

# Introducing Lean practices through simulation: A case study in an Italian SME

Stefano Frecassetti<sup>a</sup> , Bassel Kassem<sup>a</sup> , Kaustav Kundu<sup>b</sup> , Matteo Ferrazzi<sup>a</sup> , and Alberto Portioli-Staudacher<sup>a</sup> 

<sup>a</sup>Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy; <sup>b</sup>Department of Industrial Systems Engineering and Management, National University of Singapore, Singapore, Singapore

## ABSTRACT

Lean is a management paradigm that focuses on respect for people and promises improvement in a company's performance across sectors and sizes. SMEs, in particular, are a point of interest, considering that their malleability in bureaucracy allows for a more significant margin of continuous improvement application. Several organizational theories have gained advantages from technological innovation, and Lean is no exception. The relationships between Lean and new technologies have been studied throughout the years and gained particular interest in the years when Lean started to be integrated with Industry 4.0 (I4.0) to enhance firms' performance. This article would like to take that discussion from a different point of view, that of I4.0's impact on proving the importance of implementing Lean in manufacturing companies. Through a mixed-method approach of case study and Simulation, this article will answer the identified research question: "How do Lean tools and their integration impact SMEs' process performance?" by showing the importance of implementing Lean tools in a non-Lean company. The results show that Simulation can identify the Lean tools that benefit the company's performance most. Managers could benefit from this study by highlighting which tool or combination to invest in according to the impact on operational performance.

## ARTICLE HISTORY

Received 19 July 2022  
Accepted 6 September 2022

## KEYWORDS

Industry 4.0; Lean; simulation; small and medium-sized enterprises; SMEs

## Introduction

Liberalization and globalization have significantly changed from a market composed of different and separate national economies to a single global market. The practical possibility of connecting customers and companies thousands of miles apart is due to the technical development that has characterized the last twenty years. In a context like that, many authors have pointed out that it is necessary to react quickly to changes in the market and clients' needs to survive (Bevilacqua, Ciarapica, and De Sanctis 2017). Thus, flexibility is becoming an important characteristic. Flexibility in producing various products by rapidly converting production processes while containing costs can be achieved using Lean techniques. Lean was developed to improve effectiveness and efficiency (Marodin et al. 2018). Effectiveness increases quality and value from the customer's perspective. Efficiency is enhanced by minimizing internal and external variability through waste (cost) reduction. The kind of

efficiency that Lean manufacturing focuses on can be defined as "resource efficiency." Efficiency is measured by the ratio of the output obtained over the input used, so an increase can be achieved by improving production or reducing intake. Lean seeks to improve that ratio by affecting both. On one side, a reduction of the input through the cut of all the costs that do not carry value, and on another side, through the adoption of techniques that improve the output produced. Manufacturing is one of the sectors most affected by this market evolution, with a consequent increase in competition (Singh and Singh 2020). For this reason, the first implementations of this philosophy were observed in this sector. However, Lean manufacturing has been fundamental to the survival of many large companies in different sectors (Rossini and Portioli 2018; Costa et al. 2019).

Although Lean is widespread in large companies, the implementation of Lean in SMEs is still at an early stage (Torri et al. 2021). Moreover, there are very few

examples of Lean practices in SMEs (Belhadi, Touriki, and Elfezazi 2019). Due to uncertainty about the costs and tangibility of the results, Achanga et al. (2006) believed that the Lean principles become less important in small- and medium-sized companies. Costa et al. (2019) clearly stated the importance of organizational and economic stability for successfully implementing Lean practices. Also, Nguyen (2015) stated that basic and inexpensive tools such as 5S, Kaizen, and visual inspection should be adopted first, followed by sophisticated Lean practices in SMEs. Hu et al. (2015) analyzed about 101 papers (until February 2015) on the practical implementation of Lean principles in SMEs.

Apart from SMEs, Industry 4.0 is becoming important nowadays. With the automation it provides, questions have arisen about the interoperability with the Lean approach. A Lean environment creates a more receptive culture to new technologies, especially those that reduce waste (Bittencourt, Alves, and Leão 2021). In this sense, Lean and Industry 4.0, despite different perspectives, should be considered together since they aim to reduce costs and increase productivity for companies (Rossini, Powell, and Kundu 2022). The authors reviewed this interaction, focusing on Lean's role in the ongoing fourth Industrial Revolution. They derived that Lean could facilitate to implementation of Industry 4.0 in companies, which is also discussed by Kolberg and Zühlke (2015). Therefore, the maturity level of Lean within a system is an important metric that determines the association with Industry 4.0 (Saxby, Cano-Kourouklis, and Viza 2020). However, the authors stressed the importance of understanding which Lean elements support the Industry 4.0 introduction. This is necessary to avoid huge investments, both in terms of money and time, for re-inventing operations systems (Kassem and Portioli 2021; Rossini, Powell, and Kundu 2022). At the same time, a simple update of some elements effectively supports Industry 4.0 technologies implementations (Saxby, Cano-Kourouklis, and Viza 2020).

As our research is focused on emerging topics, Simulation, an essential pillar of Industry 4.0 (Ciano et al. 2021), is a helpful tool for testing changes to the production process in an environment with minimal expenditure of resources. For this reason, many firms have taken advantage of this opportunity to test the application of various Lean techniques. Abdulmalek and Rajgopal (2007), in their study, simulated a manufacturing process. The main objective was to demonstrate the difference between a scenario with and without Kanban to understand its benefits to the

production process. Comparing the two simulated realities showed that Kanban significantly reduces WIP and increases value-added (VA) time. Pekarcikova et al. (2020), in their study, quantitatively demonstrated the effects of Kanban through Simulation. As a result of their work, percentage improvement values were achieved by adopting this Lean technique. Another research was done with the same objective (Lin et al. 2020). In this study, layout redesign and Kanban were the tools used by the authors to improve the manufacturing process's performance. In addition to this, the model inferred that it also plays a crucial role in reducing production time (Dagmara, Joanna, and Anna 2020).

Organizational paradigms have benefited from technological advancements, and Lean is a case in point. The interaction between Lean and the various industrial revolutions was discussed throughout its diffusion in the industrial world. Although Lean practices are relatively emerging in SMEs, their interaction with Industry 4.0 is not fully revealed. The interaction with I4.0 gained momentum in the last few years. The discussion surrounding it focused mainly on how one paradigm could benefit from the other to advance the company's performance. The research aims to tackle the subject from a different perspective, that of I4.0's impact on proving the importance of implementing Lean in manufacturing companies.

Under such context, the Lean principles and tools are tested in an SME through Simulation, and the performance results are discussed. Thus, this paper will aim to answer the following research question:

*"How do Lean tools and their integration impact SMEs' process performance?"*

The article is organized as follows: a literature review about the applicability of the Lean philosophy and Industry 4.0 in SMEs is provided in Section "Theoretical background". The research methodology is discussed in Section "Methodology". The case company is described in Section "Results". In Section "Discussion", the project results are elaborated on and discussed. Finally, the conclusion is depicted in Section "Conclusions".

## Theoretical background

Lean Management is one of the most diffused managerial philosophies in the manufacturing sector. Applying Lean Management and its tools can benefit firms that follow this practice. According to a study conducted by Antony et al. (2012), Lean is well accepted by the 700 companies surveyed. 63% believe

in the benefits it can bring, 66% of companies experienced success, 31% experienced little change, and only 3% failed.

The spread of Lean went beyond its birthplace, being applied in manufacturing and service industries. Thanks to its easy applicability and significant benefit of reducing waste without additional requirements of resources (Chahal and Narwal 2017), it has expanded to all fields (Rafique et al. 2016) where non-value-added activities could be identified. Many case studies have shown how techniques can be adapted without being overturned to apply Lean in other sectors such as agriculture organizations (Satolo et al. 2017), engineering-to-order companies (Rossini et al. 2019), small and medium-sized enterprises (SMEs) (Yadav, Mittal, and Jain 2018), construction companies (Costa et al. 2019), product development (Nepal, Yadav, and Solanki 2011), services (Malmbrandt and Åhlström 2013; Kundu and Manohar 2016; Torri et al. 2021) and supply chain (Rossini and Portioli 2018). The degree of success has been different based on the country. It has been much more successful in developed countries than in developing ones (Alefari, Almani, and Saloni 2020).

The advantages of Lean practices have been highlighted for over thirty years (Abu et al. 2019). Numerous studies claim that Lean generally benefits the firm's operational performance (Marodin et al. 2018; Amrani and Ducq 2020). The application of Lean brings benefits to internal quality in terms of a decrease in the rate of defects and errors (Amrani and Ducq 2020; Belfanti 2019) while improving customer responsiveness and satisfaction (Abu et al. 2019; Silvério, Trabasso, and Pessoa 2020) and customer lead time (Bevilacqua, Ciarapica, and De Sanctis 2017). Some studies from the literature review showed an improvement in labor and asset productivity (Bevilacqua, Ciarapica, and De Sanctis 2017), a reduction in cycle time, and an optimization of set-up time (Belfanti 2019; Abu et al. 2019; Amrani and Ducq 2020). Other studies underlined improvement in efficiency and cost reduction in space production costs and non-value-added activities (NVA) (Abu et al. 2019; Amrani and Ducq 2020). The adoption of the Lean philosophy can help obtain an improvement in transportation and inventory (Belfanti 2019; Abu et al. 2019).

Lean has positively impacted five categories of performance indicators: quality, time, customer, business results and human resources, safety, and environment (Table 1).

Even if Lean has several benefits, as shown in the table above, firms must face several barriers while coping with Lean implementation. In particular, companies tend to underestimate the correct planning and the best path to achieve successful Lean implementation projects. Thanks to the diffusion of Industry 4.0 technologies in the last years, it has been possible to estimate better the effects of a certain implementation using software, testing it in a virtual environment before proceeding to the shop floor. The most suitable technology to do this is Simulation. A simulation is a helpful tool for testing changes to the production process in different environments with minimal expenditure of resources.

For this reason, many firms have taken advantage of this opportunity to test the application of various Lean techniques. Abdulmalek and Rajgopal (2007), in their study, simulated a manufacturing process. The main objective was to demonstrate the difference between a scenario with and without Kanban to understand its benefits to the production process. Such comparison showed that Kanban significantly reduces WIP and consequently increases value-added time.

Lin et al. (2020) and Pekarcikova et al. (2020) inferred that Lean plays a crucial role in reducing production time (Dagmara, Joanna, and Anna 2020). Pollesch et al. (2017) and Woschank, Dallasega, and Kapeller (2020) analyzed the benefits of adopting different Lean techniques through Simulation. Among others, 5S was implemented. The Simulation showed a 38% improvement in the average cycle time after the implementation of 5S from 120 seconds to 78 seconds. The demonstration of the benefits of adopting 5S to the production process has also been described by Chávez et al. (2019), Punna Rao, Nallusamy, and Raman (2019) and Quezada, Siguenza-Guzman, and Llivisaca (2020).

In an automotive company, the Simulation has been used to estimate the effects of the SMED on the productive process (Basri and Mohamed 2017). The authors estimated a 53% reduction in set-up time. A reduction of this magnitude also positively affected productivity and machine and workforce utilization. Arbieto et al. (2020) analyzed the production processes of a steel company in Peru. They aimed to minimize the waste present in the company using Lean techniques. After defining the current state, a solution was designed to solve the problems identified using 5S and SMED. Using Simulation allowed them to launch different alternatives and choose the best one. The result exhibited by the Simulation was a lead time

**Table 1.** Lean and its impact on performance indicators.

Categories	Performance measures	Literature
Quality	Waste reduction	(Hallgren and Olhager 2009; Jadhav, Mantha, and Rane 2014; Searcy 2009; Bhasin 2008; Sharma, Dixit, and Qadri 2014; Fullerton and Wempe 2009; Shrivastava, Mohanty, and Lakhe 2006; McKone, Schroeder, and Cua 2001; Duque and Cadavid 2007)
Time	Scrap level	(Shah and Ward 2003; Shrivastava, Mohanty, and Lakhe 2006; Biswas and Sarker 2008)
	Rework level	(Shrivastava, Mohanty, and Lakhe 2006; Zandin and Maynard 2001)
	Lead time reduction	(Shah and Ward 2003; Bonavia and Marin 2006; Bhasin 2008; Sharma, Dixit, and Qadri 2014; McKone, Schroeder, and Cua 2001)
	Customer lead time	(Shah and Ward 2003; Bonavia and Marin 2006; Bhasin 2008; McKone, Schroeder, and Cua 2001)
Customer	Throughput time	(Bhasin 2008; Shrivastava, Mohanty, and Lakhe 2006)
	Set up time reduction	(Fullerton and Wempe 2009; Shingo 1985)
	Supplier lead time	(Shrivastava, Mohanty, and Lakhe 2006)
	Delivery reliability	(Hallgren and Olhager 2009; Jadhav, Mantha, and Rane 2014; Bhasin 2008; Shrivastava, Mohanty, and Lakhe 2006; Kaplan 1983; McKone, Schroeder, and Cua 2001)
	Volume flexibility	(Hallgren and Olhager 2009; Jadhav, Mantha, and Rane 2014; Bhasin 2008; Kaplan 1983; McKone, Schroeder, and Cua 2001)
	Customer service	(Bhasin 2008; Ray, Muhanna, and Barney 2005)
Business results	Customer complaints	(Shrivastava, Mohanty, and Lakhe 2006; Bell, Mengüç, and Stefani 2004)
	Customer satisfaction	(Shrivastava, Mohanty, and Lakhe 2006; Fornell 1992)
	Market share	(Shrivastava, Mohanty, and Lakhe 2006)
	Competitive position	(Shrivastava, Mohanty, and Lakhe 2006; Kaplan 1983)
	Cost	(Shah and Ward 2003; Hallgren and Olhager 2009; Jadhav, Mantha, and Rane 2014; Searcy 2009; Bhasin 2008; Shrivastava, Mohanty, and Lakhe 2006; McKone, Schroeder, and Cua 2001)
	Profit	(Bhasin 2008; Samuelson and Nordhaus 2010)
	Business position	(Shrivastava, Mohanty, and Lakhe 2006)
	Revenue	(Bhasin 2008)
	Pre-tax return on assets	(Jayaram, Vickery, and Droge 2008)
	Return on investment	(Jayaram, Vickery, and Droge 2008)
	Return on sales	(Jayaram, Vickery, and Droge 2008)
Human resource, safety, and environment	Inventory / WIP reduction	(Bonavia and Marin 2006; Searcy 2009; Bhasin 2008; Kaplan 1983; McKone, Schroeder, and Cua 2001; Zandin and Maynard 2001)
	Resource utilization	(Sharma, Dixit, and Qadri 2014; Leung and Chan 2009)
	Safety	(Jadhav, Mantha, and Rane 2014; Zandin and Maynard 2001)
	Employee satisfaction	(Sharma, Dixit, and Qadri 2014; Shrivastava, Mohanty, and Lakhe 2006; Sageer, Rafat, and Agarwal 2012)
	Quality of work-life	(Shrivastava, Mohanty, and Lakhe 2006; Datta 1999)
	Multi-skilled workforce	(Shrivastava, Mohanty, and Lakhe 2006; Hoyt and Matuszek 2001)
	Labor productivity	(Shah and Ward 2003; Bonavia and Marin 2006; Searcy 2009; Bhasin 2008; Shrivastava, Mohanty, and Lakhe 2006; Kaplan 1983; Koch and McGrath 1996)
	Employee innovativeness	(Jadhav, Mantha, and Rane 2014; Parzfall, Seeck, and Leppänen 2008)
The rise in green initiatives	(Sharma, Dixit, and Qadri 2014; Bergmiller and McCright 2009; Duarte and Machado 2013)	

reduction of about 7%. Alanya et al. (2020), in their study, instead tried to implement different Lean techniques. They focused on VSM, SMED, and work standardization and applied them in a Peruvian textile company. They brought these tools to the production process through Simulation and analyzed the results. It was possible to reduce rework by default from 13.12% to 4.23%, delayed processes were reduced from 18.49% to 9.61%, and the productivity index of the cutting area increased from 0.38 to 1.16. Goh and Goh (2019) simulated the production process of modular construction. Their study simultaneously applied total quality management, Just-In-Time deliveries based on E-Kanban, cross-training, and construction robotics. These Lean techniques allow for improving the operating performances. More in detail, because of adopting JIT and TQM, 13.5% and 39.5% improvements were recorded for process and cycle

times. Worker utilization improved by 17.9%, and productivity increased by 4.6%, thanks to reducing about 4% of the scrap rate. In the case study developed by Rane et al. (2017), Kaizen, total production maintenance, line balancing, and automation techniques were used with Arena simulation software to optimize an assembly line. Production increased by 60%, and machine and person utilization by 35%. WIP inventory decreased by 44%, rejections by 60%, total product cost by 35%, assembly cost by 60%, and cycle time per unit time by 37.5%.

Table 2 above shows the studies in the literature where simulation has been used to estimate the potential benefits and feasibility of Lean tools' implementation. As can be seen, few papers provide a comprehensive overview of a wider set of tools. The majority is focused on the effect of a single-tool implementation. In the same light, to the best of the

**Table 2.** Lean tools and their impact on firms' performance.

Lean Technique	Improvement	References
Kanban	• WIP reduction	Abdulmalek and Rajgopal (2007)
	• Increase %VA activities	
	• Machine utilization (+14%)	Pekarcikova et al. (2020)
	• Operational performances (+14%)	
	• Total production time reduction	Lin et al. (2020)
	• VA time (+11%)	
	• Productivity (+41%)	Dagmara, Joanna, and Anna 2020
	• Machine utilization rate (+10%)	
	• Workforce utilization rate (+15%)	Woschank, Dallasega, and Kapeller (2020)
	• Lead time (-30%)	
5S	• WIP (-57%)	Pollesch et al. (2017)
	• WIP reduction	
	• Lead time reduction	Punna Rao, Nallusamy, and Raman (2019)
	• Increase %VA activities	
	• Cycle time (-38%)	Quezada, Siguenza-Guzman, and Llivisaca (2020)
	• Cycle time (-4.5%)	
	• Lead time (-3.4%)	Chávez et al. (2019)
	• Productivity (+6%)	
	• Assembly time (-40%)	Basri and Mohamed (2017)
	• Productivity (+30%)	
VSM, Kaizen & 5S	• Productivity (+89%)	Arbieto et al. (2020)
	• Efficiency (+72%)	
SMED	• Set-up time (-53%)	Huarhua-Machuca et al. (2019)
5S and SMED	• Lead time (-7%)	
5S and SMED	• Defective parts (-11%)	Alanya et al. (2020)
VSM, SMED & Standardization	• Process time (-37%)	
	• Reworked parts (-9%)	Goh and Goh (2019)
	• Process delay (-10%)	
	• Increase productivity	Rane et al. (2017)
• Cycle time (-26%)		
TQM, JIT & Kanban	• Workforce utilization (+18%)	Mahendran and Kumar (2016)
	• Productivity (+5%)	
	• Productivity (+60%)	Lucherini and Rapaccini (2017)
	• Machine utilization (+35%)	
	• Workforce utilization	Mahendran and Kumar (2016)
	• WIP (-44%)	
	• Rejections (-60%)	Lucherini and Rapaccini (2017)
	• Product cost (-35%)	
	• Assembly cost (-60%)	Mahendran and Kumar (2016)
	• Cycle time (-37.5%)	
5S, JIT, SMED, TQM	• Space used (-50%)	Mahendran and Kumar (2016)
	• Inventory (-82%)	
	• Set-up time (-61%)	Lucherini and Rapaccini (2017)
	• Workforce utilization (+38%)	
SMED and JIT	• Productivity (+7%)	Lucherini and Rapaccini (2017)
	• WIP (-30%)	

authors' knowledge, no articles focus on analyzing the combined effects of Lean tools applied together through Simulation.

## Methodology

The methodology proposed in this paper combines the use of both case studies and Simulation. This choice was driven by specific reasons dictated by the research context and to give a great consistency to the final results. Indeed, through the real case study, it is possible to confirm the importance of applying Lean tools, especially in non-Lean companies, thus showing the effects on processes. On the other side, using the Simulation allowed the company to avoid the immediate adoption of Lean tools, which often involve long times of implementation, having a near vision of the

simulated process. So, Simulation is fundamental to obtaining rapid results with no costs. Moreover, being Simulation one of the pillars of I4.0, using both techniques together can also prove the benefits of I4.0 digital tools on firms' processes.

In this section, we will show how these methodologies have been used and what benefits they bring to the final consistency of the results.

## Case study

There are many cases in the literature where researchers use case studies to test hypotheses and find new knowledge. Although to contribute to global knowledge in a meaningful way, many case studies are needed; as quoted by Sunder, Mahalingam, and Krishna (2020), even a single case study can contribute to worldwide

knowledge and improve the current state of things. Using the case study as a research method stems from the desire to obtain quantitative and qualitative results (Choudhary et al. 2019) to add future practitioners and researchers (Sunder, Mahalingam, and Krishna 2020). In addition, the case study has an advantage over other methodologies because (Torri et al. 2021):

- It has flexibility in design and application (Merriam and Tisdell 2015);
- It helps test existing theories, produces new approaches, and provides a basis for applying solutions to business problems (Gijo, Palod, and Antony 2018);
- It is beneficial for studying the evaluation of programs such as Lean (Zhang, Narkhede, and Chaple 2017; Sunder, Mahalingam, and Krishna 2020);
- It allows for first-person content analysis by quickly identifying cause-and-effect relationships.

The case study under analysis regards a medium-sized enterprise operating in northern Italy, producing plastic components for Tier-1 automotive suppliers. So, this company belongs to Tier 2 of the automotive supply chain. There, the level of Lean maturity is still in a primordial state (as it is generally in small and medium-sized enterprises, Torri et al. 2021).

This advantage allows different technique tests in a neutral environment without interference deriving from other Lean tools. The case study was carried out using different data sources through which it was possible to gather data for the simulation part. Using multiple data sources has been relevant for data triangulation and the robustness of the study. In particular, the sources of information have been the following:

### 1. Face-to-Face Interviews

Face-to-face interviews were fundamental for drafting the company's current state, thus drafting the flow chart and the conceptual models. They have also been used for assessing and validating the AS-IS model. The interviewed people for this phase were the key ones related to the production part of the company; in particular, they were the Operations Direction, Planning and Logistics Manager and Industrialization and Maintenance Manager. While evaluating the impact of certain Lean tools to be applied in the TO-BE phases, three senior shift leaders and the plant supervisor, together with a wider set of operative people, were interviewed. For both phases, more than one round of interviews has been done involving two different interviewers to give structure, robustness,

and quality to the analysis.

### 2. Internal Documents

Internal documents were very relevant to understanding all the factors related to the production, such as cycle times, failure rates, percentage of scraps, change over time and machine characteristics. The aggregate data have also been used to assess and validate the model together with the opinion of the managers.

### 3. Direct Observation

Direct observation has been very useful in all the study phases and carried out throughout several Gemba Walks. Initially, direct observation has been relevant to drafting the flow of products and highlighting troubles and challenges on the shop floor.

While in the modeling phase, Gemba Walk helped address some troubles in the simulation model, thus shaping it better. Also, it has been used to test and observe the impact of the implementation of some tools, thus leading to a right understanding of the impact in terms of the performance of the implemented tools in the TO-BE condition.

All of these data have been merged and triangulated to understand possible pitfalls and depict a model closer to reality as much as possible.

## Simulation

Intending to answer the research question to fill the gap identified in the literature, the tool chosen was the Simulation, identified as the only one capable of testing in a dynamic way different proposals for improvement. This has meant recording the results of applying the various Lean techniques without implementation costs.

The great advantage of Simulation is the possibility to test different hypotheses thanks to the creation and Simulation of scenarios affected by the scheduled improvements. This allows for observing the virtual consequences of the decisions taken with limited time and economic resources (Possik, Amrani, and Zacharewicz 2018; Andrade, Pereira, and Conte 2016; Bait, Di Pietro, and Schiraldi 2020). Simulation is a very strong instrument that has become very diffused in the last decade thanks to the continuous interest in industry 4.0. Despite that, it is necessary to follow some proper steps to ensure consistent simulations. Before deciding to use the Simulation, it has been

necessary to understand the practical possibility of realization. The first step was a preliminary analysis to obtain a model that could be validated and represent reality. In this feasibility study on data availability for the creation of the model, one of the limits, in fact, of the Simulation is the necessity to have a high quantity of data to obtain reliable results.

Three phases are necessary for the simulation process (Goh and Goh 2019):

### 1. Abstraction and modeling

After collecting all the data needed to describe the current situation, the AS-IS model was realized in this phase. Before starting, only a small part of the whole set of company products had been considered in the analysis. In fact, according to Pareto's rule, only a part of products significantly affects the company's performance (80% of the effects from 20% of the causes). Thanks to an ABC analysis, the products represent around 80% of the revenues and the time available for production. Thus 31 (20%) products have been obtained. After that, various conceptual models with an increasing level of detail were created and subsequently "translated" into simulation language; the chosen Discrete Event Simulation (DES) software was Arena. Under some assumptions, the starting model was run several times to evaluate its yearly performance, comparing them to the company's previous years. During this phase, many refinements and adjustments were made to have a simulation model fit as much as possible with reality. As the last thing, a warm-up time has been defined; according to Law and Kelton (1991), a warm-up time needs to be determined to represent the actual performance of the process. While simulating industrial processes, initial conditions may affect the initial dynamics of the system. A warm-up period was considered for starting the system at time zero to load the system with entities and WIPs.

### 2. Verification and validation

Once completing the AS-IS model, the objective is to evaluate the reliability in this step. Some indicators' results obtained through Simulation are compared with the real ones. If they differ within a confidence interval, it is possible to state that the model is verified and validated. As the last step of the current state simulation, it was necessary to check whether the represented processes corresponded to reality. As brought back in literature, one observation is not enough, but more is needed: Law and Kelton (1991) suggested a

range from 10 to 30 replications. Therefore, five runs of 20 replications each have been carried out. So, it was decided to take an average number but evaluate them on different runs. They were then validated according to two parameters: Pieces produced annually and Average throughput time per batch. The MAPE has been considered an estimator of the overall error in a particular way. The necessary condition to validate it was avoiding more than 5% deviations. The results were 2.15% for pieces produced and 2.42% for the throughput time. These have been validated through interviews and meetings with the planning manager and the company's operations director to have a greater certainty of the data.

### 3. Experimentation and decision making

Finally, in this phase, the improvement proposals, represented by Lean techniques and their combination, are applied, and the results are collected and analyzed. In particular, after having verified and validated the model, five different techniques were found and tested as described:

- Kanban: reduction of the WIP number in the process;
- SMED: reduction of the Set-up time;
- 5S: reduction of a part of the processing times;
- TQM: reduction of downtimes related to poor quality of production;
- TPM: reduction of downtimes related to maintenance.

The reductions in WIP, processing times and downtimes have been estimated as a combination of sample tests done on the shop floor and the literature average's value. In the picture below, the steps performed in the case study are represented (Figure 1).

### **Advantages of combined use of methodologies**

The combined use of case studies and simulations has led to the study of these countless benefits. Through the collection of data from a real case, we were able, through the use of Simulation, to enrich and consolidate the analysis, thanks to the countless advantages given by this methodology. Firstly, discrete-event Simulation allows the dynamic analysis of production systems to identify possible improvements in the "AS-IS" state and the possibility of introducing improvements in future "TO-BE" scenarios. We have better understood the system in its

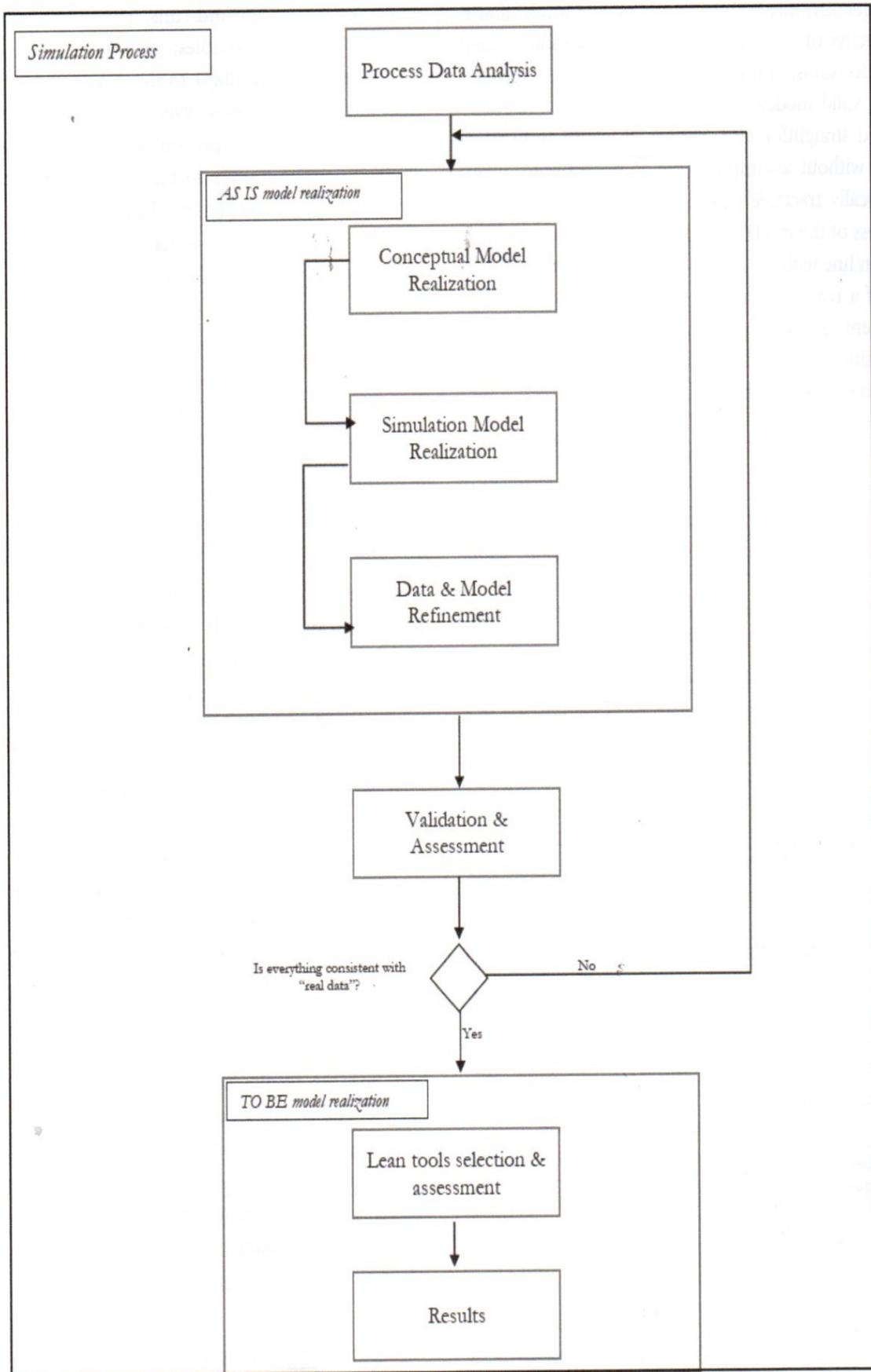


Figure 1. Simulation process used in this study.

initial phase through the Simulation. Moreover, the great advantage of the Simulation is being able to analyze possible solutions for future implementations without disrupting the environment of a company. Thanks to the Simulation, it is possible to validate possible solutions in a time-lapse and avoid investing

money in solutions without having the certainty that they could carry concrete advantages. One of the fundamental advantages of Simulation is that it can tolerate much less restrictive modeling assumptions, unlike exact analytical methods that rely on more restrictive assumptions.

Consequently, this leads to an underlying model that is more reflective of reality and, therefore, more valid, leading to better decisions. Simulation allows researchers to build and study valid models of complex systems in a relatively simple and straightforward manner. It allows us to study problems without assumptions made primarily to obtain an analytically tractable model, which may endanger the truthfulness of the model. This type of analysis approach is perfectly in line with the analysis of a real case study. In the context of a real company, it is necessary to represent its environment as faithfully as possible. Hence, the combination of using a case study and simulating its future process made the discussion of the results in this paper.

**Results**

Once identified these actions, firstly, the single tools were tested individually and then simulated using

**Table 3.** Results from the Simulation: impact on pieces produced per year.

Scenario	Pcs produced		
	Absolute value	Delta % vs AS IS	Delta % vs Previous Tech. Number scenario
AS IS	16.934.245	0%	0%
One Technique	17.709.858	4,6%	4,6%
Two Techniques	18.315.961	8,2%	3,4%
Three Techniques	18.696.224	10,4%	2,1%
Four Techniques	18.942.738	11,9%	1,3%
Five Techniques	19.137.532	13,0%	1,0%

**Table 4.** Results from the Simulation: impact on throughput time.

Scenario	Throughput time		
	Absolute value	Delta % vs AS IS	Delta % vs Previous Tech. Number scenario
AS IS	1.486	0%	0%
One Technique	1.390	-6,5%	-6,5%
Two Techniques	1.269	-14,6%	-8,7%
Three Techniques	1.140	-23,3%	-10,2%
Four Techniques	976	-34,3%	-14,4%
Five Techniques	770	-48,2%	-21,1%

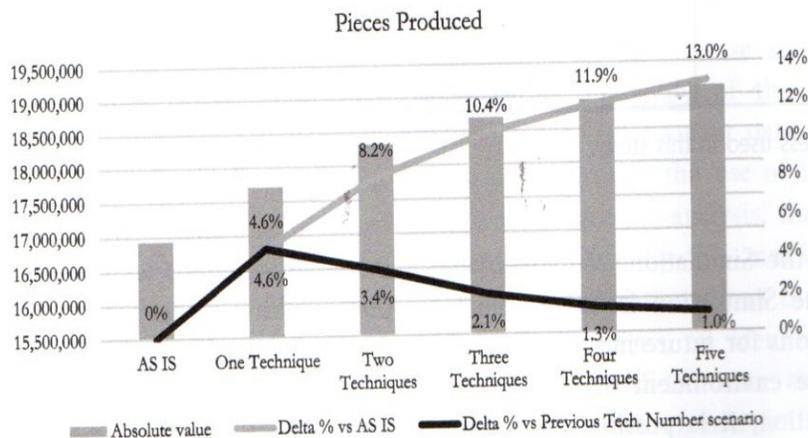
different replications and runs. Then the results, based on two output variables, were analyzed through ANOVA (using Minitab) to determine their statistical relevance. The chosen evaluation parameters were pieces produced per year and throughput time. Based on them, it has been possible to prove that company performance is affected by Lean tools and demonstrate that results have a statistical significance. The following step was simulating all the combinations of these techniques. As a result, 32 combinations were tested using the same number of runs and replicating the previous step. Afterwards, one DOE (Design of Experiment) for each output variable was built to observe the statistical relevance of the study undertaken (Tables 3 and 4, Figures 2 and 3).

**Discussion**

This section discusses simulation results showing the advantages of Lean tools in SMEs.

After analyzing the sector, it was found that even if a slight growth was present in the automotive industry after the Covid-19 outbreak, there was a market contraction.

It is well known that companies of moderate size are usually the most affected by crises, and this study becomes even more interesting from a pure survival perspective. Companies in this period will have "to do more with less". As specified, one of the objectives of this study is to guide companies in choosing the proper techniques from the perspective of continuous improvement. Providing companies with a model that can drive them to optimize their efforts to obtain the best possible results will have a considerable impact. So, this choice makes even more sense. The simplicity of the Lean tools will encourage more practitioners to incorporate them. Due to the increasing number of SMEs, implementing the mentioned combination of Lean tools will become more popular so.



**Figure 2.** Improvements in terms of pieces produced using a different number of techniques.

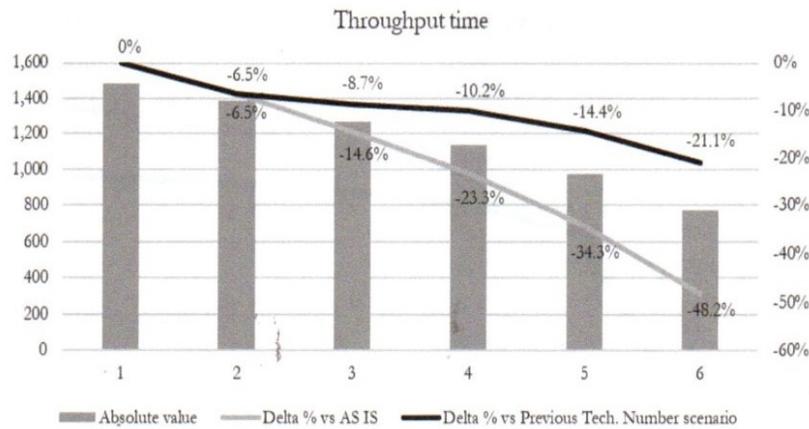


Figure 3. Improvements in terms of throughput time using a different number of techniques.

Although the Lean tools studied and their interactions were fundamental for this research, understanding how to work in a real company through Simulation is essential to living it and gaining experience. The throughput time reduction using a different combination of Lean tools will become essential for managers in SMEs.

## Conclusions

This research was born to understand how Lean tools and their interaction can impact the performance of SMEs. Through the analysis of a case study and simulations using real data collected from the case study, we could answer the research question.

First, we can say there is a correlation between the different Lean tools and business performance. In fact, from the analysis conducted through the simulations, we have evidence that the adoption of the various Lean techniques, applied individually, has a statistically significant impact on the operational performance of the production process; in this case, pieces produced led time per batch. Secondly, there is a correlation between the combination of the various Lean tools and company performance. From the results obtained, it is possible to state that integrating the different tools is statistically significant for the output variables considered.

In this specific case, those with a greater significance for the parts produced are Kanban SMED, Kanban 5S, Kanban TQM, Kanban TPM, 5S TQM TPM, Kanban 5S SMED, Kanban SMED TPM, Kanban 5S TQM, Kanban 5S TQM TPM, Kanban 5S TPM. Instead, in terms of throughput time, on the other hand, the most promising combinations are Kanban SMED, Kanban 5S, Kanban TQM, Kanban 5S SMED, Kanban TPM 5S SMED, Kanban SMED TQM, Kanban SMED TPM, SMED TQM TPM, 5S TPM.

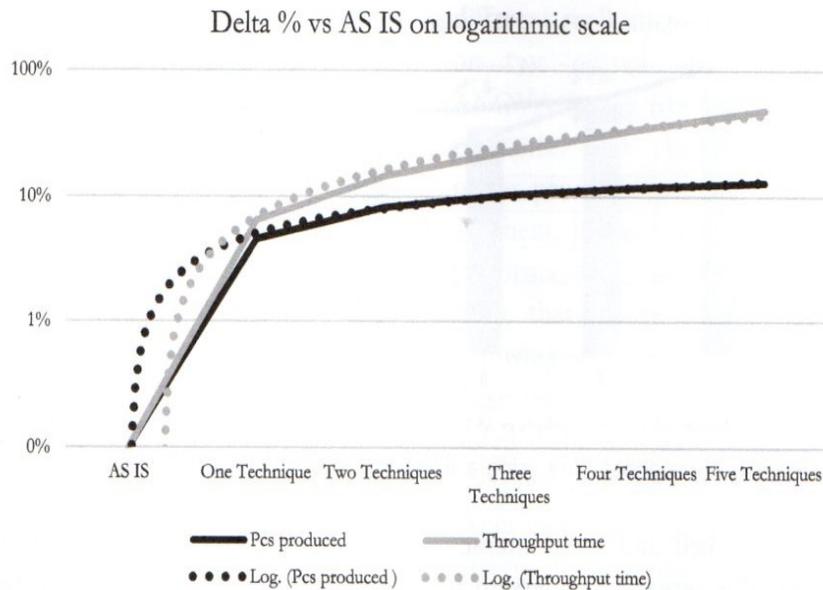
Furthermore, by looking at Figure 4, it is possible to conclude that the increase in benefits obtained from integrating different techniques follows a logarithmic trend. This is a significant result for several reasons.

First, it represents a proxy for the results expected from implementing Lean and the possibility of entering a Lean path. In this way, a hypothetical company can have an idea of the expected results in relation to the effort required. The second reason is the possible use of these results as a blueprint and driving factor in implementing Lean. Let us consider a company that needs to enter the Lean world. If it starts with techniques that bring marginal improvements, it may be disappointing and stop the process. If the firm follows this study, it could start with the most promising techniques, achieving excellent results early in the process. This will motivate more to pursue the path of continuous improvement.

The third reason is the possible use of these results to remove the most significant barriers to successful Lean implementation. As previously described, one of the most important factors to consider is the human one. In fact, all barriers derive, in different percentages, from the extent to which the people involved in the Lean process decide to adapt and strive for change. In this way, the firm can achieve its goals in the future. Not seeing high results during the first phase of implementation, the firm in question may be mistakenly convinced of the futility of the change. This is due to the fact of marginal improvements which could be hampered by human resistance. With this study, the company can easily understand that some factors are negatively affecting Lean implementation in case of deviation with respect to expected performance improvement.

The fourth reason is the confirmation that it is possible to have continuous improvement, even if marginal, as the number of techniques considered increases.

As mentioned above, the benefits of integrating multiple Lean techniques follow a pattern similar to that of



**Figure 4.** Results in terms of both throughput time and pieces produced are plotted using the logarithmic scale.

a logarithmic curve. This means that they are characterized by a substantial initial increase that decreases as the number of techniques added increases. Therefore, it is possible to predict the benefits obtained and estimate the best implementation path depending on the starting scenario. A result that emerged from this study is the need to have a model that favors the proper implementation of Lean tools. As mentioned above, adopting Lean tools increases performance by following the S shape curve proposed by Netland and Ferdows 2015.

The graph represented in Figure 4 the results have a very similar shape to the one depicted in their study. The only difference lies in the first part, where there is a significant difference in the slope of the curve in this study. Using the simulation approach and assumptions, this study has neglected some interferences that could be present while implementing Lean tools for the first time (e.g., resistance to change, lack of expertise, economies of learning, pitfalls or troubles while implementing the tools). Thus, it has considered the effect of the tools as "at full capacity", and it is so possible to hypothesize that considering these factors, the curve could be flatter (i.e., the increase in performance with the implementation of the first tool will be lower, and so the slope of the curve). Considering this hypothesis as plausible, the findings coming from this study could be considered very similar, if not completely aligned with the ones obtained by Netland and Ferdows (2015).

On the one hand, this lets us think that the search approach is correct. On the other hand, it is possible to think that through structured and validated guidelines, it is possible to create a model of adoption of Lean tools that leads to further improvement of business performance, moving upward the maximum value of performance that can be achieved. Moreover, this research

has allowed us to investigate the implementation of the Lean approach through digitization. The simulation tool allowed the company to take a case study to implement some Lean tools effectively and, above all, with a very low effort. The encouraging results obtained from this research can lead to two different pushes. On the one hand, researchers can investigate the integration of Lean tools through digitization in other SMEs in the same sector to have wider evidence of these benefits. On the other hand, managers of other companies, encouraged by the performance gains proposed in this paper, can test the implementation of Lean tools at zero cost through simulation methodology.

From a managerial point of view, this study investigates the interactions between Lean tools providing a total point of view. It represents a guideline for SMEs seeking to implement some Lean tools. Secondly, it is worth pointing out the benefits of Simulation in studying the benefits of combining Lean tools in SMEs, where it is expensive to create different environments. Finally, to make a combination of Lean tools a success in SMEs, managers should consider the findings of this research as a reference to promote the benefits of Lean tools.

### Limitations

Although the discussed results on the interrelations between different Lean tools have contributed to enhancing the knowledge in this field, this paper has certain limitations, which are depicted as possible future research directions.

Firstly, this study is concentrated on single company information in Italy. It will be interesting to apply the findings of this study to other SMEs across the world. Secondly, we have used the benefits of a

pillar of Industry 4.0, i.e., Simulation. So future researchers may also consider using other pillars of Industry 4.0 while investigating certain Lean tools' benefits in their studies.

### Disclosure statement

No potential conflict of interest was reported by the authors.

### About the Authors

**Stefano Frecassetti** is a PhD Candidate at the Department of Management, Economics and Industrial Engineering of Politecnico di Milano and a Lecturer in Operations Management and Industrial Management courses at the MSc level at Politecnico di Milano. His research is focused on the integration of Lean Management and Digital technologies.

**Bassel Kassem** is a Post Doc researcher and Lecturer at Politecnico di Milano. His main research area is operational excellence in the digital era. In particular, his interest is the intersection between Lean Production and Industry 4.0 and understanding how to implement them in manufacturing companies.

**Kaustav Kundu** works as a Research Fellow at the Center for Next Generation Logistics, National University of Singapore, Singapore. He holds a PhD with a concentration in operations management from Politecnico di Milano, Italy. His main focus areas are production and logistics in the manufacturing sector using Simulation and modeling.

**Matteo Ferrazzi** is a PhD Candidate at Politecnico di Milano. His main area of research is the interaction between the lean approach and sustainability. In particular, his interest is the influence of lean manufacturing practices on environmental sustainability in manufacturing companies.

**Alberto Portioli Staudacher** is a Full Professor of Operations and Supply Chain Management at the Politecnico di Milano, a Member of the European Association of Industrial Management, and Director of the Lean Excellence Center. He has been responsible for numerous research and consultancy projects for private companies and public administrations.

### ORCID

Stefano Frecassetti  <http://orcid.org/0000-0002-9649-314X>  
 Bassel Kassem  <http://orcid.org/0000-0001-8991-8050>  
 Kaustav Kundu  <http://orcid.org/0000-0002-1262-4465>  
 Matteo Ferrazzi  <http://orcid.org/0000-0001-9035-0773>  
 Alberto Portioli-Staudacher  <http://orcid.org/0000-0002-9807-1215>

### References

- Abdulmalek, A., and J. Rajgopal. 2007. Analysing the benefits of Lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics* 107 (1):223–36. doi: 10.1016/j.ijpe.2006.09.009.
- Abu, F., H. Gholami, M. Z. Mat Saman, N. Zakuan, and D. Streimikiene. 2019. The implementation of Lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications. *Journal of Cleaner Production* 234:660–80. doi: 10.1016/j.jclepro.2019.06.279.
- Achanga, P., E. Shehab, R. Roy, and G. Nelder. 2006. Lean manufacturing for SMEs: Enabling rapid response to demand changes. In *Proceeding of the 15th International Conference on Engineering Design*, Melbourne.
- Alanya, B. S., K. E. Dextre, V. H. Nuñez, G. E. Marcelo, and J. C. Álvarez. 2020. Improving the cutting process through lean manufacturing in a Peruvian textile SME. In *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, Singapore, 1117–1121.
- Alefari, M., M. Almani, and K. Salonitis. 2020. Lean manufacturing, leadership and employees: The case of UAE SME manufacturing companies. *Production & Manufacturing Research* 8 (1):222–243. doi: 10.1080/21693277.2020.1781704.
- Amrani, A., and Y. Ducq. 2020. Lean practices implementation in aerospace based on sector characteristics: Methodology and case study. *Production Planning & Control* 31 (16):1313–35. doi: 10.1080/09537287.2019.1706197.
- Andrade, P. F., V. G. Pereira, and E. Conte. 2016. Value stream mapping and Lean simulation: A case study in automotive company. *The International Journal of Advanced Manufacturing Technology* 85 (1–4):547–55. doi: 10.1007/s00170-015-7972-7.
- Antony, J., G. Manville, R. Greatbanks, R. Krishnasamy, and D. W. Parker. 2012. Critical success factors for lean six sigma programmes: A view from middle management. *International Journal of Quality & Reliability Management* 29 (1):7–20. doi: 10.1108/02656711211190846.
- Arbieto, M., J. Vásquez, E. Altamirano, J. Álvarez, and E. Marcelo. 2020. Lean manufacturing tools applied to the metalworking industry in Perú. In *Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI)*, Bogota, Colombia, 1–5.
- Bait, S., A. Di Pietro, and M. Schiraldi. 2020. Waste reduction in production processes through simulation and VSM. *Sustainability* 12 (8):3291. doi: 10.3390/su12083291.
- Basri, A. Q., and N. Mohamed. 2017. The study of extended single minute exchange of die (SMED) method in 1200 tonnage tandem press line for operation improvement. In *Proceedings of International Conference on Computers and Industrial Engineering, CIE 2017*, Lisbon, Portugal.
- Belfanti, N. 2019. Adoption of Lean practices as management innovation. A review and conceptualisation. *International Journal of Business Innovation and Research* 18 (2):242–77. doi: 10.1504/IJBIR.2019.097254.
- Belhadi, A., F. E. Touriki, and S. Elfezazi. 2019. Evaluation of critical success factors (CSFs) to Lean implementation in SMEs using AHP: A case study. *International Journal of Lean Six Sigma* 10 (3):803–29. doi: 10.1108/IJLSS-12-2016-0078.