International Journal of Production Management and Engineering

https://doi.org/10.4995/ijpme.2023.18840

Received: 2022-11-24 Accepted: 2023-01-24

Interpretive structural modelling of critical success factor for lean product lifecycle management in industry 4.0

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Abstract:

The industrial revolution has gone through four revolutions, this fourth one is Industry 4.0 or I4.0, which aims to improve the performance of companies by moving towards digitalization and relying on the internet of things technology IOT and the cyber physical system CPS. Lean product lifecycle management (Lean-PLM) is a system that has become a pillar of Industry 4.0 because of the benefits it brings: productivity improvement, performance, waste reduction. The objective of our study is to examine the correlation between Lean/Industry 4.0 and PLM/I4.0 and to present an implementation model using the ISM (Interpretive Structural Modelling of Critical Success Factor) method of Lean-PLM in Industry 4.0. The results obtained from this research show that Lean can be associated with Industry 4. 0, which gives us Lean 4.0, PLM is a pillar of Industry 4.0 and finally the success of the Lean-PLM model in Industry 4.0 is based on the support and commitment of top management", "Big Data (BD)", "Change Management" and "Professional Training and Development (PTD)".

Key words:

Lean management, product lifecycle management, lean-PLM, industry 4.0, ISM, the critical success factors (CSFs).

1. Introduction

You will find here IJPME's guidelines for the preparation of Today, one of the most popular buzzwords in manufacturing is "Industry 4.0" (D'Antonio et al., 2017). it is a concept that reflects an important path through the four existing industries (Rojko, 2017). Several authors state that this concept is related to the application of the Internet of things (IOT) technology in the production/manufacturing sector, this technology contributes to have a better communication between machines and humans and favors the implementation of cyber-physical systems (D'Antonio et al., 2017).

The digitization of companies favors the possibility of collecting all the necessary information on the product throughout its life cycle (Gehrke et al., 2020). This is why Product Lifecycle Management (PLM) is proving to be an indispensable tool in the digitization process, as it enables the right data to be provided to the right person at the right time (Rossi et al., 2016). PLM sees itself as a pillar of Industry 4.0 (Vila et al., 2017). Manufacturers are encouraged to embrace advanced technologies, automation and digitization as the next digital frontier to improve Lean in business and achieve operational excellence (Powell et al., 2018). Therefore, the blend of Lean-PLM would ensure intelligent communication while guaranteeing data security within the company (Gecevska et al., 2012). Thus, reducing costs, improving business performance and reducing waste (El Faydy and El Abbadi, 2022). Lean-PLM and I4.0 are supposed to overcome the future challenges of manufacturing (Mayr et al., 2018).

In the previous work, we studied the implementation of Lean-PLM, we concluded that this mix is

To cite this article: El Faydy, N., El Abbadi, L. (2023). Interpretive structural modelling of critical success factor for lean product lifecycle management in industry 4.0. *International Journal of Production Management and Engineering, 11*(1), 65-72. https://doi.org/10.4995/ijpme.2023.18840

beneficial to the company, it turned out that the commitment and contribution of all parts of the company contribute to the success of Lean PLM. In this work we will use some key factors of our previous work to project them in the industry 4.0. Hence the objective of our research is to identify the key factors of the implementation of Lean-PLM in the industry 4.0, to do this we will use the ISM method and the MICMAC analysis.

2. Problematic

The world of industry has experienced 4 industrial revolutions: (Koh et al., 2019). The Fourth revolution or the industry 4.0 appeared in Germany at the industrial exhibition in Hannover, the fourth generation of industry is a digital transformation in factories, and the goal of this is to create an intelligent factory (Bartodziej, 2017). We can describe The Intelligent Factory as a factory when CPS (cyber physical system) ensures communication through batch processing and also accompanies humans and machines in carrying out their missions (Reimann and Sziebig, 2019). Talking about CPS; are software/algorithm driven devices designed to meet the needs of users via the internet (Reimann and Sziebig, 2019).

Industry 4.0 at the beginning had a perspective of assembling by creating a global network of companies that have similar machines, production facilities with the aim of developing their industrial processes, including manufacturing, engineering.... throughout the product life cycle (Vila et al., 2017).

PLM is a strategy that contributes to the realization of a product while optimizing in time, cost and having a good quality (Navarro et al., 2013). The link of Lean PLM is simply to apply the principles/methods of Lean in the PLM implementation (Gecevska et al., 2013). In order to successfully implement Lean PLM, it has been proven that the support of top management is essential (El Faydy and El Abbadi, 2022).

Among the essential elements of Lean is the focus on the customer, in order to respond well to his needs, therefore the link with PLM allows to respond well to his needs so allows companies to eliminate waste, reduce cost (Gecevska et al., 2013) and the sharing of good practices(Navarro et al., 2013)

Industry 4.0 has the ability to collect, exploit, interpret and exchange all data with the different machines. Thanks to CPS or the Internet of Things (IoT), it is now possible to respond quickly and efficiently to problems while reducing costs (Ejsmont et al., 2020).

PLM is considered an effective technological and organizational solution for managing product development and creation processes. Beside the application of PLM is beneficial to manufacturing. (D'Antonio et al., 2017).

In this context the digital manufacturing DM is a fundamental technology for the next technology, called "cyber-physical system", which is considered as a mechanism controlled by algorithms and which interacts with the physical world via the Internet. The CPS needs a digital model of all the components of the company, including the PLM, which connects and preserves the continuity of the systems (D'Antonio et al., 2017). PLM is a pillar and a key to Industry 4.0 (Vila et al., 2017).

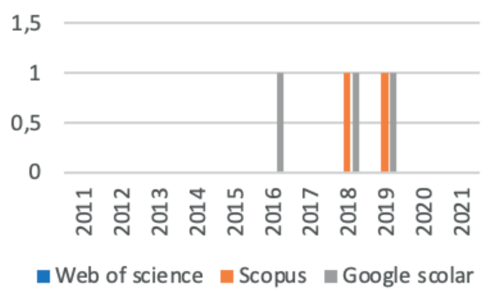

Figure 1. Documents by year of Lean PLM in industry 4.0.

Figure 1 is based on an analysis on SCOPUS, Google Scolar and Web of science, it shows the number of articles that have dealt with Lean PLM in industry 4.0. we could find three articles that talk about Lean principles in PLM through industry 4.0.

We attempted to run a scan on articles that dealt with Lean PLM based on the ISM scan, but no articles were found on: Scopus, web of science and google scholar. On the other hand, several articles deal with Lean PLM.

3. Research methodology

The methodology of our work consists in presenting a model of the success of Lean-PLM in Industry 4.0, the ISM method is very useful because it allows to determine the key factors and to analyze their correlation. The following paragraph explains the sequence of our ISM method.

3.1. ISM methodology

Interpretive Structural Modeling (ISM) is defined as an approach that identifies the correlation between item that may constitute a problem or a topic (Attri et al., 2013). This approach was introduced in order to know the complex industrial system (Luthra et al., 2020). The steps of the ISM for the present study are as follows:

- Identify the key success factors for the implementation of Lean PLM in Industry 4.0
- Study the correlation between these factors (CSF) under a structural self-interaction matrix (SSIM)
- Establish a final attainability matrix from an initial attainability matrix based on the transitivity rule.
- Determine the various levels of the matrix.
- Build the structural model of CSFs in the implementation of Lean PLM in Industry 4.0.
- Analyze the results using the MICMAC method.

4. Results

4.1. Success factors CSF

In order to choose the criteria, I consulted several articles that talk about Industry 4.0, Industry 4.0 and Lean, Industry 4.0 and PLM or finally Lean and PLM, then I listed the criteria that were the most treated by the researchers in their article

Before choosing the success factors, a workshop was organized to define the most selected factors: the organization of our workshop is done as follows: to select the participants, we consulted factories, companies in the industry, or service companies, and finally the universities. In the end, the selected profiles are managers, engineers who work in the transformation of factories to Industry 4.0, managers with a good knowledge of PLM and PLM software and researchers in the field. The next step is the distribution of the groups, our approach was to have in each group, an engineer, a manager and a researcher, it should be noted that our survey lasted one month to have the confirmation of the participants. The total of the participants is 18 people (6 researchers, 6 managers and 6 engineers) distributed in 6 groups. Below are some questions from our survey to select the criteria:

- Is the Lean PLM applied in your organization?
- Do you confirm that Industry 4.0 positively affects Lean management, operations optimization and production improvement?
- Do you think that the implementation of Lean PLM requires a model?
- Do you confirm that PLM is considered a pillar of Industry 4.0.
- Is the combination of Lean PLM in Id 4.0 different from Lean PLM ?
- Will the application of Lean PLM in Id 4.0 be profitable for Industry 4.0 ?
- Please share from your experience the criterion(s) that you consider essential to the success of Lean PLM in Id 4.0.
- What are the Lean methods that are important in Lean PLM in Id 4.0?
- What are the barriers that the implementation of Lean PLM in Id 4.0?

The table below contains the choice of these groups

Based on the decision Table 1, we concluded that 67% chose the same 12 criteria (Group 2, Group 3, Group 5 and Group 6), while Group 1 and Group 4 selected less than 12 criteria.

After a Teams meeting, the sending of the questionnaire was automatic thanks to a software for each group, at the beginning 9 groups were chosen for the sending, finally 6 among the 9 answered our experiment.

The collection of the answers was automatic in order to evaluate and interpret the answers of the 6 groups

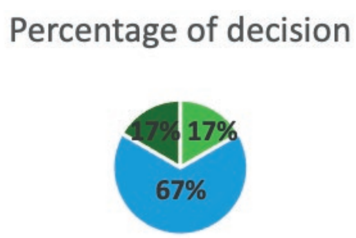

Figure 2. Percentage of decision.

Following the results, we will choose the 12 criteria chosen by groups 2, 3, 5 and 6.

Table 1. Decision matrix.

CSF	Source	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Product life cycle PLM and good Lean tools	(El Faydy and El Abbadi, 2022)	✓	✓	✓		✓	✓
Integration of supplier	(Rossi et al., 2016)						
Big Data (BD)	(Devi et al., 2021)	✓	✓	✓	✓	✓	✓
Include PLM information in enterprise systems	(Gecevska et al., 2013)	✓			✓		
Adopt a lean approach in the different stages of the product lifecycle	(El Faydy and El Abbadi, 2022)		✓	✓	✓	✓	✓
Develop a Lean PLM deployment strategy	(Navarro et al., 2013)	✓					
Digitalize the infrastructure	(Karadayi-Usta, 2020)		✓	✓	✓	✓	✓
Presence of standardization	(Vigneshvaran and Vinodh, 2020)		✓	✓		✓	✓
IOT is essential in the implementation of Industry 4.0	(Devi et al., 2021)	✓	✓	✓		✓	✓
Top-Level Management support and commitment	(Devi et al., 2021), (El Faydy and El Abbadi, 2022)	✓	✓	✓	✓	✓	✓
Human ressources	(Cattaneo et al., 2017)				✓		
Change management	(Luthra et al., 2020)	✓	✓	✓		✓	✓
Professional Training and Development (PTD)	(Devi et al., 2021)		✓	✓		✓	✓
Cyber-Physical System (CPS)	(Devi et al., 2021)	✓	✓	✓	✓	✓	✓
Engaged staff	(Maginnis et al., 2019)		✓	✓	✓	✓	✓
Integrate Industry 4.0 in the global framework of Lean theory	(Cattaneo et al., 2017)	✓			✓		
Understanding benefits of I4 practices	(Luthra et al., 2020)		✓	✓		✓	✓
Guarantee the transmission of quality data over time	(Navarro et al., 2013)	✓					

4.2. CSFs For Lean PLM System

We have used several keywords in the search platforms like: Scopus, Google scholar, Web of science, 12 key success factors CSF have been identified to successfully implement Lean-PLM in I4.

Based on article research, Table 2 contains the 12 factors that contribute to the success of Lean PLM in Industry 4.0.

4.3. Structural self-interaction matrix (SSIM)

In order to carry out our study, a meeting was held with the participants of the 4 groups to identify the influence between the 12 criteria.

We have used these symbols to identify the influence between the 12 CSF, which we have put in Figure 3.

V: CSF i will help to achieve CSF j;

A: CSF i will be achieved by CSF j;

O: CSFs i and j are unrelat.

Table 2. CSFs for Lean PLM implementation in industry 4.0.

CSF	
Product life cycle PLM and good Lean tools	(El Faydy and El Abbadi, 2022)
Big Data (BD)	(Devi et al., 2021)
Adopt a lean approach in the different stages of the product lifecycle	(El Faydy and El Abbadi, 2022)
Digitalize the infrastructure	(Karadayi-Usta, 2020)
Presence of standardization	(Vigneshvaran and Vinodh, 2020)
IOT is essential in the implementation of Industry 4.0	(Devi et al., 2021)
Top-Level Management support and commitment	(Devi et al., 2021), (El Faydy and El Abbadi, 2022)
Change management	(Luthra et al., 2020)
Professional Training and Development (PTD)	(Devi et al., 2021)
Cyber-Physical System (CPS)	(Devi et al., 2021)
Engaged staff	(Maginnis et al., 2019)
Understanding benefits of I4 practices	(Luthra et al., 2020)

CSF	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1
C1	O	V	A	A	A	A	A	A	A	X	A	
C2	O	V	V	V	X	A	V	V	V	V		
C3	A	V	A	A	A	A	A	A	A			
C4	O	V	A	A	O	A	A	X				
C5	X	V	A	A	A	A	A					
C6	O	V	V	O	O	O						
C7	V	V	V	V	V							
C8	V	V	O	X								
C9	O	V	V									
C10	V	O										
C11	A											
C12												

Figure 3. Structural self-interaction matrix (SSIM).

4.4. Reachability Matrix

The SSIM is transformed into a binary matrix by applying 0 or 1 to the values A, V, O and X following the constructions mentioned in the Table 3.

Table 3. Converting SSIM into initial reachability matrix[M].

(i, j) value in SSIM	(i, j) value in Matrix [M]	(j, i) value value in Matrix [M]
V	1	0
A	0	1
O	0	0

Table 6 shows that there are 7 levels of influence. It should be noted that the lower-level CSFs are the most important and can influence the higher factors.

4.5. Building the ISM model

Following this model, we conclude that the "Top-Level Management support and commitment" is essential for the implementation of Lean PLM in Industry 4.0.

To deepen our analysis, the first levels: "Top-Level Management support and commitment", "Big Data (BD)", "Change management" and "Professional Training and Development (PTD)" have a very high influence in the implementation of Lean PLM in Industry 4.0

Table 4. The Reachability matrix[M].

C	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	1	0	1	0	0	0	0	0	0	0	1	0
C2	1	1	1	1	1	1	0	1	1	1	1	0
C3	1	0	1	0	0	0	0	0	0	0	1	0
C4	1	0	1	1	1	0	0	0	0	0	1	0
C5	1	0	1	1	1	0	0	0	0	0	1	1
C6	1	0	1	1	1	1	0	0	0	1	1	0
C7	1	1	1	1	1	0	1	1	1	1	1	1
C8	1	1	1	0	1	0	0	1	1	0	1	1
C9	1	0	1	1	1	0	0	1	1	1	1	0
C10	1	0	1	1	1	0	0	0	0	1	0	1
C11	0	0	0	0	0	0	0	0	0	0	1	0
C12	0	0	1	0	1	0	0	0	0	0	1	1

Table 5. Final reachability matrix[M].

C	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	Driving Power
C1	1	0	1	0	0	0	0	0	0	0	1	0	3
C2	1	1	1	1	1	1	0	1	1	1	1	1*	11
C3	1	0	1	0	0	0	0	0	0	0	1	0	3
C4	1	0	1	1	1	0	0	0	0	0	1	1*	6
C5	1	0	1	1	1	0	0	0	0	0	1	1	6
C6	1	0	1	1	1	1	0	0	0	1	1	1*	8
C7	1	1	1	1	1	1*	1	1	1	1	1	1	12
C8	1	1	1	1*	1	1*	0	1	1	1*	1	1	11
C9	1	1*	1	1	1	1*	0	1	1	1	1	1*	11
C10	1	0	1	1	1	0	0	0	0	1	1*	1	7
C11	0	0	0	0	0	0	0	0	0	0	1	0	1
C12	1*	0	1	1*	1	0	0	0	0	0	1	1	6
Independence	11	4	11	9	9	5	1	4	4	6	12	9	

Table 6. Level partitions of the final reachability matrix.

CSFs	Reachability set	Antecedent set	Intersection set	Level
C1	1, 3, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	1,3	II
C2	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	2, 7, 8, 9	2, 8, 9	VI
C3	1, 3, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	1,3	II
C4	1, 3, 4, 5, 11, 12	2, 4, 5, 6, 7, 8, 9, 10, 12	4, 5, 12	III
C5	1, 3, 4, 5, 11, 12	2, 4, 5, 6, 7, 8, 9, 10, 12	4, 5, 12	III
C6	1, 3, 4, 5, 6, 10, 11, 12	2, 6, 7, 8, 9	6	V
C7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	7	7	VII
C8	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	2, 7, 8, 9	2, 8, 9	VI
C9	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	2, 7, 8, 9	2, 8, 9	VI
C10	1, 3, 4, 5, 10, 11, 12	2, 6, 7, 8, 9, 10	10	IV
C11	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	11	I
C12	1, 3, 4, 5, 11, 12	2, 4, 5, 6, 7, 8, 9, 10, 12	4, 5, 12	III

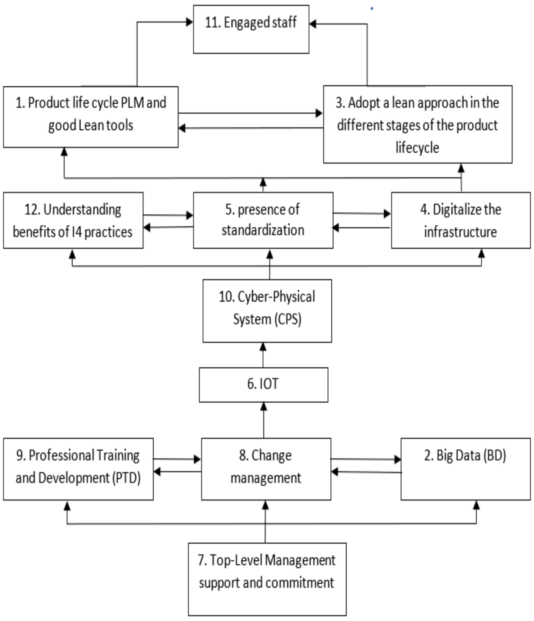

Figure 4. Structural model of CSFs in Lean PLM implementation in industry 4.0.

4.6. Matrix of cross-impact multiplications applied to classification (MICMAC) analysis

MICMAC is an analysis that helps decision makers to come up with a strategy, to do so it allows them to identify the key variables, essential to develop a strategy/model. Through the sum of the training power and the dependencies of the variables identified in Table 5, these results are used in the MICMAC analysis. This analysis contains 4 groups:

- Group 1: Autonomous success factors;
- Group 2: Dependent success factors;
- Group 3: Linking success factors;
- Group 4: Independent success factors.

- **Group 1: Autonomous success Factors** – This group contains factors that have low drive and dependency. In this group we found the factor: Cyber-Physical System (CPS) (factor 10).

- **Group 2: Dependency success Factors** - This group contains factors that have low drive but high dependency. In this group we found the factor: Product life cycle PLM and good Lean tools (factor 1), Adopt a lean approach in the different stages of the product lifecycle (factor 3), Digitalize the infrastructure (factor 4), presence of standardization (factor 5), Engaged staff (factor 11) and Understanding benefits of I4 practices (factor 10).

- **Group 3: Linking success factors** - This group contains factors that have a high driving power as well as a high dependency. We didn't find any factors in this group.

- **Group 4: Independent success factors** - This group contains factors that have high driving power but low dependence. This group contains five factors: Big Data (BD) (factor 2), IOT (factor 6), Change management (factor 8), Professional Training and Development (PTD) (factor 9) and Top-Level Management support and commitment (factor 7).

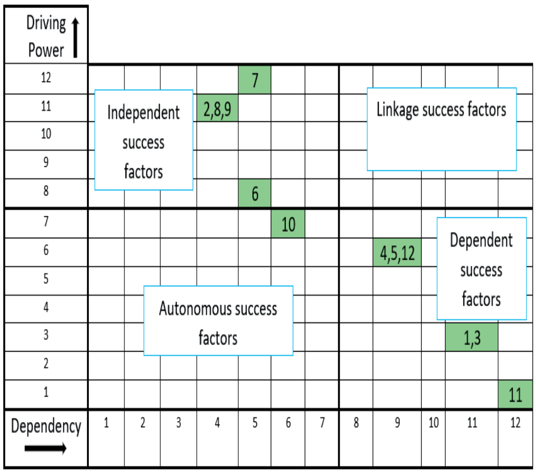

Figure 5. Driving-Dependence Graph of CSFs.

5. Discuss

To further our analysis, and through the MICMAC analysis, we see that the first three levels "Executive Management Support and Commitment", "Big Data (BD)", "Change Management", "Professional Training and Development (PTD)" and "IOT" are the most critical as they are at the bottom of the model and help the others to be done effectively.

Our work consists in showing the effectiveness of the application of Lean PLM principles/concepts in Industry 4.0.

The implementation strategy is based, according to our article, on a model that allows to follow the steps for a good success, it should be noted that during the workshop the Lean, PLM and Industry 4.0 are already implemented, our goal was to concretize them an official model. Because if the processes are inefficient, we can't project ourselves towards automation.

Figure 6 is a conclusion and analysis following the research mentioned in the previous paragraphs:

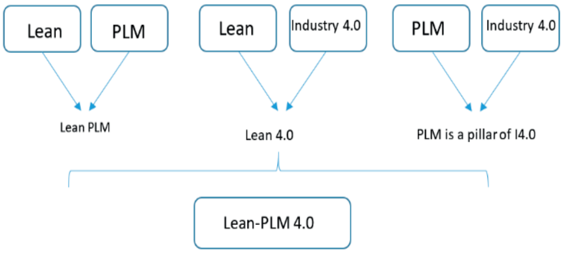

Figure 6. Lean PLM in industry 4.0.

PLM, through the use and sharing of product information, allows decision makers to use Lean tools to better reduce waste. We note that PLM shares the same benefits as Lean, namely: Quality, Time and Cost. PLM can be adapted to the company's strategy, so each company must define the objectives of the PLM project, these objectives will be aligned with Lean, that's why Lean-PLM contributes to the competitiveness and success of a company. Moreover, in our previous article the success of the implementation of Lean-PLM relies on Top management support and commitment. As mentioned in the previous paragraphs, PLM is considered a pillar of Industry 4.0. Table 1 illustrates that I4.0 tools have a positive impact on Lean tools/concepts. By this fact, we conclude that Lean-PLM in Industry 4.0 which we will name Lean-PLM 4.0 plays an important role in the industry world, which is characterized by its positive impact such as decrease in processing time, cost reduction, quality improvement and most importantly customer satisfaction. Thus, the successful implementation of Lean PLM in Industry 4.0 is linked to the first levels mentioned above.

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