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A BIBLIOMETRIC ANALYSIS ON THE RELATIONSHIPS BETWEEN THE USE OF LEAN TOOLS AND TECHNOLOGIES 4.0 ON THE PRODUCT DEVELOPMENT PROCESS

UMA ANALISE BIBLIOMETRICA SOBRE AS RELAÇÕES ENTRE A UTILIZAÇÃO DAS FERRAMENTAS LEAN E AS TECNOLOGIAS 4.0 SOBRE O PROCESSO DE DESENVOLVIMENTO DE PRODUTOS

UN ANÁLISIS BIBLIOMÉTRICO SOBRE LAS RELACIONES ENTRE EL USO DE HERRAMIENTAS LEAN Y TECNOLOGÍAS 4.0 EN EL PROCESO DE DESARROLLO DE PRODUCTOS

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PALAVRAS-CHAVE: Processo de Desenvolvimento de Produto; Indústria 4.0; *Smart Manufacturing*; *Lean Manufacturing*; *Lean Production*.

PALABRAS CLAVE: *Proceso de Desarrollo de Producto; Industria 4.0; Smart Manufacturing; Lean Manufacturing; Lean Production.*

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ABSTRACT

The Product Development Process (PDP) takes place and depends on a series of integrated steps, incorporating different technologies and adapting to production standards. In this sense, the use of Lean tools can help to continuously improve processes in a systematic way, ensuring that all these processes really add value to the product. Allied to this, the implementation of Industry 4.0 technologies can help improve these production processes, enabling companies to obtain competitive advantages. Therefore, this research aims to map, correlate and analyze the existing scientific knowledge on PDP, Industry 4.0 and Lean Manufacturing. For this, searches will be carried out to retrieve articles from the Scopus database, and the data will be processed with the bibliometrix software. The results obtained show that there is a greater proximity between PDP and Lean Manufacturing, connected *a priori* and with a later connection with Industry 4.0. With this, it is possible to affirm that researchers and managers have a view that Lean tools are directly connected to the PDP, continuously helping for its success, while Industry 4.0 technologies are usually considered in a second moment regarding the execution of the PDP.

RESUMO

O Processo de Desenvolvimento de Produtos (PDP) ocorre e depende de uma série de etapas integradas, incorporando diversas tecnologias e adequando-se aos padrões de produção. Nesse sentido, a utilização de ferramentas do Lean pode auxiliar a melhorar continuamente os processos de forma sistemática, garantindo que todos esses processos realmente agreguem valor ao produto. Aliado a isso, a implementação de tecnologias da Indústria 4.0 pode auxiliar no aperfeiçoamento desses processos produtivos, possibilitando a obtenção de vantagens competitivas às empresas. Diante disso, esta pesquisa tem por objetivo mapear, correlacionar e analisar o conhecimento científico existente sobre os temas PDP, Indústria 4.0 e Lean Manufacturing. Para isso, serão realizadas buscas para recuperação de artigos da base de dados Scopus, e os dados serão processados com o software bibliometrix. Os resultados obtidos mostram que existe uma maior proximidade entre o PDP e o Lean Manufacturing, conectados à priori e com uma conexão posterior com a Indústria 4.0. Com isso é possível afirmar que os pesquisadores e gestores tem uma visão que as ferramentas do Lean estão diretamente conectadas ao PDP, auxiliando continuamente para o seu sucesso, enquanto que as tecnologias da Indústria 4.0 costumam ser consideradas em um segundo momento quanto da execução do PDP.

RESUMEN

El Proceso de Desarrollo de Producto (PDP) ocurre y depende de una serie de pasos integrados, incorporando diferentes tecnologías y adaptándose a los estándares de producción. En este sentido, el uso de herramientas Lean puede ayudar a mejorar continuamente los procesos de forma sistemática, asegurando que todos estos procesos realmente agreguen valor al producto. Unido a esto, la implementación de tecnologías de Industria 4.0 puede ayudar a mejorar estos procesos productivos, permitiendo a las empresas obtener ventajas competitivas. Por tanto, esta investigación pretende mapear, correlacionar y analizar el conocimiento científico existente sobre PDP, Industria 4.0 y Lean Manufacturing. Para ello, se realizarán búsquedas para recuperar artículos de la base de datos Scopus, y los datos serán procesados con el software bibliometrix. Los resultados obtenidos muestran que existe una mayor proximidad entre PDP y Lean Manufacturing, conectado a priori y con una conexión posterior con la Industria 4.0. Con esto, es posible afirmar que investigadores y gestores tienen la visión de que las herramientas Lean están directamente conectadas al PDP, ayudando continuamente para su éxito, mientras que las tecnologías de la Industria 4.0 suelen ser consideradas en un segundo momento respecto a la ejecución del PDP.

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INTRODUCTION

The development of advanced electronic, information and manufacturing technologies is changing the productive processes of companies (Santos et al., 2020), transforming traditional manufacturing into intelligent manufacturing, increasing the competitiveness and flexibility of organizations (Hughes et al., 2020; Maddikunta et al., 2022). In this sense, Industry 4.0 is a way for companies to promote competitive advantages through the application and integration of new technologies, such as *the Internet of Things* (IoT), *Big Data Analytics*, *Artificial Intelligence*, *Deep Learning* and others (Contreras et al., 2017). The implementation of these technologies aims to improve industrial performance to achieve productivity, flexibility, competitiveness, sustainability and customization in manufacturing (Dalenogare et al., 2018).

This quest to increase business competitiveness also leads to a greater focus on the role of organizational efficiency in business performance. This has contributed to the popularity of different management theories in the industrial field, including Lean Manufacturing, which is a systematic approach to eliminate processes without added value based on continuous improvement (Womack & Jones, 2003). Lean is a continuous process of pursuit of perfection that involves everyone in the organization, including the owners, with the vision of improving competitiveness (Achanga et al., 2006). Also, modifying production processes seeking continuous improvement through the elimination of activities that do not add value to the product (Venugopal & Saleeshya, 2019), which are the first seven Lean wastes identified in the literature are: defects, overproduction, waiting time, transport, inventory, movement of people or materials and extra processing.

In this sense, new products are demanded and developed to meet specific market segments, incorporate different technologies and integrate with other products and uses, in addition to adapting to new standards and legal restrictions (Rosenfeld et al., 2010). Really understanding what drives a customer to purchase a product should be the main concern during the Product Development Process (PDP) (Fuchs & Gutmann, 2022). Additionally, digitalized product development processes allow us to face four major challenges: the need for multi-objective optimization, the need to allow multi-domain simulation, the need to explore different families of topological products and the need to deal with constantly changing environments (Glönkler et al., 2022). Product development involves monitoring the product after launch, in order to make the necessary changes in specifications, plan the product's discontinuation in the market and incorporate the lessons learned throughout the product's life cycle (Amaral et al., 2006).

The use of hybrid approaches to improve production processes has shown good results in manufacturing environments (Tripathi et al., 2022). In view of this, this research seeks to concatenate the concepts of PDP, Industry 4.0 and Lean Manufacturing, bringing managerial insights on the joint use of these concepts in industrial processes. Thus, the objective of this article is to map, correlate and analyze the existing scientific knowledge on PDP, Industry 4.0 and Lean Manufacturing.

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The remainder of the article is organized as follows: Section 2 details the methodological procedures, Section 3 presents the results, Section 4 presents the discussions and academic and practical implications, and Section 5 brings the article's conclusions.

METHODOLOGICAL PROCEDURES

Mapping publications, authors and literature growth patterns is an important step in the discussion and construction of knowledge on a topic (Olczyk, 2016). This mapping can be performed with the aid of bibliometrics (Martínez et al., 2015), which uses analytical tools to evaluate authors and subject in a clear and objective way (Abramo et al., 2014). Thus, considering the objective of this research focused on the analysis of the literature on topics such as Industry 4.0, Lean and the Product Development Process, a previous search was carried out in the Scopus database, seeking articles that addressed the three themes concomitantly, but only 4 articles were found. In this way, it was defined that, in order to enable a mapping of the literature addressing the three themes, the searches were carried out in pairs, searching by Industry 4.0 and Lean, then by Industry 4.0 and PDP and by Lean and PDP, enabling the realization of bibliometric connections about the topics in question. Regarding time, it was surveyed every year, as there is a large time lapse between the emergence of the concept of Lean Manufacturing and Industry 4.0, which led to a need to understand the origins of these concepts and how they are related in the present. Thus, Table 1 presents the search terms and filters to be used to perform the retrieval of articles in this research.

Table 1. Search filters.

Filter	Scopus Database
Document Type	Articles
Search in	Title, abstract or keywords
Search Area	All
Years	All years
Search Terms	*"Industry 4.0" OR "smart manufacturing*" AND "lean";* *"Industry 4.0" OR "smart manufacturing*" AND "product development process*"* *"lean" AND "product development process*"*

Source: Authors (2022).

Searches were performed in November 2022 and, initially, the amounts of articles retrieved for each combination of search terms were as follows:

- "industry 4.0" OR "smart manufacturing*" AND "lean": 741 articles.
- "industry 4.0" OR "smart manufacturing*"AND "product development process*": 70 articles.
- "lean" AND "product development process*": 233 articles.

Articles were merged to exclude duplicates, resulting in a total of 1029 articles. The metadata of these articles was downloaded in *. bib so that they could be processed with the bibliometrix software, which enables bibliographic analyses, co-citations, collaboration networks, word co-occurrences and author networks (Aria & Cuccurullo, 2017).

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In bibliometrix software, the following analyzes were performed:

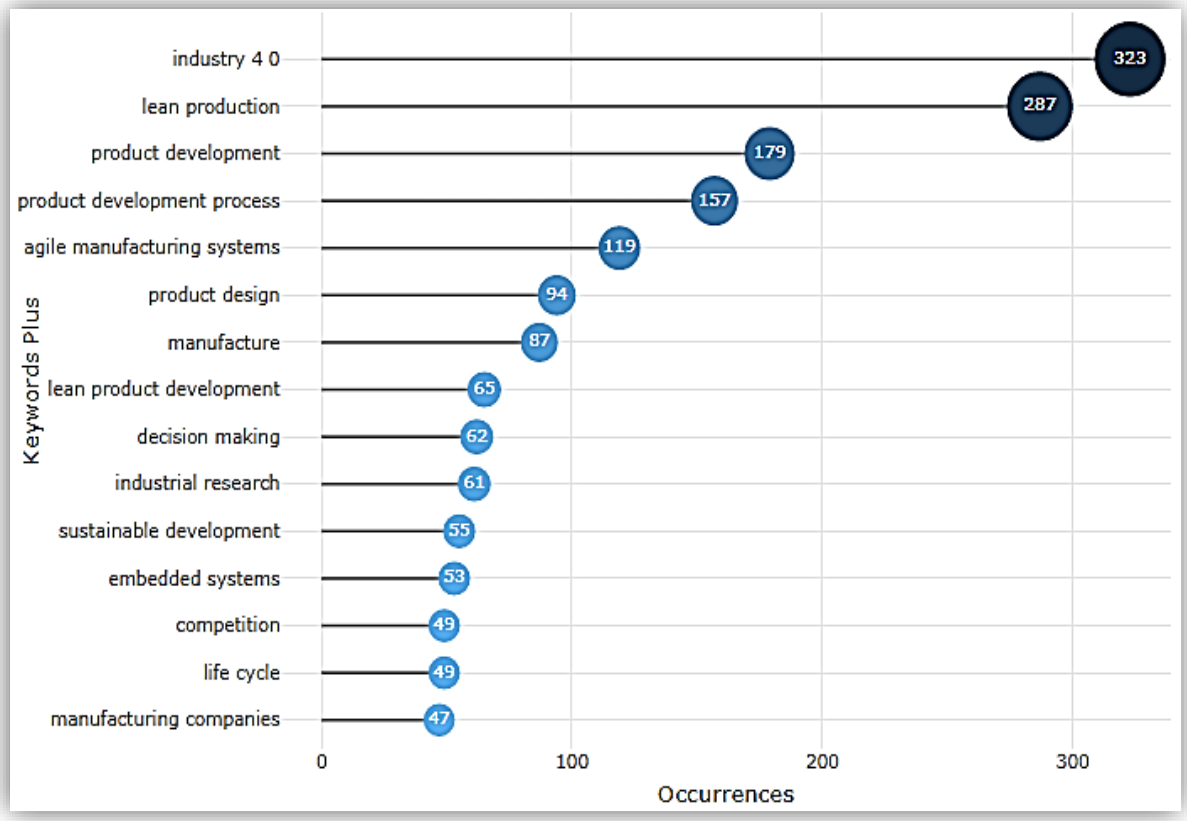
- Terms with the highest number of occurrences in retrieved articles;
- Grouping of the most frequent terms in a cloud of words;
- Network of co-occurrence of terms showing the links between them;
- Dendogram to demonstrate the level of proximities between terms;
- Concept map from a multivariate analysis.

With these analyses, it was possible to obtain relevant insights into the existing relationships between the use of Lean Tools and Industry 4.0 technologies, and how this has impacted the Product Development Process in manufacturing companies.

RESULTS

In this section, the results of the analyzes obtained through the bibliometrix will be presented. The first analysis, presented in Figure 1, is that of the most frequent terms in the 1029 retrieved articles, where it can be seen that the main themes of this article are also the most frequent: industry 4.0, lean production, product development and product development process. In the sequence, it is possible to verify the existence of terms that suggest the connection of these main themes, such as “lean product development”, “agile manufacturing systems” and “product design”.

Figure 1. Most frequent terms.



Source: Authors (2022), through bibliometrix software.

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Figure 2 brings a cloud of words, presenting in a larger format and with more density those with greater relevance in the retrieved articles.

Figure 2. Word cloud.

Source: Authors (2022)

Figure 3 presents a view of the co-occurrence of words in retrieved articles. In this figure it is possible to see the formation of two larger groups (in red and blue) and a smaller group (in green). In the group in red, terms related to Industry 4.0 and Lean Manufacturing predominate, such as “industry 4.0”, “lean production” and “agile manufacturing systems”, while in the blue group PDP-related terms predominate, such as “product development process”, “product development” and “product design”. The figure shows that there is a connection between the red group and the blue group, with the main point of connection between the groups going through the term lean production, showing that there is a greater proximity between the use of Lean tools and the PDP. However, there is a strong connection between Industry 4.0 and Lean, showing that there is consistent research on the use of the two concepts together, which can be a way for companies to succeed when implementing the PDP.

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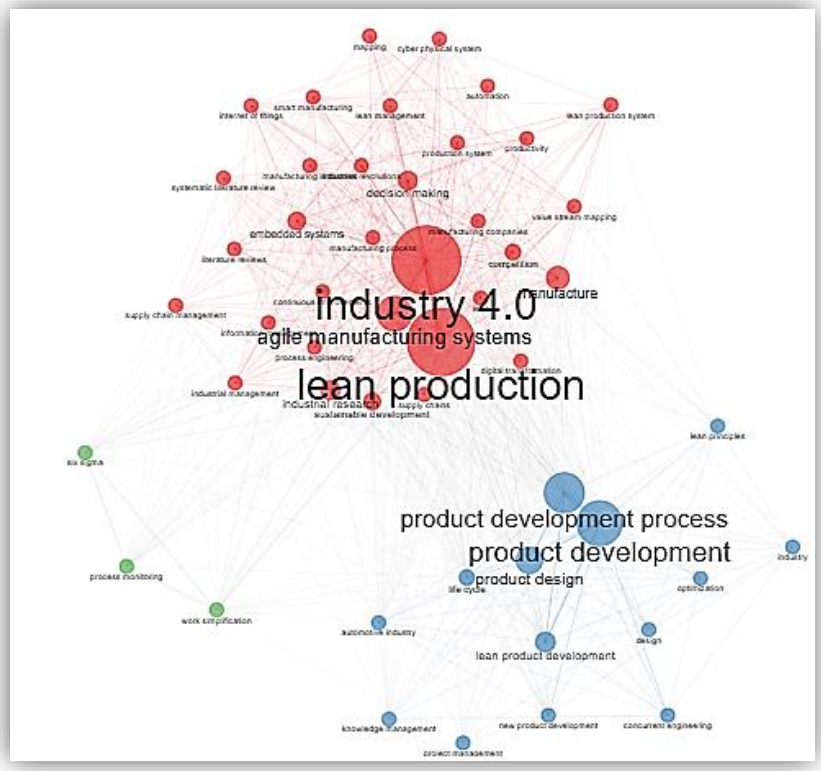
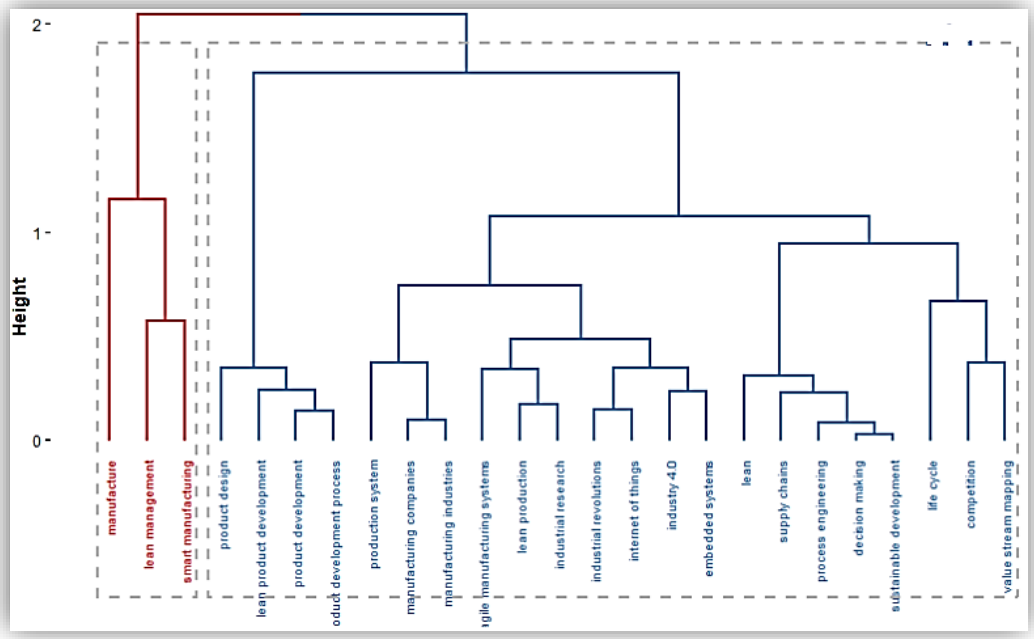
Figure 3. Word co-occurrence analysis.



Source: Authors (2022)

Figure 4 presents a dendogram with the level of proximity and similarity between the terms. In this figure it is evident the formation of two groups, with a separation between the PDP before the lean production and Industry 4.0, and a closer connection between PDP and lean can be seen in production, with a later connection to the term “industry 4.0”.

Figure 4. Proximity dendrogram of terms.



Source: Authors (2022)

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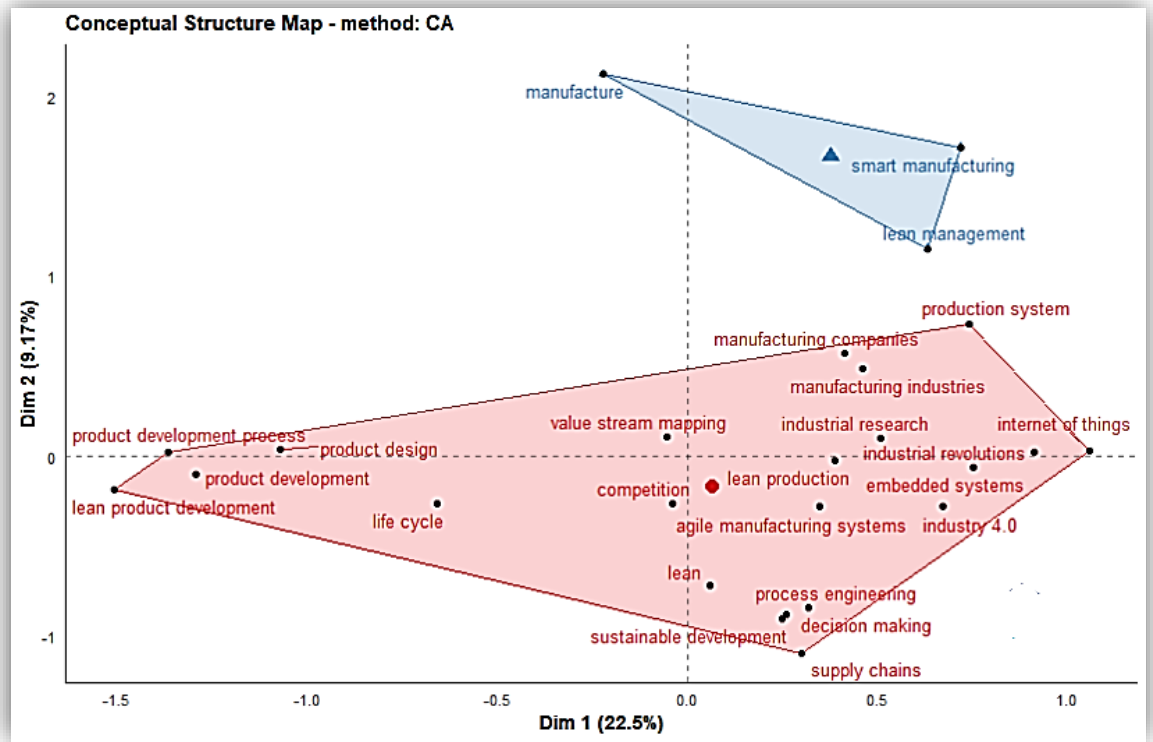
Figure 5 brings a PCA analysis, where the first two dimensions are presented, explaining 31.67% of the relationships between terms found in the articles. In this figure, two clusters appear again, however, in this construction the terms related to the PDP appear positioned more closely to the Lean terms.

Figure 5. Conceptual map of terms.



Source: Authors (2022)

DISCUSSION OF THE RESULTS

As industry 4.0 brings with it many new technologies and when these begin to be used more effectively, there is also a development of lean manufacturing that makes companies start to carry out their activities in a much more agile and precise way. As the current market is increasingly competitive, companies must always try to offer the best product at the lowest possible price.

Lean Manufacturing is one of the most popular management philosophies aimed at reducing costs and increasing efficiency. The introduction of Industry 4.0 and its integration with Lean introduced the hybrid term “Lean 4.0” (Mayr et al., 2018).

Combining Industry 4.0 practices with Lean concepts, it can be said that there is an increasingly effective search for improvement. As Lean is about doing more with less, the automation and integration of technological processes that are increasingly contributing to this purpose.

One of the examples that we can cite between Industry 4.0 and Lean is automation with robotics that have traditionally been used on the factory floor, but in recent years, new and more advanced solutions have been introduced to replace human work or cooperate with human employees to improve productivity and reduce errors (Bahrin et al., 2016).

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In turn, Sanders et al. (2017) conclude that to facilitate the integration of Lean and Industry 4.0 technologies in the smart factories of the future, it will be necessary to rethink, for example, such important concepts of lean manufacturing as “takt time”, among other issues.

As far as lean practices are concerned, although their effect has not been what we had hoped, managers should not forget Bill Gates' comment that if automation is applied to an efficient operation, it will increase efficiency. However, if it is applied to an inefficient operation, it will increase inefficiency (Krishnan, 2013). This concept emphasizes the unavoidable fact that an inefficient process, even when automatic, is still inefficient and is essentially automation becomes a kind of waste (Nicoletti, 2013).

Having companies on the path of industry 4.0 and with Lean Manufacturing already ingrained, can help improve their product development to achieve, often, a certain efficiency in market performance with speed and agility.

Lean is often associated with the production of physical products, where the goal is repetitive operations that achieve high-quality results with minimal cost and time, i.e., maximizing customer value while minimizing waste (JP Womack et al., 2007). Lean product development is a philosophy fully suited to improving efficiency in product development based on customer value (Synnes & Welo, 2016).

Design is often constrained by the manufacturing method, so a new manufacturing technology will create a technological boost in design. One example is 3D printed parts, which can allow lighter parts and better material utilization if the design fully utilizes the processing process opportunities (Synnes & Welo, 2016).

For a company to convert its technology and ideas into new products that meet customer requirements and the company's strategic objectives, it needs a product development system that effectively integrates people, processes and technology (Gagné, 2018; Kennedy, 2004). Methods that lead to shorter development time, faster product realization, reduced product development cost, and improved quality should be taken advantage of.

One of the technologies of Industry 4.0 is IoT that can help in the development process, based on Lean concepts, through the collection of product usage data. This allows the development team to gain valuable insights into how the product is used by the customer and which features are most valued. This information can be used to optimize the product design and improve its usability (Santos et al., 2020). It also allows the development team to monitor processes and equipment in real time, improving production efficiency and gaining valuable insight into customer product improvement.

Automation is also one of the Industry 4.0 technologies, in which one of its main contributions to the product development process, based on Lean concepts, is the reduction of wasted time and resources (Dalenogare et al., 2018). With automation, many manual tasks can be automated, reducing the need for human intervention. This allows the development team to

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focus on more strategic tasks with greater added value, such as identifying opportunities for process improvement.

Artificial Intelligence, which is also one of the Industry 4.0 technologies, can be used to improve product quality, based on Lean concepts. For example, machine learning algorithms can be used to analyze production data and detect product defects in real time (Sartal et al., 2022). This allows the production team to quickly identify and correct any issues that may arise, preventing defective products from being delivered to customers. Artificial Intelligence can also be used to customize the product based on customer preferences. For example, Artificial Intelligence can analyze data from customer purchase history and preferences to suggest products that meet their specific needs.

As another Industry 4.0 technology, Big Data can be used to forecast market demand and adjust production accordingly. This can help the product development team to better plan production and avoid over-producing unsold products along with Lean concepts (Yin et al., 2017). This technology can also be used to analyze product performance data and identify opportunities for improvement. For example, the product development team can analyze product usage data and customer feedback to identify common issues and areas for improvement.

Therefore, from a business point of view, companies face many difficulties when developing new products, mainly with project quality problems, long lead times and very high development costs. And it is in this scenario that a more efficient product development system with less waste becomes quite strategic.

And also, from the practical point of view, industry 4.0 and Lean Manufacturing can lead companies to accelerated advances in the design of new products, as well as significant reductions in time and expenses associated with activities such as maintenance, product recall, compliance regulatory requirements and the reformulation of manufacturing processes.

CONCLUSION

The objective of this article was to map, correlate and analyze the existing scientific knowledge on PDP, Industry 4.0 and Lean Manufacturing. Bibliometric analyzes were performed using bibliometrix software with the metadata of articles retrieved from the Scopus database. These analyzes provided relevant information on which terms are most used in research and which terms have the greatest relationship and similarity in research on Lean Manufacturing, Industry 4.0 and PDP. From this, it became evident that there is a greater proximity between the use of Lean tools and the PDP, with Industry 4.0 technologies exerting a second influence on the PDP.

From a practical point of view, considering the systemic approach, this research brought new contributions by presenting new insights for companies regarding the PDP, showing the importance of using Lean Manufacturing methodologies and Industry 4.0 technologies to obtain improvements in the PDP and in market performance. It can be seen that in the results

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of this research there is a distance between Industry 4.0, Lean Manufacturing and PDP, and that the article sought to fill this gap, promoting the idea of practical relevance, informing that it is necessary to discuss more about the impact of the adoption of methodologies of Lean Manufacturing and also of Industry 4.0 technologies on the PDP.

This research was limited to analyzing the articles retrieved from the Scopus database using the terms in pairs, which made it necessary to merge them into a single list to enable a broader view of the use of these concepts in scientific research. As future research, it is intended to study the effects and influences of using Lean tools and Industry 4.0 technologies on the PDP.

BIBLIOGRAPHICAL REFERENCES

Abramo, G., Costa, C., & D'Angelo, C. A. (2014). A multivariate stochastic model to assess research performance. *Scientometrics*, 102(2), 1755–1772. https://doi.org/10.1007/s11192-014-1474-5

Achanga, P., Shehab, E., Roy, R., & Nelder, G. (2006). Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management*, 17(4), 460-471. https://doi.org/10.1108/17410380610662889/FULL/XML

Amaral, D. C., Toledo, J. C., Silva, S. L., Alliprandini, D. H., & Scalice, R. K. (2006). *Gestão de Desenvolvimento de Produto: uma referência para a melhoria do processo.* Saraiva.

Aria, M. & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959-975. https://doi.org/10.1016/J.JOI.2017.08.007

Kamarul Bahrin, M. A., Othman, M. F., Nor Azli, N. H., & Talib, M. F. (2016). Industry 4.0: a review on industrial automation and robotic. *Jurnal Teknologi*, 78(6-13). https://doi.org/10.11113/jt.v78.9285

Contreras, J. D., David, J., & Pastrana, D. (2017). Developing of Industry 4.0 Applications. *International Journal of Online Engineering*. https://doi.org/10.3991/ijoe.v13i10.7331

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, 204, 383-394. https://doi.org/10.1016/J.IJPE.2018.08.019

Santos, L. M. A. L., dos., da Costa, M. B., Kothe, J. V., Benitez, G. B., Schaefer, J. L., Baierle, I. C., & Nara, E. O. B. (2020). Industry 4.0 collaborative networks for *industrial performance. Journal of Manufacturing Technology Management*. https://doi.org/10.1108/JMTM-04-2020-0156

Fuchs, C. & Gutmann, T. (2022). How Technical Market Segmentation Can Help Build Products Your Customers Really Need. I*EEE Engineering Management Review*, 50(1), 17-19. https://doi.org/10.1109/EMR.2022.3140715

Gagné, D. (2018). La révolution 4.0 : le retour du pendule pour les travailleurs et travailleuses du XXIe siècle? Ad Machina, 2, 52-72. https://doi.org/10.1522/RADM.NO1.914

Glönkler, V., Reick, B., Stetter, R., Till, M., & Pfeil, M. (2022). A Contribution to Sustainable Product Development Using the Example of Battery Electric Vehicles. *Sustainability*, 14(7), 3729. https://doi.org/10.3390/SU14073729

Hughes, L., Dwivedi, Y. K., Rana, N. P., Williams, M. D., & Raghavan, V. (2020). Perspectives on the future of manufacturing within the Industry 4.0 era. *Production Planning & Control - The Management of Operations,* 33(2-3), 138-158. https://doi.org/10.1080/09537287.2020.1810762

Kennedy, M. N. (2004). The Toyota product development system. *Machine Design*, 76(9), 152. https://doi.org/10.4324/9781482293746/TOYOTA-PRODUCT-DEVELOPMENT-SYSTEM-JAMES-MORGAN-JEFFREY-LIKER

Krishnan, K. (2013). *Data warehousing in the age of big data*. A volume in MK Series on Business Intelligence. Elsevier. ISBN 978-0-12-405891-0. https://doi.org/10.1016/C2012-0-02737-8

Maddikunta, P. K. R., Pham, Q. V., B, P., Deepa, N., Dev, K., Gadekallu, T. R., Ruby, R., & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, 26, 100257. https://doi.org/10.1016/J.JII.2021.100257

Martínez, M. A., Cobo, M. J., Herrera, M., & Herrera-Viedma, E. (2015). Analyzing the Scientific Evolution of Social Work Using Science Mapping. *Research on Social Work Practice*, 25(2), 257-277. https://doi.org/10.1177/1049731514522101

Mayr, A., Weigelt, M., Kühl, A., Grimm, S., Erll, A., & Cirp, M. P. (2018). Lean 4.0-A conceptual conjunction of lean management and Industry 4.0. Procedia CIRP, 72, 622-628.

Nicoletti, B. (2013). Lean and automate manufacturing and logistics. *IFIP Advances in Information and Communication Technology*, 415, 278-285. https://doi.org/10.1007/978-3-642-41263-9_34/COVER

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Olczyk, M. (2016). Bibliometric approach to tracking the concept of international competitiveness. *Journal of Business Economics and Management*, 17(6), 945-959. https://doi.org/10.3846/16111699.2016.1236035

Rosenfeld, H., Forcellini, A. F., Amaral, D. C., Toledo, J. C., Silva, S. L.,da, Alliprandini, D. H., & Sacalice, R. K. (2010). *Gestão de Desenvolvimento de Produto - Uma referência para melhoria dos processos*. Saraiva.

Sanders, A., Karthik, K. R., Redlich, T., & Wulfsberg, J. P. (2017). Industry 4.0 and lean management – synergy or contradiction?: A systematic interaction approach to determine the compatibility of industry 4.0 and lean management in manufacturing environment. *IFIP Advances in Information and Communication Technology*, 514, 341-349. https://doi.org/10.1007/978-3-319-66926-7_39/FIGURES/3

Sartal, A., Llach, J., & León-Mateos, F. (2022). "Do technologies really affect that much? exploring the potential of several industry 4.0 technologies in today's lean manufacturing shop floors". *Operational Research,* 22(5), 6075-6106. https://doi.org/10.1007/S12351-022-00732-Y/TABLES/5

Synnes, E. L. & Welo, T. (2016). Enhancing Integrative Capabilities through Lean Product and Process Development. Procedia CIRP, 54, 221-226. https://doi.org/10.1016/J.PROCIR.2016.05.090

Tripathi, V., Chattopadhyaya, S., Mukhopadhyay, A. K., Sharma, S., Li, C., Singh, S., Saleem, W., Salah, B., & Mohamed, A. (2022). Recent Progression Developments on Process Optimization Approach for Inherent Issues in Production Shop Floor Management for Industry 4.0. *Processes*, 10(8), 1587. https://doi.org/10.3390/PR10081587

Venugopal, V. & Saleeshya, P. G. (2019). Manufacturing system sustainability through lean and agile initiatives, 12(3), 159-173. https://doi.org/10.1080/19397038.2019.1566411

Womack, J. & Jones, D. (2003). *Lean Thinking*. Simon and Schuster.

Womack, JP, Jones, D., & Roos, D. (2007). *The machine that changed the world: The story of lean production--Toyota's secret weapon in the global car wars that is now revolutionizing world industry.*

Yin, Y., Stecke, K. E., & Li, D. (2017). The evolution of production systems from Industry 2.0 through Industry 4.0. *International Journal of Production Research*, 56(1-2), 848-861. https://doi.org/10.1080/00207543.2017.1403664