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THE IMPLEMENTATION OF THE CONJUNCTION OF LEAN SIX SIGMA AND INDUSTRY 4.0: A CASE STUDY IN THE CZECH REPUBLIC

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Abstract:
As advanced technologies are becoming a natural part of the industrial environment, the influence of these technologies on organizational practices is becoming more expanding. In this paper, an attempt was made to understand the conjunction of Lean Six Sigma and Industry 4.0. The study was conducted in the Czech Republic and qualitative data was gathered from 10 companies. The information on the benefits, weaknesses and challenges of the conjunction was summarized. For the research purposes literature review and qualitative analysis were performed. It was found out that, although the conjunction is connected with challenges, the perspectives are beneficial for industrial companies. The data generated also allowed to introduce the readiness assessment model for the implementation of the conjunction based on 4 categories: technological, managerial, financial and human. This information could be used for theoretical and practical purposes for the creation of a successful Lean Six Sigma pattern in Industry 4.0.

Key words: *Lean, Six Sigma, Industry 4.0, optimization, technologies*

INTRODUCTION

The increasing complexity of the contemporary world and the development of technologies have led to the emergence of a new concept called Industry 4.0 or the Fourth Industrial Revolution. As the fourth industrial revolution is becoming increasingly widespread, the interest towards it is also growing. Many specialists and scientists are interested in creating the framework for the usage of new technologies of Industry 4.0. Companies are enthusiastic about introducing new technologies to the production processes. So, the need has appeared of evaluating different existing techniques, tools and methods from the point of view of their suitability for Industry 4.0.

As one of the leading techniques of the last decades has become Lean Six Sigma, companies and engineers working with this methodology are trying to find a way to adapt the existing tools to the new challenging environments. One of the ways to achieve this goal may become Industry 4.0 technologies.

Despite the similar goals of Lean Six Sigma and Industry 4.0 to improve efficiency, their integration has not yet been thoroughly analyzed [1]. With the rapid change in the environment and advanced improvement of technologies, the integration of Lean Six Sigma and Industry 4.0 is inevitable as Lean Six Sigma tools and principles have to be shifted in accordance with the demands of the modern world.

It also has been stated that Lean Six Sigma might serve as a good foundation for Industry 4.0 [1] as it helps to analyze the process and identify the most perspective fields for Industry 4.0 implementation. Considering the fact, that many companies have to struggle in the competition, this integration is promising as it may help companies to achieve better results.

The aim of this research is to analyze the conjunction of Lean Six Sigma and Industry 4.0 to contribute to a better understanding of the issue for practitioners and researchers. As the research on Lean Six Sigma in Industry 4.0 is in its infancy these results might provide useful insights for future research. The research is conducted in one of the European countries, namely the Czech Republic, thus the results might bring useful information to other countries as well. However, the results should be further verified in other countries as well.

This research consists of theoretical analysis of the existing literature i.e. the systematic literature review and data gathering from practitioners of Lean Six Sigma and Industry 4.0 in the form of a Survey. The general amount of participating companies is 10 (4 large size, 3 middle size and 3 small size).

The paper is structured in the following way: first, the theoretical background of Lean Six Sigma, Industry 4.0 and their combination is presented; next, the methodology used in this paper is discussed; this is followed by the data gathered with surveys and its analysis; finally, the conclusions, limitations and implications are provided for both the scientific and practitioners fields.

LITERATURE REVIEW

Lean Six Sigma

Lean Six Sigma has emerged as a combination of 2 successful methodologies Lean and Six Sigma. At the end of the XX century, they started to be combined [2] that led to improvement of the results of their application. Lean Six Sigma is a methodology to improve the processes by 'improving quality, speed, customer satisfaction, and costs' [3] based on data collection and analysis. It is aimed at the reduction of variation, wastes and defects with Lean speed and Six Sigma robustness, using a well-structured approach [4].

Lean Six Sigma projects are usually limited in time to one – three years and it works with complex projects, thus, it is a desirable approach for many organizations [5]. It is also aligned with the strategy of organization for the choice of the projects and has established an organizational system, consisting of Master Black Belts, Black Belts, Green Belts [4] and Yellow Belts.

In summary, Lean Six Sigma is an integration of two methodologies that are aimed to reduce wastes, using the Lean approach, and lower the number of defects according to the Six Sigma process. Lean Six Sigma comprises the usage of Lean tools and the DMAIC system. Lean Six Sigma DMAIC cycle is used to solve existing problems, manage projects and see ideas [6].

Industry 4.0

The increasing complexity and advancement in technologies have led to the emergence of a new concept of Industry 4.0, which was first mentioned at the Hannover Fair in 2011 by the German Government [7, 8]. As the goal of every industrial revolution is the creation of the processes that better respond to the market demands [9], the Industry 4.0 (or the Fourth Industrial Revolution) concept is connected with the creation of smart factories where the activities are interconnected [7, 10].

With the increasing amount of customer demands and constantly developing technological environment, companies have to meet the challenge of becoming more flexible and coordinated in a smart way. Nowadays all kinds of products are becoming smart [11]. Industry 4.0 is aimed at creating the production where the technologies are interrelated, self-controlled and flexible [9]. The creation of an environment where independence and flexibility exist at every level is the main goal of the Fourth Industrial Revolution [12]. As the third revolution was connected with the widespread of IT, the 4th revolution is connected with the Cyber-Physical Systems with the real world fully integrated with them [13, 14].

Industry 4.0 is a term that includes several technologies that are connected with the latest technological advancements but it may slightly vary depending on the source. According to Rossini et al. [15], the 16 technologies connected with Industry 4.0 are: Robotics, RDIF, Real-time scanning, Sensors, Augmented reality, Cloud computing, Real-time data sharing, Real-time monitoring, Artificial intelligence and machine learning algorithms, Digital automation, Additive manufacturing, Integrated engineering systems, Big Data, Internet of Things and Production Processes autonomous management. Salkin et al. [7] added simulation as well.

Even though Industry 4.0 technologies are becoming widespread, the integration of these technologies is not an easy task for organizations [12]. The shift in the excepted processes is needed and the integration of new technologies with existing practices and methodologies is necessary. Thus, this challenge is also sharp from the point of view of Lean Six Sigma integration and change.

Lean Six Sigma in Industry 4.0

It was noted by Alblooshi M. and Shamsuzzaman M. [5] that Lean Six Sigma has helped organizations to be prepared for innovations. Industry 4.0 comprises the whole spectrum of different innovative technologies and techniques that could benefit from the existing Lean Six Sigma structure in companies. Currently, this idea was slightly evaluated as the existing amount of companies already experienced with both Lean Six Sigma and Industry 4.0 technologies is not immense.

Considering the Six Sigma dependence on data, Big Data could possess great potential for Lean Six Sigma tools as it will make the process of data collection faster and smoother. However, there are just a few studies on the interconnection of Lean Six Sigma Tools and Big Data so far [4].

It was noted by Chiarini A. and Kumar M. [1] that Lean Six Sigma could serve as a good foundation for automation integration as it could prepare the company by reducing wastes and variation in the processes [1].

Lean Six Sigma has been accepted in many organizations as a methodology to solve problems [16] and it has demonstrated positive results [2]. Although the changing environment according to Industry 4.0 has an impact on Lean Six Sigma methodology especially from the point of view of data gathering and analysis. Unfortunately, the analysis of the integration of Lean and Six Sigma has not been provided with sufficient research [1]. Thus, this paper aims to analyze the integration of Len Six Sigma and Industry 4.0.

METHODOLOGY

The theoretical development of this research was based on the systematic literature review and followed by a practitioners' survey conducted in the Czech Republic. The data from practitioners was gathered via a questionnaire with open questions for the purpose of conducting the qualitative research. The aim of qualitative research is

not to measure the data statistically but to deepen the understanding of the problem.

The research questions for this survey were:

- What are the advantages and disadvantages of the conjunction of Industry 4.0 and Lean Six Sigma?
- What are the challenges connected with the conjunction of Industry 4.0 and Lean Six Sigma?

The data for the literature review was gathered from publications that were accessed via Web of Science (Core Collection) and Scopus databases. The results were limited to the publications and conference papers found in two databases. The conference papers were included in the research as the number of articles, available on Lean Six Sigma and Industry 4.0 is low. Moreover, only publications available in English that were published before January 2021 were considered.

The search combination comprised (Lean OR Six Sigma) AND (Industry 4.0). As it could be seen in Figure 1, the search resulted in 38 articles and 58 conference papers in Scopus and 31 articles and 33 conference papers in Web of Science.

The review of the articles was performed to identify the publications that were investigating the relationships between Lean and Six Sigma and Industry 4.0, and 98 publications were chosen.

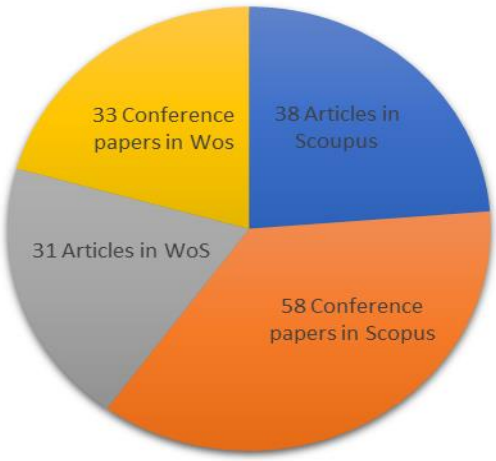

Fig. 1 The amount of papers in SCPUS and Web of Science

The process of the search for relevant papers could be seen in Figure 2.

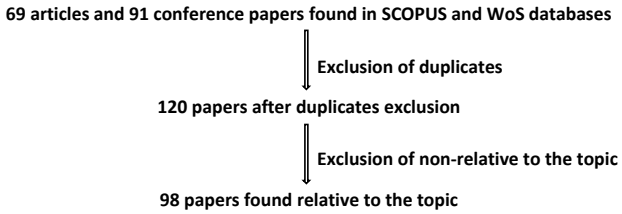

Fig. 2 The search process and the results

The publications were analyzed and from the literature review several tendencies were identified: benefits of Lean and Six Sigma for Industry 4.0, benefits of Industry 4.0 for Lean and Six Sigma that were summarized; challenges that are connected with the integration and conjunctions of different technologies for different tools. The results were analyzed from the point of view of the perspectives of conjunction in the future. The survey for this research was also run in 10 companies in the Czech Republic in October-December of 2020. The managers of the participating companies answered the questions on the topic of integration and blend of Lean Six Sigma and Industry 4.0. The companies participating in the survey were of different sizes (4 large companies, 3 medium and 3 small). The choice of the companies was random however it was targeted on the industrial sector. The most experienced with both Lean Six Sigma and Industry 4.0 are large companies as the majority of them use the tools and the technologies. In the given research all participating large companies have both Lean Six Sigma and Industry 4.0 implemented in their processes. This also explains the prevailing amount of companies in the work. In small and medium enterprises the amount of companies having introduced both Lean Six Sigma and Industry 4.0 is considerably lower, especially this applies to the small companies where the level of usage of Lean Six Sigma tools is the lowest. In the given research only middle-size companies with experience in Lean Six Sigma and Industry 4.0 were participating, while only one of three small-size company has an experience with both Lean Six Sigma and Industry 4.0. However, it is important to note, that all of the participating companies are experienced with some of the Industry 4.0 technologies. The gathered data was analysed and presented with the purpose to depict the perspectives of the conjunction. Further, the model framework for the conjunction of Lean Six Sigma and Industry 4.0 was proposed based on the prior analysis.

RESULTS

The relations between Lean and Lean Six Sigma and Industry 4.0

The first publication connected with Lean in Industry 4.0 appeared in the year 2015. Since then the number of publications is augmenting. As it can be seen in Figure 3 the interest towards the topic has grown significantly in the last three years. This, the interest towards the integration of Lean Six Sigma (especially Lean) and Industry 4.0 has grown sufficiently from the year 2017.

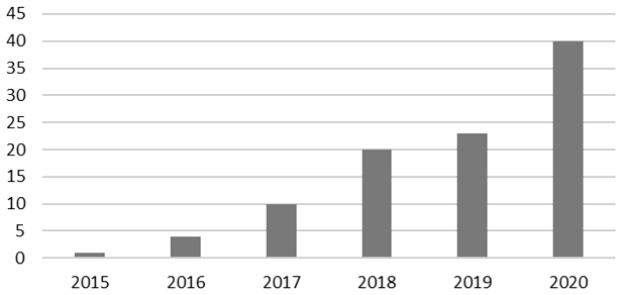

Fig. 3 Number of publications in a year

The assessment of the synergies of Lean and Industry 4.0 was done in several papers. Although Lorenc M. [17] argues in the paper that Lean and Industry 4.0 have no significant correlation according to the papers connected

with Industry 4.0, many authors depict in their publications that Lean might influence the success of Industry 4.0, as well as Industry 4.0 might improve Lean. Several papers have reflected the technologies that could be applied to Lean tools and improve existing methodology [6, 9, 18, 19, 20] and others. Dogan et al. [6] analyzed LSS from a data perspective and summarized technologies for DMAIC steps. Rauch et al. [11] proposed guidelines of the process with Industry 4.0 technologies to achieve lean and smart production. They also divided Industry 4.0 technologies that can be used in the processes according to the Lean wastes types [11]. Similar work was accomplished by Yeen Gavin Lai et al. [9], who also divided new technologies according to the types of wastes. Pereira et al. [8] conducted a literature review on how Industry 4.0 tools can enhance lean methodology and divided new technologies according to the existing lean tools that benefit from them.

Also, several authors argued that Lean Six Sigma might serve as a basis for Industry 4.0 introduction [14] and will continue to be important [13], as it eliminates wastes and variations, thus, preparing the production to be optimized with the new technologies. However, it was also mentioned that Lean principles are rarely integrated into Industry 4.0 implementation [12]. To solve the problem Sony has proposed a Lean and Industry 4.0 integration model [14], that could be beneficial for organizations for the implementation of new technologies. Rossini et al. [15] state that in Europe Lean must be implemented in order to achieve better results in Industry 4.0. Moreover, they argue that the impact of Lean is still higher than the one of Industry 4.0 technologies. The majority of papers connected with the topic prove that the conjunction of Lean and Industry 4.0 is beneficial for both. At the same time, the papers could be divided into two groups: the works where the influence of Lean on Industry 4.0 is discussed, especially from the point of view that Lean serves as a prerequisite, and papers where the influence of Industry 4.0 on Lean Six Sigma tools are depicted.

At the same time, many authors state that there are some challenges connected with the conjunction. The most mentioned challenges are changes that need to be done in a factory, insufficient knowledge and the role of humans [21, 22]. The conjunction of different technologies and Lean Six Sigma tools have proved to be positive, however, some challenges connected with the implementation of new technologies and their combination with Lean Six Sigma tools are unavoidable [23].

In the following part, a practitioners' opinion was gathered with the help of a survey to answer the question what are the major challenges and benefits of Lean Six Sigma and Industry 4.0 conjunction.

The conjunction of Lean Six Sigma and Industry 4.0 in Czech companies

To develop the answer to the research questions the data was also gathered in 10 companies in the Czech Republic. Considering the fact that the research was qualitative, the gathered information was only partly structured. The gathered information is presented in Table 1, where the respondents' answers were summarized into 3 following sections:

- Advantages of the usage of Lean Six Sigma and Industry 4.0 that were gathered from the answers.
- Weaknesses – where the disadvantages of the conjunction were summarized.
- And Challenges where the challenges connected with both introduction and usage of the conjunction were discussed.

Each section was further divided into 4 categories, that emerged from the answers' analysis i.e. Human, Managerial, Technological and Financial as all the answers of respondents were connected with one of these categories. The results of the analysis are depicted in Table 1.

Table 1
The usage of Industry 4.0 for Lean Six Sigma

	Advantages	**Weaknesses**	**Challenges**
Managerial	Increased speed, Quality improvement	"Correct" people	Coordination
Human	Mistake prof	Lack of knowledge, Workers support	Team (including management) qualification and reluctance
Technological	Automatization and digitalization, stability and control, Decreased process complexity	Technical complexity	Technological maturity, Implementation
Financial	Long-term savings, Key indicator's improvement	Costs	Financial challenge

As it could be seen from Table 1, the advantages are similar to the benefits that have been mentioned in previous papers, discussed in the Literature review section, and are connected with improvement of processes and quality as well as with process automatization. The weaknesses that are mentioned in Table 1 are connected with the technical complexity, costs as well as with people. There are several weaknesses connected with people: lack of knowledge of emerging technologies by many people which also influences the 'correct' people issue – whom to choose to study the technologies better, and workers support, especially from the point of view of substitution of workers by the technologies. The challenges are connected with the weaknesses mentioned above and the process of implementation itself.

It was also mentioned in the answers that Lean Six Sigma should provide the solid basement for Industry 4.0 introduction as Industry 4.0 consists of technologies that might help us to reach the goal but Lean Six Sigma provides a way to reach the goal.

Thus, it could be seen from the survey, that the benefits of the usage of Industry 4.0 and Lean Six Sigma in a combination although being promising is connected with a set of challenges, however from the long-term perspective might become necessary for companies' success, especially, considering that the widespread of the technologies lead to the better awareness that might help to overcome challenges.

Lean Six Sigma and Industry 4.0 readiness assessment model

The challenges, advantages and weaknesses of the conjunctions mentioned above allowed to introduce the conceptual framework model for implementation readiness assessment that allows to avoid challenges and weaknesses and maximize benefits during the implementation of Lean Six Sigma and Industry 4.0 combined. This model considers the problems of the conjunction together with the benefits provided. The model resembles the wheel where there are 4 main axes each of that is divided into 2 parts. The model is depicted in Figure 4.

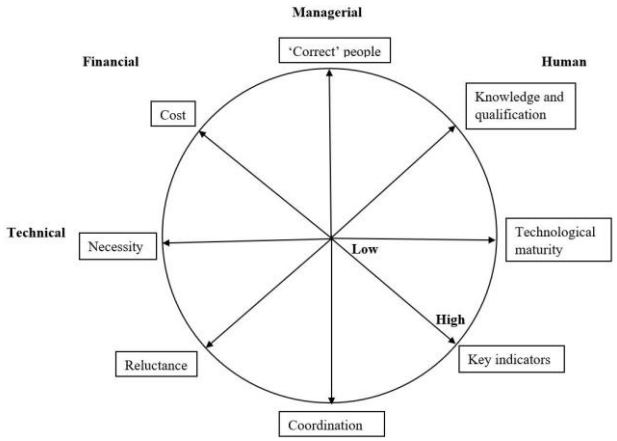

Fig. 4 The readiness wheel

As it can be seen, to introduce the conjunction several factors to avoid challenges and maximize benefits should be considered. These factors could be divided into 4 groups: technological, managerial, financial and human. These factors should be evaluated before the implementation of the conjunction from law to high level from the point of view of their readiness for the implementation. Thus, to construct a working model, it is compulsory to thoroughly consider these factors and their readiness for the technological change connected with optimization tools. From the human point of view, it is also necessary to understand that the introduction of new technologies is inevitably connected with the shift in human competencies, and while technological and managerial factors could be influenced by a group of people (usually including top management), the human factor is a complicated issue, thus the thorough consideration of this factor is required. Also, managerial factors are an important issue due to the reason that managerial commitment and management issues should emanate from the readiness of the technological and human groups. The last group here is the financial factor as the lack of finances could influence the introduction. As the model resembles a wheel, to keep the form the factors should be balanced. The more equally factors are spread in groups – the stronger is the balance, the higher is the level of readiness of factors, the higher is the success.

The accurate estimation of the readiness of the factors mentioned above and their combination is required as it allows to avoid the challenges and magnify the benefits of Lean Six Sigma and Industry 4.0 connected. Thus, a company should consider the evaluation of the factors prior to the implementation or expansion of the usage of Lean Six Sigma and Industry 4.0.

The readiness assessment model has been sent to 2 large international industrial companies in the Czech Republic and gathered positive feedback. The positive aspects mentioned by the practitioners were that the model is easy to be applied and to be understood, however, some think that the model could be further improved with scales on the axes. Generally, as the model was assessed positively, it could also be further applied in other companies, especially in the Czech Republic and assessed in other countries.

DISCUSSION

The introduction of contemporary technologies to industrial life requires companies to redesign their managerial systems. The increasing interest of authors and practitioners proves the idea that the conjunction of Industry 4.0 and Lean and Six Sigma is disputable. However, the majority of works prove that the conjunction is beneficial for the production ([24, 25, 26] and others mentioned above), the challenges that arise from the implementation still need to be considered.

Several works have already been published, proposing a framework and model for the successful implementation and operation of Lean and Six Sigma in the Industry 4.0 environment. An integration model was proposed by Sony [14], however it was based on vertical, horizontal and end-to-end integration without mentioning general requirements. Several frameworks were also proposed based on literature review and experience: Salvadorinho J. and Teixeira L. [27] propose a framework based on the mtual influence of Lean and Industry 4.0; Ejsmont K. and Gładysz B. [28] analysis the Industry 4.0 potential to decrease wastes and proposed Lean framework for waste typology. At the same time, many authors consider the fact that the research is in its infancy [1] and needs to be further developed.

In this paper, an attempt to summarize and analyze the benefits, opportunities and challenges was performed. Moreover, the framework model of readiness assessment based on the literature analysis and data gathered in the Czech Republic was performed. The results of the study might provide useful information for theoretical and practical purposes. From a practical point of view, the results might contribute to the understanding of the conjunction and the necessary information that should be considered by practitioners willing to implement either Lean Six

Sigma together with Industry 4.0 technologies or Industry 4.0 technologies for Lean Six Sigma. From a theoretical perspective, the results provide useful insights into the topic and deepen the understanding of the emerging conjunction.

The work could serve as a motivation for better understanding and integration of Lean Six Sigma and Industry 4.0 combination from both theoretical and practical points of view. This work could be further developed by deepening the understanding of the conjunction of Lean Six Sigma and Industry 4.0 and pattern development for this conjunction. Moreover, not many papers were based on practical application with definite results, thus the practical point of view could also be further investigated. Considering the number of papers on Six Sigma and Industry 4.0, this topic should be analyzed better to provide the necessary information on the influence of Industry 4.0 either on Six Sigma or Lean Six Sigma.

CONCLUSIONS

The increasing development of technologies is influencing the usage of existing methodologies such as Lean Six Sigma. In this paper, the conjunction of Lean Six Sigma and Industry 4.0 was analyzed based on the survey in the Czech Republic companies. The results of the paper might contribute to the understanding of the issue also in other countries, however, they should be verified better as some differences might occur.

The literature review revealed the fact that there is a positive relationship for both Lean Six Sigma and Industry 4.0. Several authors have already analyzed several aspects of what technologies should be used for Lean Six Sigma, Lean Six Sigma is a necessary prerequisite for projects connected with Industry 4.0. Despite the mutually beneficial cooperation between Lean Six Sigma and Industry 4.0, it is still connected with some challenges.

In the practical part, the challenges and weaknesses and strengths of the conjunction were gathered and it was found out that while advantages are connected with technological automatization and long-term process improvement (thus, cost savings), the weaknesses and challenges are also connected with technologies, in particular the lack of knowledge of technologies, and costs. Further, the framework model for the readiness assessment for the conjunction of Lean Six Sigma and Industry 4.0 was developed based on the data from the analysis, which consists of 4 major categories influencing the conjunction: technical, managerial, financial and human.

The authors are aware of the subjectivity and limitations of the research and thus, further discussion on this topic is inspired.

In conclusion, it is important to say that, as the conjunction was proved to be beneficial from both theoretical and practical views, the implementation of the conjunction, despite its weaknesses and challenges, should provide a competitive advantage in the closest future and the framework model proposed in the study might contribute to better integration of Lean Six Sigma and Industry 4.0.

In the future it would be valuable to consider the influence of Industry 4.0 on Lean Six Sigma project success; the impact of Lean Six Sigma on the implementation of Industry 4.0 technologies and the contribution of separate Industry 4.0 technologies on Lean Six Sigma.

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