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Toward a Holistic Understanding of Performance in Lean Manufacturing: A Discussion on the Relevance of Its Indicators.

Abstract:

Purpose: This study proposes a novel approach to select and prioritize performance indicators on Lean Manufacturing depending on whether they are influencing or being influenced by others, thereby assisting in the decision-making process for improving overall performance.

Design/methodology/approach: The methodology comprises two stages. First, a literature review was conducted in order to identify the performance indicators, and then their interrelationships were analyzed by means of the DEMATEL multi-criteria decision-making (MCDM) method.

Findings: The results provide a comprehensive visualization of the performance indicators in Lean Manufacturing, with a total of 50 identified indicators. Among these, 29 were categorized as causal, meaning that their results mainly influence the others; and 21 as influenced, with their results mostly being influenced by others. Among the causal indicators, those related to the Human Factor (8 indicators) were the most predominant. However, the most-cited performance families in the literature do not stand out as being causal, but rather as mostly influenced.

Originality: Performance measurement plays a crucial role for organizations, but due to the increasing number of metrics, there lacks an established framework. This exploratory study thus opens the discussion on relevance to determine a group of coherent and connected indicators that could help measure performance in a more comprehensive manner, rather than in several isolated parts.

Practical implication: This study can help managers improve and analyze performance more effectively, while focusing on the importance of choosing causal over influenced indicators.

Keywords: Performance Indicators; Lean Manufacturing; Lean Production; DEMATEL; Decision Making; Continuous Improvement

Article classification: Research Paper

1. Introduction

Today more than ever before, industrial sectors are characterized by high variability, increasing complexity, strong competition and customer-driven markets. This situation therefore requires manufacturing companies to keep pace with these challenges and increase their competitiveness in order to succeed. Companies are thus in a constant quest to improve their performance (Soltan and Mostafa, 2015). Companies must adopt new methodologies and learn to be more effective and flexible to improve their quality, cost and service delivery to customers (Agus and Shukri Hajinoor, 2012; Psomas and Antony, 2019). As performance is the primary goal of a company (Lakri *et al.*, 2015), it becomes of great interest to understand what performance is and how it is measured. Performance is defined as a measurable result, which can be applied to quantitative as well as qualitative data (International Organization for Standardization, 2015). Performance is also viewed as the measure of the results of the execution and implementation of an organization's strategies (Defee and Stank, 2005).

Based on the important role of performance, companies implement different methodologies to improve upon and pursue higher levels of performance. Among them, Lean Manufacturing stands out as one of the most recognized and widely adopted around the world since its origins at Toyota (Dieste *et al.*, 2019; Psomas and Antony, 2019; Sahwan *et al.*, 2013). Lean Manufacturing is a methodology that is based on a series of principles and practices, which are aligned to bring continuous improvement to performance, by removing that which does not add value to the product (Bhasin and Burcher, 2006; Taj and Morosan, 2011). Lean Manufacturing seeks to improve performance in the company by identifying and eliminating different types of waste in processes (Liker and Morgan, 2006; Rosman *et al.*, 2017). This waste (also called *muda*) represents everything that does not add any value to the final product or the process. Seven types of *muda* have been defined: transportation, waiting, unnecessary motion, defects, reworking, inventory and overproduction (Ohno, 1988; Taj and Morosan, 2011).

Authors like Ferdousi and Ahmed (2009) have stated that by implementing Lean Manufacturing and reducing the aforementioned *muda*, companies will enjoy multiple benefits in their performance, such as improvements to quality, delivery, lead time, inventory level and employee motivation, among others. Hence, when tracking expected improvements in performance, it becomes of great importance to adequately measure performance indicators on a constant basis (Liker, 2004). Their follow-up is crucial for identifying the different transformation opportunities to further improve performance (Buonamico *et al.*, 2017; Kaur *et al.*, 2016). Despite the essential and strategic nature of this subject, it seems that literature in Lean Manufacturing still falls short on giving a clear understanding of the performance indicators and how to manage them for the decision-making process. This is in fact more crucial today, given the challenges and opportunities of the current changing context. There are authors who highlight the wide variety of performance indicators in the literature (Belekoukias *et al.*, 2014) and the lack of a clear framework to aid in identifying which of those indicators are the most critical ones (Bhamu and Sangwan, 2014). Furthermore, it has also been shown in recent studies that there is a high rate of companies unable to sustain improvements over time, resulting in unsuccessful implementations (Mirdad and Eseonu, 2015) or unexpected termination of improvement initiatives (Antony and Gupta, 2019). Lately,

this has been studied through the identification of some barriers for success and the subsequent analysis of the interactions among them (Chaple *et al.*, 2021), but leaving aside how to measure this success or failure. Furthermore, there appears to be a link between unsuccessful implementations and the lack of clarity and standardization of Lean concepts, such as performance and its indicators (Bhamu and Sangwan, 2014).

Thus, the issue that arises from the literature is to determine which are the critical performance indicators in Lean Manufacturing that should be analyzed in order to help in the decision-making process for improving and maintaining performance? Consequently, this exploratory study's research objectives are first, to establish a set of performance indicators in order to have a more complete and updated view of performance, while considering its multiple facets, and second, to prioritize these performance indicators by means of a more comprehensive analysis through the assessment of their possible interrelations and whether they could be influencing the others or be influenced by them. This study seeks to contribute to helping academics and practitioners track improvements in implementing Lean Manufacturing or continuous improvement strategies in their organizations in a more oriented way.

To do so, the authors propose to base the assessment of these interrelations on the Decision-Making Trial and Evaluation Laboratory (DEMATEL), an MCDM method developed in the 1970s by Fontela and Gabus (1976), as this is a method that evidences the direction and level of influence among criteria. For the purpose of this study, DEMATEL stands out as the most suitable MCDM method to be used. Other commonly-utilized MCDM methods, such as MAUT (multi-attribute utility theory) and AHP (analytics hierarchy process) (Velasquez and Hester, 2013) make the assumption that the analyzed criteria are mutually independent neglecting any possible interrelations between them (Tan *et al.*, 2012; Tzeng *et al.*, 2007), something that is the core of the DEMATEL method. Regarding the ANP (analytic network process), DEMATEL allows the relations to be identified, and also makes it possible to determine which criteria are causal and which are influenced, and represent them in a visual model by digraphs, making DEMATEL a comprehensive method for analyzing the causal interrelationships of a complex system (Seyed-Hosseini *et al.*, 2006; Wu, 2008).

The literature concerning the application of DEMATEL in Lean Manufacturing includes studies like the one by Azadeh *et al.* (2015), whose focus was on assessing leanness degree in an Iranian packing and printing enterprise. They established different criteria of Leanness and, among other steps, evaluated the degree of impact among them based on the DEMATEL method. Also, there is the study by Seleem *et al.* (2016), in which, by means of DEMATEL, the Theory of Constraints and the Balanced scorecard, they proposed an approach for prioritizing improvement initiatives or projects to be implemented (previously proposed based on a root cause analysis). Then, Sharma *et al.* (2016) proposed the use of DEMATEL in a case study of an Indian manufacturing company. In this study, they sought to prioritize a defined group of tools for implementing Lean Manufacturing. Lastly, Wu and Tsai (2011) implemented DEMATEL in order to determine the causal relationships between dimensions and criteria for supplier selection. The criteria were gathered from a non-exhaustive literature review and the opinions of experts from Taiwan. They only analyzed influence between the 7 major dimensions and among the criteria inside each dimension, and did not analyze the possible interrelationships between the criteria across dimensions. All these studies are very

valuable and interesting and through them it is possible to see the applicability of DEMATEL. As yet, however, none of them has addressed performance indicators and the influences among them and across different dimensions or facets of performance.

This research therefore aims to contribute to this field of study by proposing an approach for analyzing performance while prioritizing its indicators. It also reevaluates the relevance of the performance indicators most widely used in Lean Manufacturing and emphasizes the importance of focusing more on causal indicators than on influenced indicators. Accordingly, this document is structured as follows: an overview of the concepts of performance and Lean Manufacturing is presented in the second section. Following that, in the third section, the methodology of this study is described, showing how the literature review for identifying the performance indicators in Lean Manufacturing was structured, and how the influences of these performance indicators over each other were then evaluated using DEMATEL. Afterward, the results are shown and analyzed in the fourth section. In the fifth section, the discussion and managerial implications are presented. Finally, the conclusions, limitations and directions for future research of this work are presented in the sixth section.

2. Overview of Performance and Lean Manufacturing

This section is divided into two parts in order to bring clarity to the core elements of the research: performance and performance measurement, and Lean Manufacturing. It aims to emphasize the research gap which this study intends to contribute to filling, while highlighting the importance of performance analysis in Lean Manufacturing, which is worth analyzing from a practical and theoretical point of view.

2.1. Performance and Performance Measurement

Performance is understood in the literature as a result that shows the comparison of how the processes are actually being carried out against a given standard in an organization (Rosman *et al.*, 2017). This result should contribute to the strategic objectives of the organization and to the creation of value. Therefore, the analysis of performance should cover the short, medium and long term (Issor, 2017), suggesting that nowadays, performance has a particularly strategic scope, which should at the same time consider the expectations of various stakeholders (Marche, 2018).

Over the years, the notion of performance has evolved and changed. It is no longer seen through a purely financial focus lens, but instead, with a broader, multifaceted view (Lakri *et al.*, 2015). This goes hand in hand with the various changes and challenges in today's complex environment (Issor, 2017), focusing more interest than before on other aspects, such as flexibility and human and social dimensions. This is also emphasized by recent studies, such as that by Beelaerts van Blokland *et al.* (2019), which proposed a stability-leverage maturity

model, while highlighting that by keeping a purely financial view of performance, the real current and future situation of company performance might be neglected.

As Taouab and Issor (2019) stated in their work, when striving for better performance, it is crucial to be able to measure it. It has been noted that performance measurement plays a key role in the organization, but especially for managers when it comes to identifying potential areas in a company for making improvements and further enhancing the level of performance (Mirdad and Eseonu, 2015). Furthermore, Radnor and Barnes (2007) referred to measurement and management of performance as the process of quantifying its different measures, reporting them, analyzing them, and taking actions, which should result in improvements, better control and innovations. Performance assessment has an essential function, it is based on company strategies and should be intended not only to be monitored, but to improve it on an ongoing basis, in order to achieve continuous improvement. The measurement of performance thus enables the decision-making process of the companies and becomes crucial for effective management (Taouab and Issor, 2019).

Based on the points of view of the different authors discussed above, we could summarize by saying that performance is a qualitative or quantitative outcome of an organization. It is multifaceted and comprises different groups of criteria (quality, time, cost, etc.). The performance metrics contribute to value creation for stakeholders. Their measurement is strategic to assess the current state and help in the decision-making process for analyzing future improvements. However, some authors have remarked that it is still a subject that generates a lot of confusion among researchers and practitioners, and that even a clear definition of its meaning is still lacking (Bourne *et al.*, 2018). Although research on performance began in the 1950s and research on performance measurement dates back to the 1980s, there is still a lot of misunderstanding, resulting in measurement of a large amount of performance indicators, but without knowing or understanding which are truly relevant (Taouab and Issor, 2019).

Furthermore, as stated by Radnor and Barnes (2007), performance measurement in companies has been perceived as consuming large amounts of time and resources due to an increasing number of measures, but without the proper understanding of their meaning and implications. They emphasized the great importance of performance measurement for organizations and, at the same time, stressed that to achieve its potential, the real challenge is to be able to determine and measure the right indicators. To be able to develop a set of performance indicators that are coherent and connected in order to measure performance as a whole, rather than multiple indicators measuring only specific parts or activities in an isolated manner. This is the main motivation for this study, to explore the connections and causal interrelations between the performance indicators to achieve a more comprehensive view and understanding of performance in Lean Manufacturing and thus assist the decision-making process more effectively.

2.2. Lean Manufacturing

Lean Manufacturing (known initially as the Toyota Production System) originated at Toyota Motor Company in Japan. It was born after World War II and was motivated by the economic

situation and changes in the market. Although its creation was driven by a need, it was not until the recession in 1973 that it began to be disseminated throughout Japan (Ohno, 1988). The Toyota Production System started to be more popularly known as Lean (Lean Manufacturing or Lean Production) after the influential publication of Krafcik (1988), in which he referred to it as a Lean production capable of having high flexibility and low inventories while maintaining high quality levels. Krafcik referred to Lean as a better and improved version of pure Fordism. He highlighted the success of Lean by stating that soon after its implementation, Toyota was becoming more efficient than the leading companies at the time.

It has been a long journey since the beginning of Lean, as Stone (2012) illustrated in his systematic literature review, which identified five phases in the history of Lean, characterized first by an early appearance of descriptive publications, secondly by a focus on understanding and propagating its concepts, followed by an increase of implementations and, subsequently, by studies in other areas besides the manufacturing shop floor. Finally, the fifth phase appeared around 2006. Since then, an important increase in the number of scientific publications has been observed, showing implementation of improvements. During this phase, several studies were conducted with the collaboration of Toyota's executives. Through these studies it was possible to gain insight into their practices. Among those studies, those by Liker stand out.

In his book *The Toyota Way*, Liker (2004) captured the nature of Lean as a result of 20 years of studying Toyota. He states that most efforts to implement Lean remain superficial because it is often seen exclusively as a goal, and not as a process in which it is necessary to change the way of thinking. To genuinely integrate the essence of Toyota when implementing Lean, it is important to bear in mind that it is not just a process for eliminating waste, but it also involves a philosophy of long-term thinking, respect for people and partners, and a problem-solving mindset based on continuous improvement and learning. He states that values and ideals are the basis of Lean, since it is through them that better performance is achieved.

The main purpose of Lean is certainly to improve the time needed to provide products and services to customers, while at the same time lowering the costs for the organization (Bhamu and Sangwan, 2014). Lean achieves that first by analyzing and specifying the value in the process, focusing on identifying the value-added and the non-value-added activities in it. Then, it seeks to eliminate the waste in the process (all non-value-added activities that are not essential), ending up with a series of activities that adds value to it (Antony *et al.*, 2017). In the literature, we find that the benefits that are expected after a Lean implementation range from the qualitative to the quantitative and include: improved quality, lower costs, reductions in lead, processing and cycle times, lower inventory levels, better morale among workers, better safety levels in the production, and empowerment of teams (Bhamu and Sangwan, 2014; Liker and Morgan, 2006).

But despite the various studies mentioning the expected benefits of Lean, authors like Psomas and Antony (2019) stated that in fact the research on Lean is fragmented. Through a systematic literature review, they determined that among the most important research gaps on Lean is the research on performance. There is therefore an identified research gap and a need for studies to focus on performance measurement and its indicators (Bhamu and Sangwan, 2014; Psomas and Antony, 2019). And although there are studies such as those of

Gonçalves *et al.* (2019) and Saini and Singh (2020), which focus on analyzing the possible impact or effect of the implementation of Lean practices on the performance of the company, they still fail to analyze the importance of performance indicators or take into account their possible interrelationships and influences. Therefore, studies such as this one are still necessary to contribute to resolving these gaps in the literature and improving the way performance is analyzed within organizations.

3. Methodology

As discussed throughout this document, despite the great relevance and interest in Lean among practitioners and researchers, there is still a lack of understanding of performance and its indicators, which is in fact paradoxical as the main motivation for Lean implementation is a promised improvement in performance. But in the absence of a comprehensive view of performance in Lean, it is not easy to measure the right indicators, and therefore to make assertive decisions. Thus, the goal of this exploratory study is to contribute to filling this gap, and to identify the performance indicators in Lean and understand the interrelationships of influence between them to improve their selection and implementation. Therefore, a methodology comprising two stages (Performance indicator identification and Performance Indicator Cause-Effect Analysis Supported by DEMATEL) is proposed here, as shown in Figure 1.

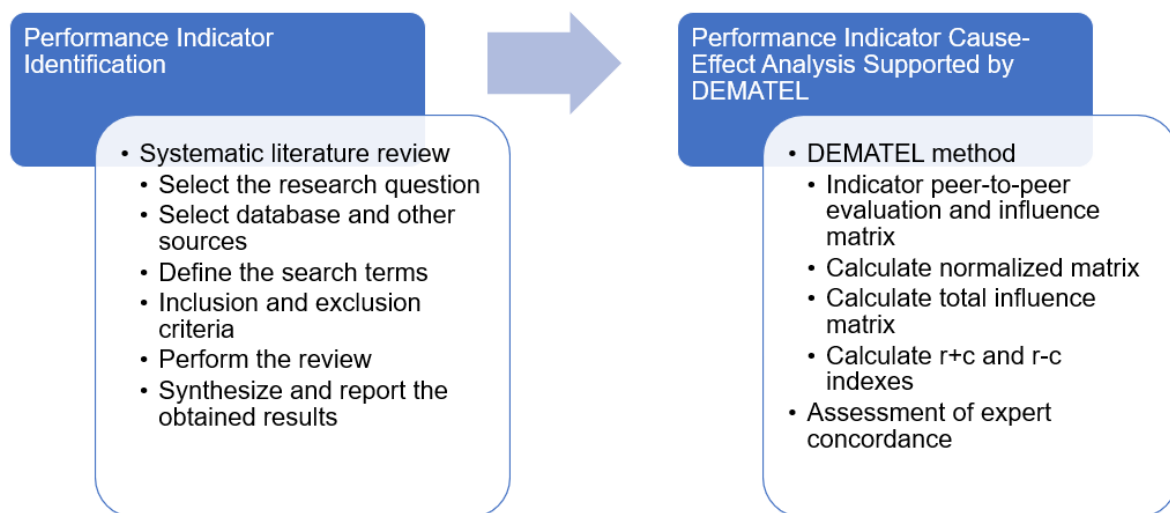


Figure 1. Methodological approach.

3.1. Performance Indicator Identification

For this stage, a Systematic Literature Review was performed in order to gather the performance indicators used in Lean since it is a well-recognized methodology, through which it is possible to gather the relevant studies in the analyzed topic, while providing a replicable

and transparent process (Tranfield *et al.*, 2003). This process includes the following steps: to select the research question, select the database or other relevant sources, define the search strategy, apply practical and methodological inclusion and exclusion criteria, perform the review, and synthesize and report the results (Gutierrez-Gutierrez and Antony, 2019; Rowe, 2014).

The aforementioned steps were followed in order to answer the research question: what are the performance indicators considered in Lean? The sources were defined as being the Scopus database, the Web of Science database and two very prominent references in studies of Lean, which were added on account of their determining role in the history of Lean, while capturing its essence: (Krafcik, 1988; Liker, 2004). As for the delimitation of the search terms used in Scopus and Web of Science, we were interested in having studies that were centered on Lean and that showed performance measurement indicators for the manufacturing sector. Four complementary parts were therefore considered: 1. overall performance, operational performance or manufacturing performance; 2. manufacturing (to restrict the results to this sector); 3. Lean (to get scientific publications on the different variants of Lean, e.g., Lean Manufacturing, Lean Production); 4. measure, measurement or indicators. These were applied to the title, keywords and abstract fields. The search was limited to journal articles or reviews written in English and dated between 2008 and 2019. The detail of the elements used in the search strategy is presented in Table I.

Stage		Description
Research question		What are the performance indicators taken into account in Lean?
Sources		Scopus database Web of Science database Additional prominent references: (Krafcik, 1988; Liker, 2004)
Search strategy	Type of studies	Journal articles
	Search equation	("overall performance" OR "Operational performance" OR "Manufacturing performance") AND manufacturing AND lean AND (measure OR measurement OR indicators)
	Fields of search	Title, abstract, keywords
	Language	English
	Period of time	2008-2019
Exclusion/inclusion criteria & title and abstract review		Articles focused on manufacturing Articles making reference to performance indicators Articles on Lean Manufacturing

Table I. Systematic literature review protocol.

This procedure resulted in an initial set of 88 journal articles, after eliminating the repeated studies from the two databases, a total of 68 journal articles was preselected. Following the methodology, an exclusion and inclusion criteria was applied, all articles that did not make reference to any performance indicator and were not related to the manufacturing sector were excluded. Also, a preliminary review by title and abstract was performed to consider only articles that were centered on the subject. Finally, a total of 32 articles were selected. The complete process is illustrated in Figure 2.

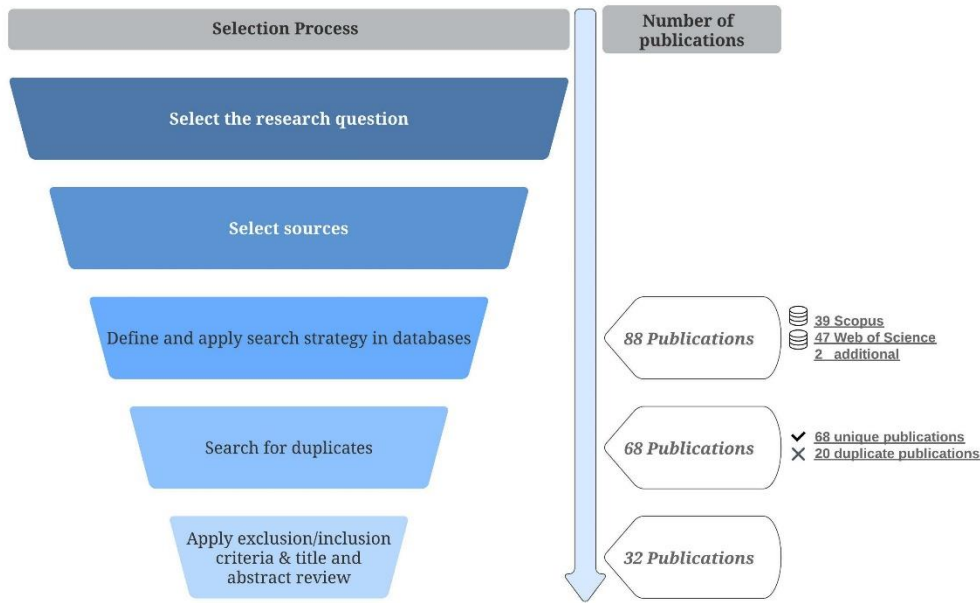


Figure 2. Systematic literature review process.

3.2. Performance Indicator Cause-Effect Analysis Supported by DEMATEL

Given the paramount relevance of performance measurement, and at the same time, the need to rationalize time and resources, it is important to be able to analyze the indicators that might exert the most influence, and thereby determine which indicators warrant action implementation in order to have the greatest impact on improving the system. Therefore, after the review of the publications, at this second stage of the methodology, the DEMATEL method was applied. As previously discussed in this document, DEMATEL was selected over other multi-criteria methods, as it stands out as a method for evaluating the interdependent relationships among defined factors. DEMATEL through its simple application identifies cause-effect chain components of a complex system while providing a visualization through an influence map that can help in solving real problems by eliciting its most important factors (Si *et al.*, 2018; Susanty *et al.*, 2020).

In addition, DEMATEL differs from other methods that explore criteria interactions, as explained by Gölcük and Baykasoğlu (2016), these methods are grouped in two main families, one focused on studying criteria dependency, and the other on exploring their interaction. In the first one we find the Analytical Network Process (ANP) (Saaty, 1996), which is a well-known method that seeks for structural dependency but not for causal dependency; moreover, it requires an a priori hierarchical structure of criteria. Regarding the second family, it analyzes the interactivity of criteria, which, in methodological and philosophical terms, differs from criteria dependence (here the word interactive is associated with the concept of togetherness). The Choquet and Sugeno integrals belong to this family (Choquet, 1954; Grabisch and

Labreuche, 2010; Sugeno, 1974). Lastly, an important feature of the fuzzy measures is that they assign degrees of importance not only to criteria but also to the coalition of criteria, making these methods insightful and more sophisticated, but its diffusion is limited due to their complexity of application.

Thus, the DEMATEL method was applied in order to analyze the possible interrelations of influence and dependency between the previously identified performance indicators. DEMATEL is a method based on interviews of experts. Its objective is to determine the intensity and direction of the influences between the criteria, which in our case were the performance indicators. To apply DEMATEL method we followed the steps as described by Azadeh *et al.* (2015) and Galvez Manriquez (2015):

The first step was to make the peer-to-peer influence evaluation of each indicator on the others and fill in the influence matrix D . It is important to note that this evaluation has to be done in both directions, which means that we have to assess the influence (on a scale from 0 to 4, with 0 being no influence and 4 being the highest influence) of indicator X on indicator Y , and the influence of indicator Y on indicator X . Influence is understood as being the fact that a change in indicator X causes a change in indicator Y . Afterward, the normalized matrix B and the total influence matrix T were calculated as shown in (1) and (2), being d_{ij} the elements in matrix D , and I the identity matrix.

$$B = \frac{1}{\text{Max}_{i,j} \sum_{j=1}^n d_{ij} \sum_{i=1}^n d_{ij}} * D \quad (1)$$

$$T = \frac{B}{I-B} \quad (2)$$

Following that, for each performance indicator i , the sum of row r_i and the sum of column c_i were calculated, with which the intensity of the influence per indicator $r_i + c_i$ and the direction of the influence $r_i - c_i$ (if positive, it is a causal indicator; if negative, it is an influenced indicator) could be determined.

As DEMATEL is a method based on the assessment of criteria by experts, one important limitation is the degree of consistency of their evaluations (Kumar and Dixit, 2018; Singh *et al.*, 2020). Therefore, to seek to overcome this limitation, the authors proposed to complement this analysis with application of Kendall's concordance and correlation coefficients (Kendall, 1938). These statistical coefficients are used for determining the conformity or reliability of experts' evaluations (Silvério *et al.*, 2020), whose results range from 0 (no agreement) to 100% (perfect agreement), meaning a strong agreement has a result over 60% (Duleba and Moslem, 2018). Besides the study from Duleba and Moslem (2018), there are other examples found in the literature, in which an approach combining MCDM and Kendall's coefficient (Athawale and Chakraborty, 2011; Ivlev *et al.*, 2015; Susanty *et al.*, 2020) is applied in diverse case scenarios, such as plants in the supply chain, sustainable public transportation development and industrial robot and medical device selection.

Consequently, to evaluate the degree of consistency and accuracy of the evaluations made by the two initial experts (two of the authors of this study with 20 and 5 years of experience in

Lean), a random sample of 20 comparisons (20 pairs of indicators) was selected from matrix *D*. Then, 4 Black Belt-certified experts in Lean Six Sigma were asked to carry out the influence evaluation from 0 to 4 for this sample. Their evaluations, along with those of the initial experts, were used to calculate the Kendall's coefficients. Using Minitab software, a 69% was obtained for the Kendall's Coefficient of Concordance between appraisers, and a 66% for the Kendall's Correlation Coefficient with the reference (Figure 3). These results, being greater than 60%, suggest strong agreement among experts.

Between Appraisers				All Appraisers vs Standard			
Kendall's Coefficient of Concordance				Kendall's Correlation Coefficient			
Coef	Chi - Sq	DF	P	Coef	SE Coef	Z	P
0,694584	52,7884	19	0,00005	0,658213	0,0811107	8,09877	0,00000000000000006

Figure 3. Result of the attribute agreement analysis with Minitab software.

4. Results and Analysis

4.1. Performance Indicator Identification

After following the steps described in the methodology section, a total of 32 scientific publications were selected. Subsequently, upon review, the performance indicators described or mentioned in them were gathered. This resulted in a preliminary list of 60 indicators (shown in Appendix 1). On this basis, it is important to highlight the great diversity and number of performance indicators among the different studies. This variety can also be seen in the fact that in some studies a large number are found, while in others it might only be one. Subsequently, through further analysis, it was evidenced that some of those performance indicators were in fact redundant, as they appeared under different names but the meaning or the purpose given in the articles was ultimately the same. They were therefore grouped together, resulting in a final set of 50 performance indicators within 19 families.

From this literature review, we were able to identify a large number of indicators, but it was also possible to note the absence of any holistic view or way of classifying or prioritizing them, resulting in the lack of an established and shared framework of reference on performance in Lean, meaning that the performance indicators are not well structured enough to help make decisions to improve performance. The reviewed studies stressed the importance of studying performance indicators in Lean, as performance measurement is crucial for continuous improvement and helps organizations move from a decision-making approach of intuition to one based on facts (Soltan and Mostafa, 2015). Some authors, such as Olivella and Gregorio (2015), even said performance measurement should be performed frequently, even on a weekly or daily basis. Paradoxically, when this is done there can be some drawbacks, like taking up people's time and distracting them for doing their jobs (Liker, 2004).

It has also been observed that although Lean aims to improve performance, there is a lack of understanding and uniformity regarding its performance indicators, making further studies in this area needed (Bhamu and Sangwan, 2014). This lack is even considered one of the reasons for failures of Lean implementations (Karim and Arif-Uz-Zaman, 2013). It is therefore necessary to analyze how performance is being measured in Lean. Some valuable studies, like the one by Mirdad and Eseonu (2015) and, more recently Kovács et al. (2020), have begun to address the issue. The former extracted some of the principles, practices, and performance measures of Lean through a literature survey, and then confronted them with experts in the field, while the latter explored the relationship between the implementation of Lean practices and performance through a longitudinal case study, identifying some categories of performance indicators. In the end, however, they failed to give a more understandable view and did not analyze the possible relationships between the different indicators. In the different studies, performance indicators have been shown in an isolated way, dependent only on the actions implemented, but the influence that they might have on one another is currently neglected in the literature.

Table II shows the families of performance indicators and the corresponding scientific publications from which they were gathered. From this table, it is worth noting that the families of performance indicators that are found most frequently in the literature are those related to quality and productivity, followed by inventory levels, with a marked difference in number of references when compared with the other families. It is also important to note that, although there are 19 different families of performance indicators, the maximum occurrence in the studies is 8 families. Lastly, another aspect worth highlighting is that in the last 5 years, the presence of different families of performance indicators has diversified. This goes in hand with what was discussed earlier, the transformation over time of the multiple facets of performance, which might be indicating a change in the context, and the need to study it.

Reference	Total cost plant	Quality	Flexibility	Speed	Lead Time	Worktime	Travel distance	Pull ratio	Mura	Waste	Inventory level	Profitability	market share	Effectiveness	Productivity	Human factor	Production rate	Transfers	Reliability
(Tortorella <i>et al.</i> , 2019)		x									x				x	x			
(Maware and Adetunji, 2019)			x	x															x
(Shrafat and Ismail, 2019)		x									x	x	x		x				
(Lotfi and Saghiri, 2018)	x	x	x																
(Santos Bento and Tontini, 2018)		x	x		x	x					x	x							
(Sahoo and Yadav, 2018)	x	x	x														x		
(Sangwa and Sangwan, 2018)	x	x	x		x	x	x	x			x			x	x				
(Tortorella and Fettermann, 2018)		x													x				

(Rosman <i>et al.</i> , 2017)	x	x	x																
(Ali and Deif, 2016)										x						x			
(Binti Aminuddin <i>et al.</i> , 2016)																x			
(Cortes <i>et al.</i> , 2016)	x	x				x		x	x	x						x	x		
(Kaur <i>et al.</i> , 2016)		x								x						x			
(Maasouman and Demirli, 2016)	x	x								x						x	x		x
(Cuatrecasas-Arbós <i>et al.</i> , 2015)		x	x		x	x				x						x			x
(Dora and Gellynck, 2015)		x				x										x	x		
(Mirdad and Eseonu, 2015)	x	x			x	x		X		x						x			
(Netland <i>et al.</i> , 2015)		x			x					x						x			
(Olivella and Gregorio, 2015)	x	x														x	x		
(Soltan and Mostafa, 2015)	x	x			x														
(Zammori, 2015)																x			
(Belekoukias <i>et al.</i> , 2014)		x	x	x												x			x
(Kumar Sharma and Gopal Sharma, 2014)																x			x
(Amin and Karim, 2013)	x	x				x	x			x	x					x	x		
(Karim and Arif-Uz-Zaman, 2013)						x	x									x	x		
(Taggart and Kienhöfer, 2013)		x									x								
(Sezen <i>et al.</i> , 2012)		x	x			x													
(Jayaram <i>et al.</i> , 2010)		x				x						x							
(Álvarez <i>et al.</i> , 2009)						x													
(Fullerton and Wempe, 2009)	x	x				x	x									x			
(Hallgren and Olhager, 2009)	x	x	x																
(Taj, 2008)		x	x			x					x					x	x		
(Liker, 2004)	x	x				x		x								x			
(Krafcik, 1988)		x														x			
TOTAL	13	27	11	2	9	11	5	2	1	2	4	4	1	2	22	7	1	1	4

Table II. Performance Indicator families per scientific publications.

Subsequently, based on the reviewed scientific publications and the authors' knowledge, the definition of each of the 50 performance indicators is provided below. These definitions, along with the objective (to be maximized, minimized or to maintain at a target) for each performance indicator, are presented grouped by each of the families shown in the previous table.

The first performance indicator, "effectiveness," can be defined as the comparison of the output of a production process against a target (Karim and Arif-Uz-Zaman, 2013; Zammori, 2015) and thus, its objective is to be maximized. Following that, there are seven indicators related to productivity. The first, "efficiency," compares the output of a process or a machine, against the utilized resources in a given period (Karim and Arif-Uz-Zaman, 2013; Zammori, 2015), the greater its value, the better. Then, "labor downtime" and "equipment downtime," for both of which the objective is to be minimized. They refer to the idle time of the resources (employees, machines, etc.) during working hours (Cortes *et al.*, 2016). Next, the "number of NVA motions" is an indicator to be minimized, as it represents all the movements that do not add value to the product or the production process. Additionally, a performance indicator that we seek to maximize, the "value-added ratio," represents the comparison between the sum of the total value-added time and the lead time (Liker, 2004). For "capacity utilization" and "uptime," the objective is also to be maximized. They represent the utilization rate of manpower and machines and the ratio between the real effective working hours and the planned working hours, respectively (Maasouman and Demirli, 2016).

Next, there are two performance indicators relating to the cost of the plant and their objective is to be minimized. They are "unit cost of manufacturing," which refers to the cost of manufacturing one good unit of final product, and "rework cost," which is the cost in material and in labor for reworking defective products. Following these, there are eight indicators related to quality, for four of which the objective is to be minimized. They are AOQL, number of Andon per department per cause, defect rate and scrap rate. "AOQL" stands for the average outgoing quality limit of the production process. The "number of Andons per department per cause" refers to the number of Andon pulls to stop the production line due to quality problems. This indicator must be monitored by each department and per specific cause (Liker, 2004). "Defect rate" represents the percentage of quality problems that occur throughout the production process and "scrap rate" is the ratio between the scrap in the process (considering all the products that are not acceptable for the customer, and defects in handling and transformation) and the total units produced (Cortes *et al.*, 2016). Next, four performance indicators were identified that are to be maximized: FYP, customer satisfaction, delivery and process capability index. "FYP", the first pass yield, represents the percentage of products that go through the production process the first time with no defects (Liker, 2004). Then, "customer satisfaction," refers to the service level of the degree of fulfilling the customer expectation by providing good-quality products at the needed time. "Delivery" represents the percentage of on-time delivery of good-quality products. Lastly, "process capability index" measures the ability of the production process to meet determined product characteristics (Pearn *et al.*, 1998; Perakis and Xekalaki, 2002).

One performance indicator denoting flexibility is "manufacturing lot size." It is the quantity of products constituting a manufacturing batch and the lower it is, the more flexible the process becomes. Also, six performance indicators were identified related to lead and working times. For the performance indicators of "lead time," "setup time" and "overtime," whose objective is to be minimized, we adapted the definitions from (Santos Bento and Tontini, 2018) as follows: "lead time" is the total time from the moment the customer orders a good until its delivery. They define "setup time" as the time during which production is stopped for a switch-over to a different product. And "overtime" is described as the time worked outside the established

working hours. Also, for the next two indicators in this group, the objective is to be minimized. They are "supplier LT," referring to the total time that passes from the moment an order is placed to the supplier until it is received. "New product launch" is the time employed for launching a new product onto the market. Finally, for this part, the "cycle time" is the time between the exit from production of one unit and the exit of the following one. Then, there are two indicators denoting travel distance: "people travel distance" and "product travel distance." The first refers to the total distance that the logistics operator travels during a shift, while the second is the total distance the product travels into the production chain.

Next is a performance indicator to be maximized, "pull ratio," expressing the proportion of the working stations that use pull (Mirdad and Eseonu, 2015). Then, three indicators to be minimized, the first is "mura," representing the unevenness in production (Cortes *et al.*, 2016). The other two relate to waste: "overproduction," is the quantity of production that is ahead of the demand of the client (Cortes *et al.*, 2016), and "inappropriate processing," which is the unnecessary or incorrect processing, or having a more complex process than needed. Next, three indicators concerning inventory, the two first of which are to be minimized and the last, maximized: "Quantity of finished goods" is the total inventory quantity of the finished products; "WIP inventory" is the work in process inventory; and "inventory turnover ratio" represents the replacement rate of a company's inventory over a given period of time (Santos Bento and Tontini, 2018). Then there are three indicators to be maximized: "cost reduction," an indicator associated with profitability, which seeks the lowest cost of production (Santos Bento and Tontini, 2018); "market share" representing the portion of the market that a given company has; and "production rate," referring to the quantity of finished products that are produced in a given time period. There are two indicators related to reliability: "MTBF," the mean time between failures, which is to be maximized; and "MTTR" to be minimized, which is the mean time to repair when a failure occurs.

Next, there are two performance indicators referring to transfers, the first one, the "transfer lot size," to be minimized, is the quantity produced per transfer batch (Cuatrecasas-Arbós *et al.*, 2015); and the second one, the "number of transfer lots," to be maximized, is the number of lots or batches that are transferred. In addition, eight performance indicators related to human factors were also found, three to be maximized, and five to be minimized. The ones to be maximized are: "employee training & team building," which represents the level of training given to the employees and the team building developed for problem resolution; "employee compensation" is the economic or non-economic incentive given to employees for their commitment and performance; and "job security," which refers to the stability of the job for workers. Then come the definitions of the last 5 performance indicators, all to be minimized. "Knowledge disconnection" represents the lack of shared objectives and culture within the different levels of an organization. "Labor turnover" is the ratio of employees entering and leaving an organization (Cortes *et al.*, 2016). Lastly, as defined by (Maasouman and Demirli, 2016), "safety risk factor" is the ratio between high and medium safety-risk workstations and the total number of workstations; "absenteeism rate," denotes the ratio between the number of man-days lost due to absenteeism and the total of working man-days available; and "ergonomic risk" refers to the ratio between the high and medium ergonomic risk workstations and the total number of workstations.

On the basis of this systematic literature review, on the one hand we have a definition of each of the performance indicators found and, on the other hand, a multifaceted view of performance, thus obtaining a more comprehensive set of performance indicators and their families than in previous studies. Since this literature review covers a variety of relevant articles, such as case studies or surveys to practitioners (Kaur *et al.*, 2016; Maasouman and Demirli, 2016), it gives an overview of the most relevant indicators in practice, as well as articles that identify the most recurrent indicators from the literature (Cortes *et al.*, 2016; Santos Bento and Tontini, 2018; Taggart and Kienhöfer, 2013).

4.2. Performance Indicator Cause-Effect Analysis Supported by DEMATEL

Once we had a clear definition and objective for the performance indicators, following the proposed methodology, the assessment of the influence of each performance indicator over the others was performed. With 50 performance indicators, this meant 2,500 evaluations. Due to the large number of evaluations, the process was divided into different sessions to avoid any bias or misevaluation due to mental workload of experts. In addition to having a clear definition of the performance indicators, it was important to only consider direct influences and assume that the other indicators (besides the two being analyzed at a given moment) were static. From the peer-to-peer comparison of the influence of the performance indicators, a first matrix of 50X50 was obtained, with an excerpt from this matrix being shown in Table III. It shows the influences of the indicators in the rows over the ones in the columns.

	Effectiveness	Efficiency	Labor downtime	Number of NVA motions	Value-added ratio	Equipment downtime	Uptime	Capacity utilization	Rework cost	Unit cost of manufacturing	AOQL
Effectiveness	0	4	0	0	2	0	1	2	2	2	1
Efficiency	0	0	0	0	0	0	0	3	2	4	2

Table III. Excerpt from the performance indicator influence matrix.

Then, after following the different steps in the DEMATEL method, two indexes for each performance indicator were obtained (Table IV). The first index, $r_i + c_i$, measures the intensity of the influence, meaning that the performance indicators for which this index is closer to zero are the ones that have the lowest intensity of influence, and the ones with a higher value have a greater intensity of influence, which in this case were: efficiency, capacity utilization and value-added ratio. The second index, $r_i - c_i$, measures the direction of the influence, thus when positive, it means that it is a "causal" indicator, it has a predominant influence over other indicators. But if on the contrary this index is negative, this indicator is "influenced," the quantity

of indicators that influence it is greater than those it is influencing. In total, there were 29 performance indicators that were causal and 21 that were influenced.

Causal Performance Indicator	R+C	R-C	Influenced Performance Indicator	R+C	R-C
#andon per dept per cause	0.98	0.17	Efficiency	1.69	-0.83
equipment downtime	0.93	0.24	Capacity utilization	1.24	-0.35
Defect rate	0.89	0.17	Value-added ratio	1.14	-0.31
AOQL	0.86	0.19	Cost reduction	1.09	-0.58
Process capability index	0.82	0.28	Lead time	0.88	-0.71
Effectiveness	0.80	0.36	Production rate	0.85	-0.25
FYP	0.75	0.08	Unit cost of manufacturing	0.83	-0.77
Ergonomic risk	0.62	0.10	Mura	0.79	-0.03
Employee training & team building	0.62	0.58	WIP inventory	0.78	-0.34
Labor downtime	0.60	0.07	Inventory turnover ratio	0.76	-0.39
absenteeism rate	0.53	0.25	Uptime	0.73	-0.06
MTBF	0.50	0.46	Speed	0.68	-0.03
Cycle time	0.49	0.12	delivery	0.65	-0.40
Setup time	0.47	0.42	Scrap rate	0.62	-0.22
MTTR	0.45	0.32	Q. finished goods inv	0.52	-0.24
Employee compensation	0.43	0.29	Labor turnover rate	0.50	-0.03
Manufacturing lot size	0.41	0.32	Rework costs	0.43	-0.33
# of NVA motions	0.39	0.11	customer satisfaction	0.42	-0.25
Product travel distance	0.38	0.33	market share	0.33	-0.28
People travel distance	0.37	0.20	Overtime	0.20	-0.06
Pull ratio	0.36	0.36	New product launch	0.18	-0.06
Number of transfer lots	0.32	0.08			
Transfer lot size	0.29	0.11			
Overproduction	0.29	0.18			
Inappropriate processing	0.28	0.23			
Job security	0.26	0.20			
Supplier LT	0.17	0.14			
knowledge disconnection	0.13	0.11			
Safety risk factor	0.13	0.08			

Table IV. Intensity and direction of the influence indexes for influenced and causal performance indicators.

Finally, from the data of the previous table, figure 4 was obtained, in which the color and form of the marker denotes the families of the performance indicators. Here, the X axis represents the intensity of the influence ($r_i + c_i$), and the Y axis the direction of this influence ($r_i - c_i$). In this way, it is possible to have a clearer view of which performance indicators are causal (the ones above the x axis), and which are the ones being influenced (below the x axis). Also, the

indicators that are further to the right are the ones with a higher degree of intensity, meaning that they are the indicators that have the greater number of (causal or influenced) interrelations with other indicators.

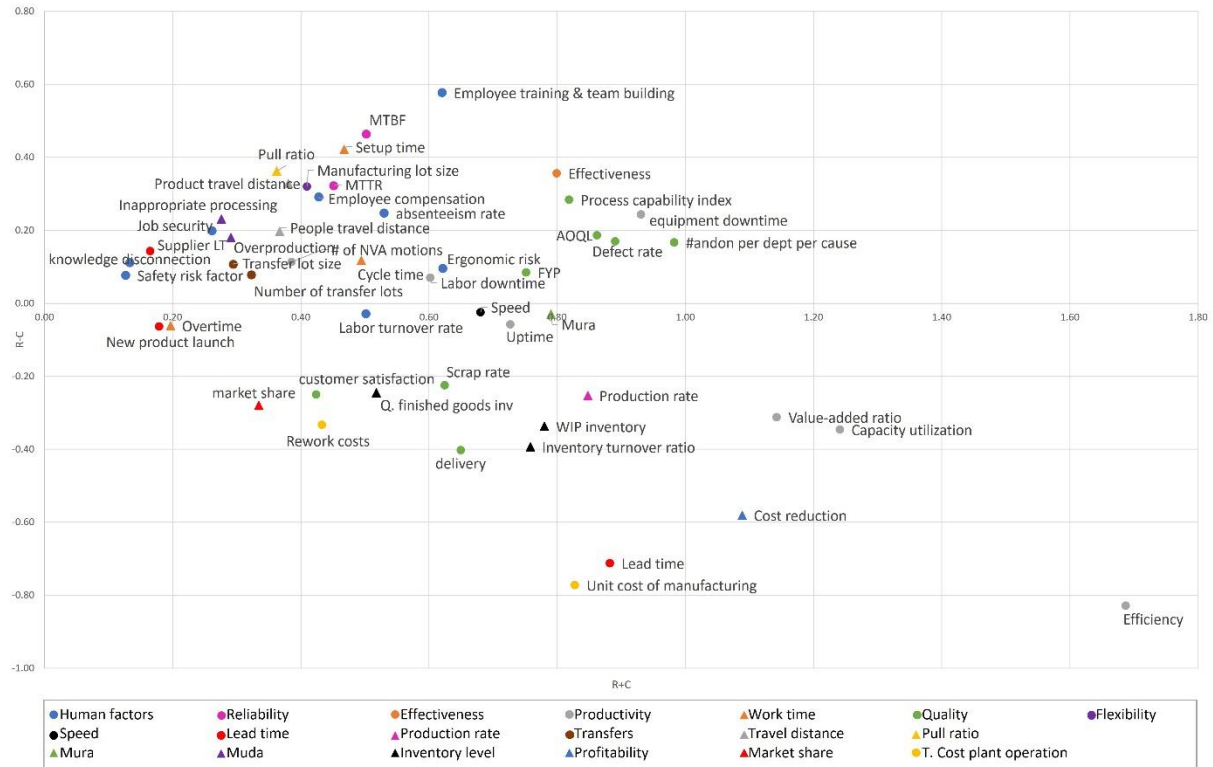


Figure 4. DEMATEL Influence map.

Focusing on the causal performance indicators (the ones in the upper part of the influence map), it is worth highlighting that the most recurrent family is the Human Factor, accounting for 24% of the total causal performance indicators, or 7 out of 29. Those indicators are: Employee training & team building, Employee compensation, Absenteeism rate, Job security, Knowledge disconnection, Ergonomic risk, and Safety risk factor. Which leads us to see and stress the critical influencing role that human factors play in the performance of a company. It is really something worth analyzing and to be considered for effective Lean implementations and improvement strategies. Also, it is possible to observe the distribution of the different families of indicators in this map. Here, it is important to note that families of productivity, quality, inventory levels and cost plant operation, which are among most commonly used or discussed in the literature (Table 1), are not in the majority the most influencing ones. For the Quality family, even though some of its indicators are considered causal, still nearly 38% of them are among influenced indicators, as is the case for “delivery,” with a $r - c$ of -0.4 (see table IV). Regarding inventory levels and cost plant operation indicators, these are entirely in the lower part of the map. And as for productivity, this family is strongly distributed in the lower and right part, indicating that even though it is one of the most discussed in literature, it does not have a high influence over the other indicators and its results are in fact highly influenced by other indicators. For example, taking Efficiency, a performance indicator in this family, it is influenced by 37 indicators and influences 19, suggesting that if a better performance level is

being targeted, those may not be the indicators to start making improvements upon, with those in the upper part of the map being a better option.

Through this influence map, it is possible to have a more comprehensive view of the performance indicators and it becomes easier to distinguish the causal from the influenced indicators. This could be a most useful insight for the decision-making process, as it might help to prioritize the analysis of the performance indicators that are causal, rather than to focus only on the influenced ones. In this way, when a need to improve the level of a given performance indicator arises, it could be possible to analyze the others that might be affecting its results. An example of this can be observed in Figure 5 showing all the influence relationships that the Employee training & team building performance indicator (higher $r_i - c_i$) has over the others, (in this case 36 indicators) suggesting that this should be an indicator worth analyzing and tracking, as its results could influence a great number of indicators.

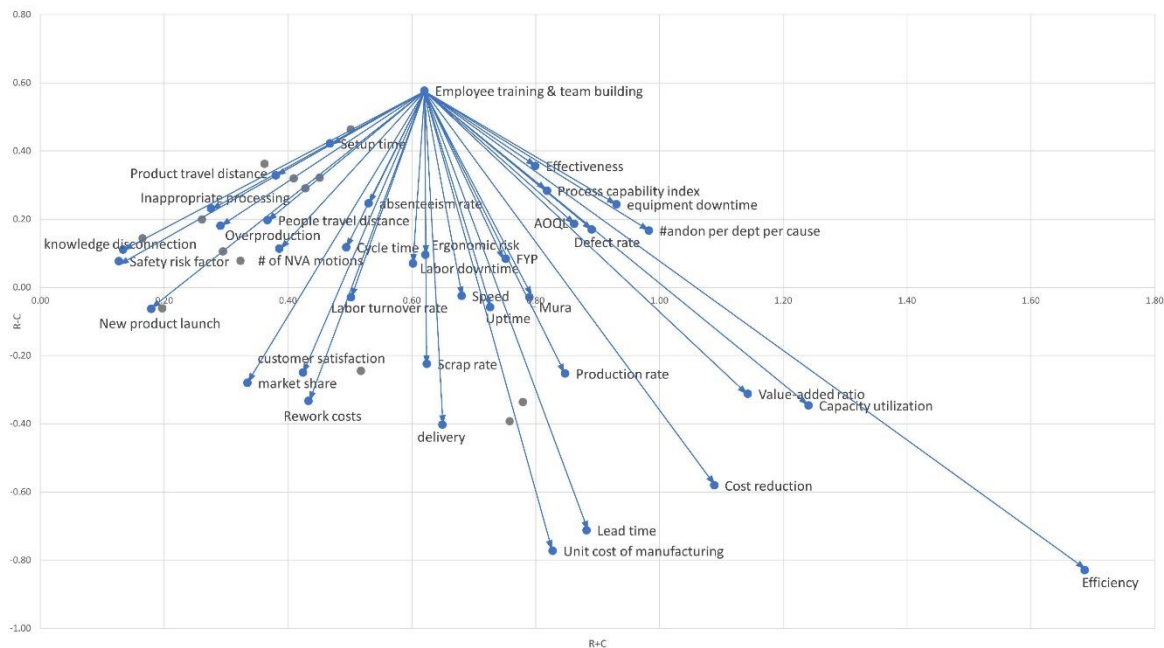


Figure 5. Influences of the Employee training & team building performance indicator.

5. Discussion and Implications

Results of this study aim to contribute to a better understanding of performance indicators in the context of Lean Manufacturing, by proposing an approach for prioritizing them according to their influence relationships, identifying the most influencing indicators and those with a higher level of importance in terms of number of relations with others. Results presented here have two-fold implications, both theoretical and managerial. As for the theoretical implications, the more holistic view of performance and the analysis of the interrelationship between

indicators made in this study could give a clearer and more complete representation of performance than the current fragmented and isolated analysis of single elements, as stated in the studies by Psomas and Antony (2019) and Jasti and Kodali (2015). In this way, it opens the path toward research that explores the representation of performance indicators under the form of a causal system, and therefore, research focused on exploring and validating causal links and their directions, thereby providing a better basis for analyzing the complex situations we have today.

As well, the identification of 19 families and the 50 performance indicators that compose them highlights the multiple facets of performance and its evolving nature, represented by an increasing diversification and the emergence of different families. Based on the literature, this study also provides clarity on the definition of concepts in Lean by providing a concrete definition of performance, as well as for all 50 performance indicators analyzed. This is indeed a key aspect for performance analysis, measurement and strategy. This clarification of the concepts is highly needed, though it is still missing in most cases, even within the same organization, as stated by Kovács et al. (2020). This clarification could be a useful insight for research on the effects or implications of Lean implementations on performance indicators.

Furthermore, results from the analysis of the influence relationship between the indicators emphasized the importance of not analyzing them solely in isolation. This highlighted the great influence of the performance indicators related to the Human Factors family, as these were the most predominant causal indicators, implying that they are worth analyzing in improvement implementations, as the human factor has lately been suggested to be one of the major determinants of success or failure in performance improvements in Lean (Henao *et al.*, 2019), and even recent studies suggest an important possible impact of human factor dimensions on companies' performance (Minovski *et al.*, 2021). Results also show that families of indicators currently within the most used in literature do not stand out in majority among casual indicators, but instead have a higher tendency to be influenced.

Also, as previously mentioned in section 2.2, there are various expected benefits when implementing Lean, namely improved quality, lower cost, lower inventory levels, reduction in lead time, processing time and cycle time, better morale among workers, better safety levels in production, and empowerment of teams (Bhamu and Sangwan, 2014; Liker and Morgan, 2006). It is therefore also interesting to analyze where the indicators related to those expected benefits are positioned. The first five are categorized as influenced, meaning they are mainly the result of improvements in other indicators, and thus, it may make improving their levels more complex than it seems. The last four benefits are related to indicators that are mostly causal.

Regarding practical implications, the authors believe the results of this study could be used by managers to monitor performance and analyze Lean implementations more effectively. Given the challenges of information availability and the need to rationalize resources and time that companies are constantly faced with, it becomes highly relevant for them to have the means to effectively prioritize their performance indicators. Through analysis of interrelationships between indicators, managers could have more clarity and be aware of the importance of choosing causal indicators over influenced ones to drive performance improvement more effectively and efficiently. So, by having a clearer view of which indicators to focus on, it could

help managers better determine which key performance indicators should be displayed on a dashboard, and which indicators are key to making more accurate decisions. It may also help improve the process of identifying areas in which to develop transformation or improvement strategies for enhancing the organization's performance. It may also allow for better monitoring and follow-up of improvement initiatives and detect or prevent potential unsuccessful implementations in time.

More precisely, the methodology proposed in this article will allow managers to analyze the network of performance indicator influences, and to see them as nodes. An example is given in Figure 6. Each node is connected on one side with the performance indicators that influence it, making it possible to look further and consider more effective improvement actions. On the other side, the node is connected to the indicators on which it exerts direct influence, thus enabling us to evaluate the possible effects on them by modifying the level of the indicator node. Consequently, when developing an improvement initiative or project, the performance indicators should no longer be considered in an isolated manner. Throughout this study, we have proposed a broader view of a network or system with influences, under which improvement scenarios can be built. The results could therefore serve as insight for complementing and aiding in the prioritization process of studies focused on assisting managers in the implementation of improvement projects (Moya *et al.*, 2019).

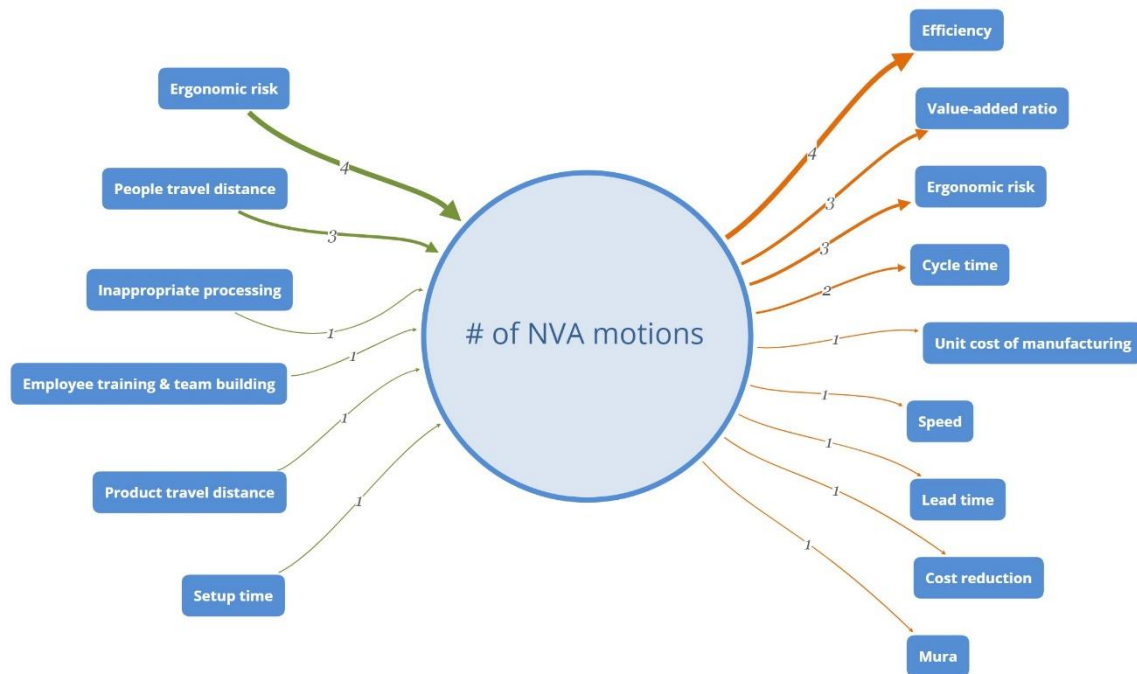


Figure 6. Diagram of a network node for "number of NVA motions" indicator.

Performance improvement interventions usually start by selecting a performance indicator for a given problem, identifying the root causes of that problem and then acting on these causes to improve the chosen indicator (Liker, 2004). Our work shows that this approach may be unsuccessful if the selected performance indicator is at the same time being influenced by others. Seeking to have a more effective analysis, we therefore suggest to look for the main

causal indicators influencing the ones we are interested in improving prior to analyzing the root causes. As illustrated in Figure 6, this means that by acting simultaneously on the root causes of all seven indicators (the node and the six causal indicators), we could have a greater impact in reducing the # of NVA motions instead of only analyzing the punctual indicator itself. We suggest not to act in an isolated basis, but with a systemic view of the indicators, establishing a methodological approach that allows to identify the most important and relevant ones as proposed in this study. Subsequently, the proposed study has the potential to set the bases and be a reference framework for enhancing the decision-making process and for developing frameworks for more effectively improve the performance in various industries.

6. Conclusions, Limitations and Directions for Future Research

Through this exploratory research study, the intention is to contribute to the discussion of scientific research on the subject of performance in Lean, and more specifically on the influence interrelationships between its performance indicators. This study contributes to the research on Lean by proposing an approach for analyzing performance in a more comprehensive way by prioritizing its indicators. For this purpose, this study was structured in two parts. In the first, the performance indicators were gathered from the literature, resulting in a final set of 50 indicators, providing a more integrated and updated set of indicators than previous studies, while covering 19 different families of indicators. Then, in the second part, an analysis to prioritize the performance indicators was performed based on elicitation of the interrelationships between them, resulting in 29 causal and 21 influenced performance indicators.

The significance of this study lies in the following points. First, results from this study suggest the importance of reevaluating the relevance of classic indicators in Lean, and emphasizing the use of causal indicators to improve performance more effectively by acting on the causes (causal indicators) and not on the consequences (influenced indicators). Additionally, the important role of causal indicators linked to the human factor was evidenced, implying the potential to continue research in exploring the inclusion of this family of indicators in the measurement of overall performance. Moreover, in this study, the complex relationships among indicators were shown, suggesting the importance of analyzing performance indicators as part of a whole system, instead of as isolated factors. Finally, the proposed approach and results have the potential to aid in the decision-making process in practical implementations to better track performance while focusing on causal indicators, as well as to serve as an important basis for future research to analyze success and failure cases in a more complete and systemic way.

However, this research work also has certain limitations. The search terms applied for developing the literature review on the performance indicators in Lean may have been somewhat restrictive, leaving aside keywords such as Lean performance or even just performance in general, which might have led to the identification of more performance

indicators. Another limitation the authors have considered is that this study was centered on the manufacturing sector. Nevertheless, the authors encourage researchers to expand this study not only to case studies in manufacturing, but also to other sectors, as they believe it could be generalized. This work is generalizable since the profile of the experts involved is mainly focused on Lean methodology in general and not only on a specific sector, which gives a transversal nature to the results. More importantly, given that through this study an approach is proposed to change from an isolated performance indicator analysis, toward a more comprehensive one, by prioritizing the performance indicators with regard to their interrelationships (based on the identification of a set of performance indicators and subsequently the analysis of their influences through the DEMATEL method), all the steps can be adapted to other sectors by revising the list of performance indicators applicable to a specific sector, as there could be changes depending on the context.

Results from this study may lead to promising perspectives. First, the analysis of influence relationships could be further extended toward Lean tools, leading toward a holistic view of Lean, while giving better clarity on the impact of Lean tools implementation over performance indicators. This would help effectively determine the most appropriate tools to apply when seeking to improve one or several indicators. Second, it would also be very interesting to further deepen the analysis of the influences by determining which have positive and which have negative influences, and via a systemic approach, to conduct causal loop analysis, identify existing reinforcing closed cycles, and simulate the impact evolution of a given indicator on the others. Also, for future studies, a complementary analysis based on PCA (principal component analysis) could be developed to validate the established links of cause and effect, and thus define the correlation between the indicators. Finally, the relevance of performance indicators is even more worthy of study in the new context of Industry 4.0. New technologies have the potential to bring challenges and advantages, and with them the possibility to improve the process of gathering data, to have access to a greater amount of data, and so the possibility to open the way to new indicators and the importance of seeing performance indicators as a system, while focusing on causal indicators.

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