu C.N., Lin C. (2011). Developing global supply chain quality management systems. *International Journal of Production Research*, 49(15), pp. 4457-4481, DOI: 10.1080/00207543.2010.501038.

Pandey H., Garg D., Luthra S. (2018). Identification and ranking of enablers of green lean Six Sigma implementation using AHP. *International Journal of Productivity and Quality Management*, 23(2), pp. 187-217, times. DOI: 10.1504/IJPQM.2018.089156.

Saaty T.L. (2006). There is no mathematical validity for using fuzzy number crunching in the analytic hierarchy process. *Journal of Systems Science and Systems Engineering*, 15, pp.457-464. DOI: 10.1007/s11518-006-5021-7.

Saaty T.L., Vargas L.G. (2013). *Decision Making with the Analytic Network Process*. Springer.

Saaty T.L., Vargas L.G. (2012). *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*. Springer.

Singh M., Rathi R. (2022). Empirical Investigation of Lean Six Sigma Enablers and Barriers in Indian MSMEs by Using Multi-Criteria Decision Making Approach. *EMJ - Engineering Management Journal*, 34(3), pp. 475-496. DOI: 10.1080/10429247.2021.1952020.

Su C.-T., Chou C.-J. (2008). A systematic methodology for the creation of Six Sigma projects: A case study of semiconductor foundry. Expert Systems with Applications, 34(4), pp. 2693-2703. DOI: 10.1016/j.eswa.2007.05.014.

Tengtarto M.A.K., Singgih M.L., Siswanto N. (2022). From 1904 to 2022: A Comprehensive Review of Six Sigma Methodology, In: *Proceedings of the International Conference on Intellectuals' Global Responsibility (ICIGR 2022)*. DOI: 10.2991/978-2-38476-052-7_69.

Vinodh S., Swarnakar V. (2015). Lean Six Sigma project selection using hybrid approach based on fuzzy DEMATEL–ANP–TOPSIS. *International Journal of Lean Six Sigma*, 6(4), pp. 313-338. DOI: 10.1108/IJLSS-12-2014-0041.

Yadav G., Desai T.N. (2017): A fuzzy AHP approach to prioritize the barriers of integrated Lean Six Sigma. *International Journal of Quality and Reliability Management*, 34(8), pp. 1167-1185. DOI: 10.1108/IJQRM-01-2016-0010.

Yadav G., Seth D., Desai T.N. (2018). Application of hybrid framework to facilitate lean six sigma implementation: a manufacturing company case experience. *Production Planning and Control*, 29(3), pp. 185-201. DOI: 10.1080/09537287.2017.1402134.

Yadav G., Seth D., Desai T.N. (2018a). Prioritising solutions for Lean Six Sigma adoption barriers through fuzzy AHP-modified TOPSIS framework. *International Journal of Lean Six Sigma*, 9(3), pp. 270-300. DOI: 10.1108/IJLSS-06-2016-0023.