The Impact of Lean on Introduction of Industry 4.0 Technologies: A Longitudinal Study

Matteo Rossini[1(✉)], Federica Costa[1], Alberto Portioli-Staudacher[1], and Guilherme Luz Tortorella[2]

[1] Politecnico di Milano, Milan, Italy
matteo.rossini@polimi.it
[2] University of Melbourne, Melbourne, Australia

Abstract. The purpose of this paper is to investigate the relationship/interaction between Lean and Industry 4.0. In particular, this research examines empirically the influence of Lean approach on industry 4.0 implementation in a longitudinal study. The research aims at understanding how the implementation of Industry 4.0 technologies changes during a time horizon of 3 years in companies with different level of Lean implementation. A survey has been selected to develop the longitudinal study, since it allows discovering the progression of Lean and Industry 4.0 implementation in several different plants, giving a general overview of the situation.

Keywords: Lean · Industry 4.0 · Longitudinal study

1 Introduction

In the last decade, the rise of industry 4.0 (i4.0) technologies has increased the research effort into how Lean and digital technologies may cooperate to achieve better performance [1]. Recently, research indicates that these two domains tend to co-exist in manufacturing companies, challenging the idea that they are incompatible, and probed a significant and strong correlation between Lean and factory digitalization [2, 3].

In the most recent years, one of the main points concerning Lean and digitalization developed in the literature is the fact that Lean is a enabler to develop Industry 4.0 [4]. Lean approach generates a fertile condition for i4.0 higher adoption levels, prepares the field for implementation of new technologies, and reduce sthe risk of digitalization of wastes when Lean practices are extensively implemented in the company [5, 6].

However, the facilitating or enabling effect of Lean on introduction of I4.0 technologies in factories is still an open debate [7, 8].

This research focuses on this debate, addressing the following research question: How is the integration between Lean and Industry 4.0 evolving over the years in manufacturing companies?

In order to answer to this research question a survey-based longitudinal study has been performed.

Published by Springer Nature Switzerland AG 2023
O. McDermott et al. (Eds.): ELEC 2022, IFIP AICT 668, pp. 143–147, 2023.
https://doi.org/10.1007/978-3-031-25741-4_13

2 Methodology

The longitudinal study shows a comparison between the recent situation (2021) and the one related to 2018.

A survey is the selected strategy to develop the longitudinal study since it allows to discover the progression of Lean and Industry 4.0 implementation in several different plants, giving a general overview of the situation [9].

In order to follow the research strategy defined, a questionnaire has been developed. The questionnaire has been implemented replicating the previous one used in 2018 in order to make the comparison significant [10]. In addition to this, it has been submitted only to companies that have answered in 2018 to be sure to obtain a snapshot of the situation of the same companies for both the periods. In this way, it is possible to study how companies evolved in the implementation level for Lean, Industry 4.0 and performance improvements. It includes different sections related to general information, Lean Practices, Industry 4.0 technologies and operational performance improvement indicators.

Following the characteristics of the sample defined in 2018, the selected companies must have one manufacturing plant located in Europe. With respect to 2018, few changes were made in the questionnaire of 2021 in order to make the questionnaire more streamlined for respondents. Changes have been only referring to the first part related to contextual factors and keeping essential information to conduct the longitu-dinal study.

Data analysis has been performed in different step. In the first step, Cronbach's alpha coefficient has been computed to check the internal consistency and the degree of reliability of the data collected [11]. The second step defined clusters of companies. In this clustering analysis, K-means clustering is used to assign each company to a specified cluster, after having defined the optimal number of clusters with the Elbow method. This two-step procedure has been applied for clustering the companies' answers (in 2018 and 2021) separately regarding their Lean implementation level, Industry 4.0 implementation level and Performance improvements, which are the three core sections of the questionnaire. Consequently, an Analysis Of Variance (ANOVA) one-way was performed to verify if the mean of a cluster is far enough from the mean of another one. In the third step, data normality has been checked for the means of each of the three aspects through a Shapiro-Wilk test. After that, the specific group assigned in the previous clusterization was considered as a categorical variable, thus allowing the application of the Chi-squared tests with contingency tables and adjusted residuals to provide a basic picture of the interrelation between variables.

The last step of the longitudinal analysis was the development of different t-tests (after checking the equality of variances) on the means of the different aspects. The first type of t-tests has been used to check if companies' level of Lean, I4.0 and Performance Improvements has changed significantly among the two years, using their means. Secondly, t-tests have been performed on the questions of Lean and I4.0. The idea was to check if a specific practice or technology had undergone a major development or backwardness because for example to specific investments or because it has become a key aspect in recent years.

3 Results

The survey resulted in 41 companies' answers, corresponding to a response rate of 41%. In order to check non-response bias, "late respondents" were used as an approximation of the companies which did not answer to the questionnaire, and after a statistical analysis there was no evidence of it. Cronbach alpha was calculated for each section of the questionnaire for both the years to guarantee a good level of the dataset reliability proving that the scales used were appropriate for successive analysis.

Then, clustering analysis resulted in optimal number of clusters obtained equal to two for each variable (Lean, I4.0 and performances), both in 2018 and 2021. For each variable and each year, clusters have been defined as Low or High performing for each of elements (Lean, I4.0, perfomances). Then, an ANOVA one-way analysis was performed affirming that for each aspect analysed in both the years the robustness of cluster division is guaranteed with the means of the two clusters significantly unequal.

Concerning the relationship between Lean Manufacturing and I4.0 technologies, a significant association was discovered both in 2018 and 2021. Figure 1 sums up the distribution of the answers for Lean adoption in 2018 and 2021, while Fig. 2 sums up the implementation level of i4.0 technologies.

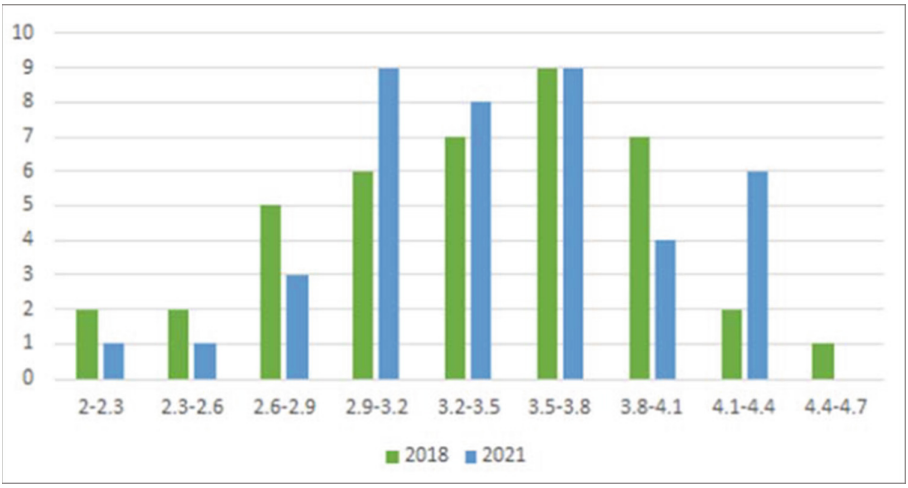

Fig. 1. Lean adoption by respondents.

Then, the association between I4.0 and Performance resulted to be significant in the two years.

Lastly, some t-tests were used to check if companies' level of Lean, I4.0 and Performance Improvements has changed significantly among the two years, using their means. There was no statistical evidence of a change in any of the aspects even if I4.0 undergoes a major improvement in its level of adoption (p-value 0.053). Going more in depth, some t-tests were performed also on specific Lean practices and I4.0 technologies. JIT adopted by suppliers, reduction of set-up time and suggestion programs by operators to

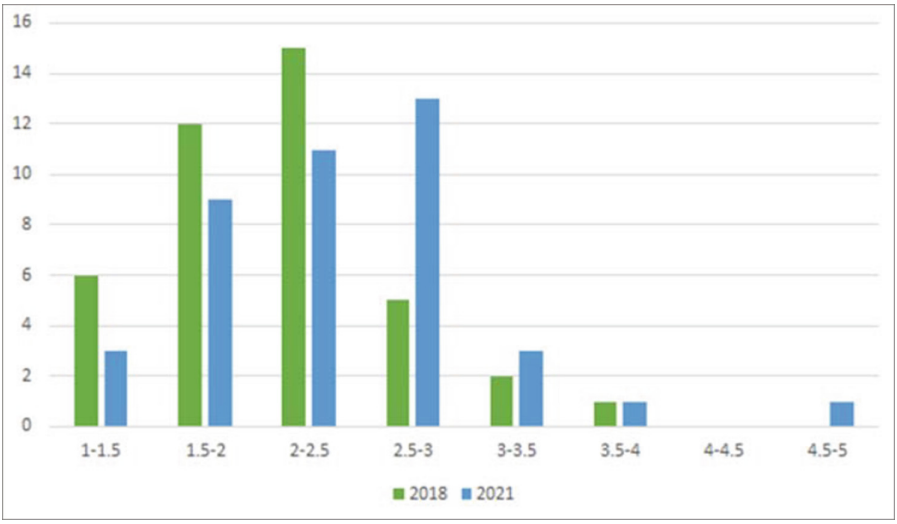

Fig. 2. I4.0 adoption by respondents.

improve processes were three Lean practices that faced important increases between the two years analysed.

4 Conclusions

This preliminary research is the first work, which analyses the evolution of Lean and I4.0 and their connection over the years. In this way, it explores how the two domains are changing, trying to find the root causes behind their relationships and their impact on performances. In particular, it is noteworthy to point out the level of Lean implementation reached by companies remained almost the same over the years. Regarding I4.0, it is important to highlight the increase in the adoption level of digital technologies over the years.

Concerning the relationship between Lean and digital technologies, it is clear that the adoption of I4.0 is significantly linked to Lean implementation: their association is significant and stable over the years showing that having a low level of Lean practices. implementation does not allow companies to strongly adopt I4.0 technologies. Future developments of this research must investigate whether Lean is actually significant in the development of I4.0 implementation, giving to management a more clear perspective on the benefits of introducing i4.0 technologies in Lean systems.

References

1. Rossini, M., Powell, D.J., Kundu, K.: Lean supply chain management and Industry 4.0: a systematic literature review. *Int. J. Lean Six Sigma* (2022)

2. Buer, S.V., Semini, M., Strandhagen, J.O., Sgarbossa, F.: The complementary effect of lean manufacturing and digitalisation on operational performance. Int. J. Prod. Res. **59**(7), 1976–1992 (2021)
3. Rossini, M., Cifone, F.D., Kassem, B., Costa, F., Portioli-Staudacher, A.: Being lean: how to shape digital transformation in the manufacturing sector. J. Manuf. Technol. Manage. **32**(9), 239–259 (2021)
4. Kolberg, D., Zühlke, D.: Lean automation enabled by industry 4.0 technologies. IFAC-PapersOnLine **48**(3), 1870–1875 (2015)
5. Powell, D., Morgan, R., Howe, G.: Lean first… then digitalize: a standard approach for industry 4.0 implementation in SMEs. In: Dolgui, A., Bernard, A., Lemoine, D., von Cieminski, G., Romero, D. (eds.) Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems. APMS 2021. IFIP Advances in Information and Communication Technology, vol 631, pp. 31-39. Springer, Cham (2021) https://doi.org/10.1007/978-3-030-85902-2_4
6. Rossini, M., Costa, F., Tortorella, G. L., Valvo, A., Portioli-Staudacher, A.: Lean production and industry 4.0 integration: how lean automation is emerging in manufacturing industry. *Int. J. Prod. Res.*, 1–21 (2021)
7. McDermott, O., Antony, J., Sony, M., Swarnaker, V.: Mapping the terrain for the lean supply chain 4.0. In: 26th International Symposium on Logistics (ISL 2022), pp 167–179. Cork University Business School, Ireland (2022)
8. Antony, J., McDermott, O., Powell, D., Sony, M.: The evolution and future of lean Six Sigma 4.0. TQM J. (2022). https://doi.org/10.1108/TQM-04-2022-0135
9. Tortorella, G., van Dun, D.H., de Almeida, A.G.: Leadership behaviors during lean healthcare implementation: a review and longitudinal study. *J. Manuf. Technol. Manage.* (2019)
10. Tortorella, G.L., Rossini, M., Costa, F., Portioli Staudacher, A., Sawhney, R.: A comparison on industry 4.0 and lean production between manufacturers from emerging and developed economies. Total Qual. Manage. Bus. Excellence **32**(11–12), 1249–1270 (2021)
11. Cronbach, L.J., Warrington, W.G.: Time-limit tests: estimating their reliability and degree of speeding. Psychometrika **16**(2), 167–188 (1951)