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Interpretive Structural Modeling of Critical Success Factors for Lean PLM Implementation

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Abstract. Today, many industrial companies use Lean management to improve productivity and reduce waste and consider The Product Lifecycle Management (PLM) as one of the pillars of this new industry. Moreover, many researches affirm that Lean and PLM are complementary, but few works study their combination. The interest of our work is to realize a model that will serve as a guide to any company wishing to implement Lean PLM. Thanks to the ISM (Interpretive Structural Modelling) method, and to the critical success factors collected from literature, our model has been developed. The structural model of CSF in lean PLM implementation shows that the following factors are the pillars of Lean PLM implementation: management support and commitment, interdepartmental cooperation, proper PLM selection and the right Lean tools. Finally, we use the Matrix of cross-impact multiplications applied to classification (MICMAC) analysis to know the direct and indirect influence of all factors on the Lean PLM system

Keywords: lean management, product lifecycle management (PLM), lean plm system, ism, the critical success factors (CSFS), micmac analysis

1. Introduction

Companies around the world are continuously trying to improve their performance, build an image in order to position themselves well in the market (Rao and Holt 2005). This requires to have a very good quality to meet the needs of their customers, minimize any unprofitable action to the company (minimize waste, reduce costs)(Gecevska et al. 2012). Among the ways to achieve this, companies need to have more efficient realization processes in order to gain market share, which allows them to focus on value-added tasks (Navarro et al. 2013).

However, it is essential to review the way companies do things and provide services today. The Product Lifecycle Management (PLM) comes as solution to link all departments of the company that are involved in product (Abramovici 2007). On the other hand, lean aims to create value through a means that is based on continuous improvement and requires the commitment of people, processes and technology (Rossi et al. 2016). The blend of Lean and PLM or in other words the use of PLM by applying lean principles will be beneficial for the company because the application of lean principles (and subsequently of its methods and tools) will improve the effectiveness and efficiency of PLM implementation projects (Navarro et al. 2013).

Despite the fact that the combination of Lean and PLM contributes to continuous improvement, cost reduction and sustainable/profitable growth for manufacturing processes (Gecevska et al. 2012). Many Lean companies find it difficult to use PLM technology with Lean (Gecevska, Anisic, and Stojanova 2013). This difficulty stems from the lack of a model that helps with their implementation (Pinel et al. 2013). Besides, few works are interested in the relationship and use of lean principles, methods and/or tools and their impact on PLM solutions implementation projects (Navarro et al. 2013).

The main objective of our research is to determine the catalysts of the implementation of Lean PLM in organizations. To do so, it is necessary to define the Critical Success Factors (CSFs) and then to study their degree of influence. Then, we will design an ISM model that will be a guide for any company wishing to implement Lean PLM, and that will give a global vision on the influence of each CSF. Finally, we will use the MICMAC method to prioritize all the factors according to their global influence on the direct and indirect system.

2. Literature Review

2.1. Lean management and PLM

The Lean has appeared in Japan precisely at Toyota(Hallam and Contreras 2016). It can be defined as "a philosophy aimed at reducing costs and time cycle by eliminating non-value added activities and waste" (Elrhanimi et al. 2018). It should be noted that Japanese people unconsciously applied some Lean manufacturing tools/practices in their home/daily life (el Abbadi et al. 2020).

The objective of Lean is to improve the processes of production, to satisfy the customer, to have a good management within the company (Gupta and Jain 2013) . As well as to eliminate all types of waste (Hallam and Contreras 2016). The Lean concept contains principles, methods and tools for organizing production/management and work in companies. It allows to produce large volumes of products and services with less effort and less cost. In essence, Lean tools are a set of methods or processes for the practical application of the proposed system. These tools include the 5S workplace organization system, just-in-time, Kanban, kaizen rapid change (SMED), Poka yoke, value stream mapping, (TPM - Total Productive Maintenance) (Ibrani et al. 2020).

The industry sees PLM as a virtual and collaborative tool (Vila et al. 2017) and it is considered as an effective technological and organizational solution for managing product development and creation processes. Besides, the application of PLM is beneficial to manufacturing (D’Antonio et al. 2017). However, PLM adopts several software tools and platforms to support innovation(Rossi et al. 2016), allows the company to simplify and reduce the critical steps of the product life cycle. Thus, it can improve the efficiency of the companies by reducing the execution time and the rejects as well as improving of the productivity (Gecevska et al. 2012). Therefore, PLM is defined as a system for managing and centralizing all information, data and processes from the initial idea to the end of life (Schuh et al. 2008).

3. Research Methodology

The purpose of this research is to identify the key factors of the implementation of Lean PLM system and to do so, we use the ISM method which will allow us to make an analysis of the correlation between the selected criteria.

3.1. ISM approach

The Interpretive Structural Modelling (ISM) methodology helps to analyze/evaluate the correlation between the selected criteria (Gardas et al. 2019). It helps to provide a fundamental understanding of complicated situations and to establish a plan of action (Salimifard n.d.).

The following steps are involved in the ISM approach (Gardas et al. 2019)

- Identify system factors CSFs For Lean PLM System.
- Determine the interrelationships/influences between the different CSFs in the implementation of Lean PLM dan Structural self-interaction matrix (SSIM).
- Transform the SSIM into a binary matrix, i.e., an initial attainability matrix (IRM).
- Determine the levels by identifying the reachability set and the antecedent set of each CSF and their intersection set.
- Develop a model based on the MIS by exchanging the nodal values with the statements of the CSFs.

- Finally, use the interpretive structural model and MICMAC analysis to analyze the factors affecting Lean PLM implementation.

4. Result

4.1. CSFs for lean PLM system

The CSFs are described as "the things that must be done for a business to succeed"(Freund 1988). They are intended to help companies control risk, including ensuring effective and successful performance of the organization. They are therefore key factors in getting things right.(Leidecker and Bruno 1984).

For the lean PLM system, It is essential to recognize and evaluate the critical success factors to ensure its successful implementation (Thanki and Thakkar 2018). In addition, a proposed CSF should only be accepted as such when its consideration results in its successful implementation (Ram et al. 2013).

Based on the existing research papers, we identified 14 different critical success factors when implementing the combined Lean PLM system. The collected factors are listed in Table 1.

Table 1: CSFs for Lean PLM implementation

N° CSFs	
C1: Managing risks;	
C2: Focusing on the customers;	(Navarro et al. 2013)
C3 : technological skills;	(Gecevska et al. 2012)
C4: Training people;	(Rossi et al. 2016)
	(Rossi et al. 2016) (M. A. Maginnis et al. 2017)
C5: Share and use information;	(Navarro et al. 2013)
C6: Ensuring effective communication between stakeholders;	(Navarro et al. 2013) (Navarro et al. 2013)
C7: Top management support and commitment;	(Rossi et al. 2016) (Rossi et al. 2016)
C8: Project management and planning;	(Houti et al. 2019)
C9: Interdepartmental cooperation;	(Houti et al. 2019)
C10: Motivation;	(M. Maginnis et al. 2017)
C11: Proper PLM selection and good Lean tools;	
	(Navarro et al. 2013)
C12: Collaborate with different aspects of the value chain;	(Pinel et al. 2012)
C13: Have a strategic, tactical and operational vision;	(Navarro et al. 2013)
C14: Adopt a lean approach in the different stages of the product lifecycle.	

After listing all the factors, we will try to study the influence between them

4.2. Structural self-interaction matrix (SSIM)

For the deployment of SSIM, we consulted a team of experts, engineers, project management, researchers, who work on Lean and PLM to determine the relationships between the 14 CSFs for the implementation of Lean PLM system within a company.

To indicate the direction of influence between factors, the following four symbols were used CSFs (i and j):

- **V:** CSF i will enable CSF j to succeed.
- **A:** CSF j will be successful in CSF i.
- **O:** CSFs i and j are not associated.

CSFs	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1
C1	O	A	O	A	O	A	A	A	A	A	O	O	V	
C2	O	A	O	A	O	O	O	A	A	O	V	O		
C3	A	A	A	O	V	A	O	A	A	A	V			
C4	O	O	A	O	V	A	A	A	A	A				
C5	A	A	A	A	V	A	O	A	O					
C6	A	A	A	O	V	O	O	O						
C7	V	V	V	V	V	V	O							
C8	O	A	A	A	V	O								
C9	V	V	V	A	V									
C10	A	O	O	O										
C11	V	V	V											
C12	O	V												
C13	A													
C14														

Fig. 1: Structural self-interaction matrix (SSIM)

The figure below illustrates the influence between the different factors defined to successfully implement the Lean PLM system.

4.3. Reachability matrix

The SSIM triangle is converted to a binary matrix, named accessibility matrix (Table 3). Table 2 below shows the rule by replacing the variables V, A and O with 0 and 1:

Table 2: Converting SSIM into initial reachability matrix

(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 3: The Reachability matrix[M]

M=

CSFs No	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	1	0	1	0	0	0	0	0	0	0	0	0	0
C3	0	0	1	1	0	0	0	0	0	1	0	0	0	0
C4	0	0	0	1	0	0	0	0	0	1	0	0	0	0
C5	1	0	1	1	1	0	0	0	0	1	0	0	0	0
C6	1	1	1	1	0	1	0	0	0	1	0	0	0	0
C7	1	1	1	1	1	0	1	0	1	1	1	1	1	1
C8	1	0	0	1	0	0	0	1	0	1	0	0	0	0
C9	1	0	1	1	1	0	0	0	1	1	0	1	1	1
C10	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C11	1	1	0	0	1	0	0	1	1	0	1	1	1	1
C12	0	0	1	1	1	1	0	1	0	0	0	1	1	0
C13	1	1	1	0	1	1	0	1	0	0	0	0	1	0
C14	0	0	1	0	1	1	0	0	0	1	0	0	1	1

Thanks to table 2, we convert figure 2 into a matrix named "The Reachability matrix[M]".

Table 4: Final reachability matrix[M]

CSFs No	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	Driving power
C1	1	1	1*	0	0	0	0	0	0	1*	0	0	0	0	4
C2	0	1	1*	1	0	0	0	0	0	1*	0	0	0	0	4
C3	0	0	1	1	0	0	0	0	0	1	0	0	0	0	3
C4	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
C5	1	1*	1	1	1	0	0	0	0	1	0	0	0	0	6
C6	1	1	1	1	0	1	0	0	0	1	0	0	0	0	6
C7	1	1	1	1	1	1*	1	1*	1	1	1	1	1	1	14
C8	1	0	0	1	0	0	0	1	0	1	0	0	0	0	4
C9	1	1*	1	1	1	1*	0	1*	1	1	0	1	1	1	12
C10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
C11	1	1	1*	1*	1	1*	0	1	1	1*	1	1	1	1	13
C12	1*	1*	1	1	1	1	0	1	0	1*	0	1	1	0	10
C13	1	1	1	1*	1	1	0	1	0	1*	0	0	1	0	9
C14	1*	1*	1	1*	1	1	0	1*	0	1	0	0	1	1	10
Dependence	10	10	11	12	7	8	1	7	3	10	2	4	6	4	

The realization of the final accessibility matrix will allow us to determine the distribution of the levels. To do this, we must first identify the Reachability set and Antecedent set from the final matrix and determine their intersection.

4.4. Level partitions

The reachability set contains all the FSCs that have the value 1. Similarly, the antecedent set consists of all the FSCs that have the value 1. Then, the intersection of these sets gets the derived FSC(s). The top level in the ISM hierarchy is defined when the reachability and intersection sets are identical.

CSFs	Reachability set	Antecedent set	Intersection set	Level

C1	1,2 3 10	1,5 6,7,8,9,11, 12, 13, 14	1	V
C2	2,3 4 10	1,2, 5 6,7, 9 11, 12 13 14	2	IV
C3	3,4,10	1, 2, 3, 5,6,7,9, 11, 12,13,14	3	III
C4	4,10	2,3,4,5,6,7,8,9,11, 12, 13, 14	4	II
C5	1,2, 3,4,5,10	5,7,9,11, 12, 13, 14	5	VI
C6	1,2,3,4,6,10	6,7,9,11,12,13,14	6	VI
C7	1 2 3 4 5 6 7 8 9 10 11 12 13 14	7	7	XI
C8	1,4,8,10	7,8,9,11,12,13,14	8	VI
C9	1 2 3 4 5 6 8 9 10 12 13 14	7,9,11	9	IX
C10	10	1 2 3,4,5,6,7,8,9,10,11 12 13 14	10	I
C11	1,2,3 4 5,6 8,9, 10 11, 12, 13, 14	7,11	11	X
C12	1 2 3, 4, 5, 6, 8, 10 12, 13	7,9, 11,12	12	VIII
C13	1, 2, 3, 4 5, 6, 8,10 13	7,9,11,12,13,14	13	VII
C14	1 2 3, 4 5, 6, 8 10, 13, 14	7,9,11,14	14	VIII

Table 5: Level partitions of the final reachability matrix

By analyzing Table 5 we see that there are 10 levels of influence. It is highlighted that the lower-level CSFs are the most important and can influence the higher factors.

4.5. Building the ISM model

After identifying the different levels, we will classify them according to our criteria in order to develop our model.

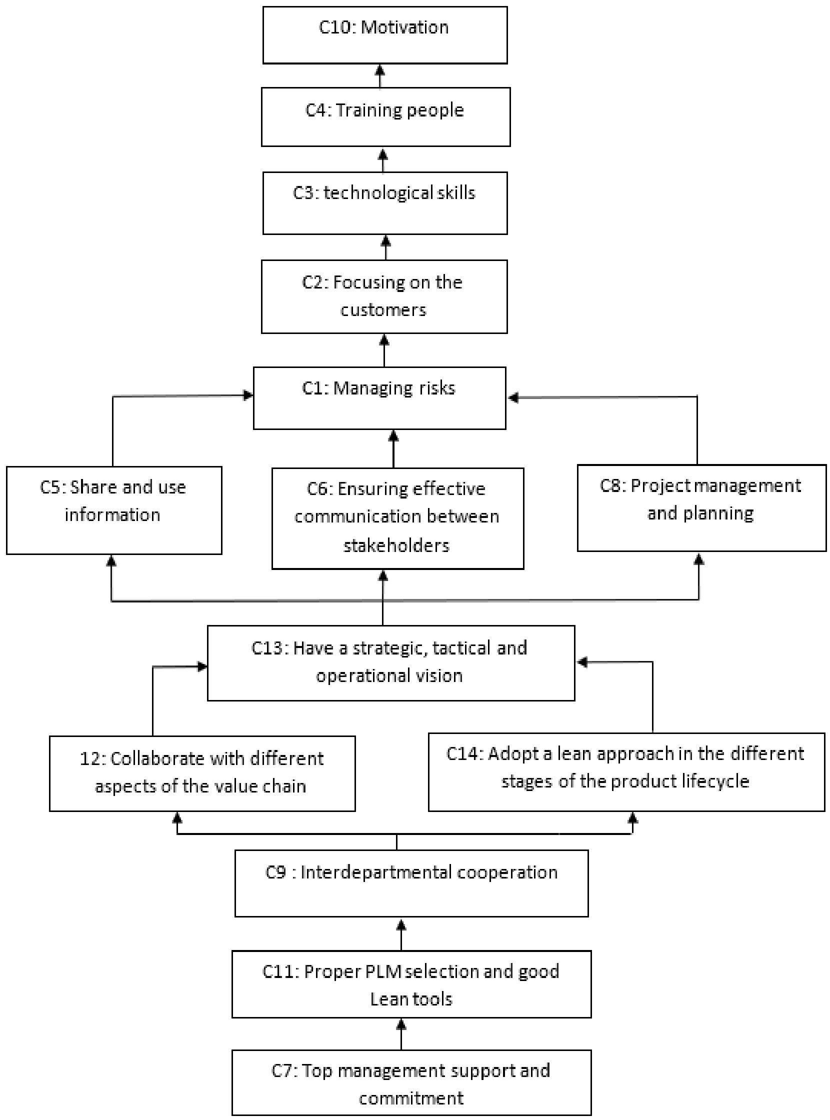

Fig. 2: Structural model of CSFs in Lean PLM implementation

According to the Structural Model of CSFs, we find that Top management support and commitment, Proper PLM selection and good Lean tools and Interdepartmental cooperation have a very important weight in the implementation of Lean PLM system, which leads us to say that the success of this implementation requires the contribution and commitment of all parts of the company.

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

The MICMAC analysis influences the decision makers in their development of the Lean PLM implementation strategy. To do this, we first start with the identification of the driving power and the dependency.

Note that the sum of all 1's in the row determines the driving power, while the dependency is provided by adding all 1's in the columns. Table 3 contains the sum of the driving power and the dependency of each CSF, the result obtained is used in the MICMAC analysis which is then presented in the graph constructed in figure 3. In the MICMAC analysis, the CSFs are classified into four groups:

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

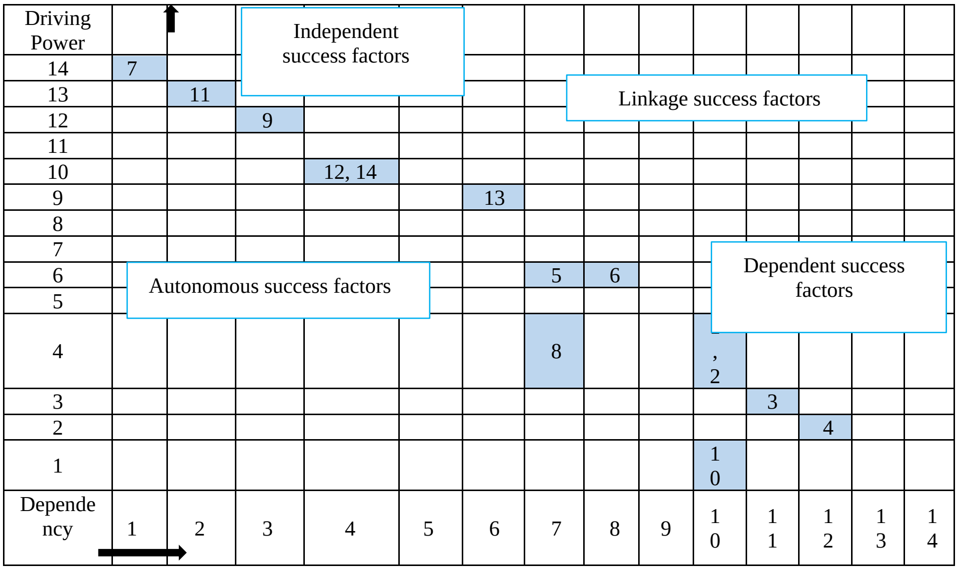

Fig. 3: Driving-dependence graph of CSFs

Group 1: Autonomous success Factors - These factors have low drive and dependency. In this group we have two factors, namely: Share and use information (factor 5), Project management and planning (factor 8).

Group 2: Dependency success Factors - These factors have low drive but high dependency. In this group we have six factors, namely: Managing risks (factor 1), Focusing on the customers 5 (factor 5), technological skill (factor 3), Training people (factor 4), Ensuring effective communication between stakeholders (factor 6) and Motivation (factor 10).

Group 3: Linking success factors - These factors have a high driving power as well as a high dependency. We have no factors in this group.

Group 4: Independent success factors - These factors have high driving power but low dependence. In this group we have six factors, namely Top management support and commitment (factor 7), Interdepartmental cooperation (factor 9), Proper PLM selection and good Lean tools (factor 11), Collaborate with different aspects of the value chain (factor 12), Have a strategic, tactical and operational vision (factor 13) and adopt a lean approach in the different stages of the product lifecycle (factor 14).

5. Discuss the Results

In the theoretical context, a lot of research states the complementarity between Lean and PLM approaches, but no model is available that helps in the implementation of Lean PLM. The interest of this study is to identify the key factors that influence the implementation of Lean PLM system using ISM technique and MICMAC analysis. These key factors presented in figures 2 and 3 have been identified by researchers from the academic and industrial world. They influence and help the implementation of Lean PLM in companies.

Based on these results, the factors Management Support and Commitment (factor 7), Interdepartmental Cooperation (factor 9), and Appropriate PLM Selection and Good Lean Tools (factor 11) have a strong driving power in Lean PLM implementation. We conclude that the commitment and contribution of all parts of the company contribute to the success of Lean PLM and should therefore be taken into account.

In the practical framework, it will have to raise awareness on the gains of these two methods through KPIs, as well as choose the Lean methods that will be or are already used by the company in production and have them integrated on the PLM tool.

We believe that the limitation of our study is related to two things, the first is the change of the factors that generate the change of the model. The second thing is the non-achievement of the pilers factors.

6. Conclusion

Lean management and Product Life Management have become pillars of the industry thanks to their benefits, which are characterized by cost reduction, improved company performance and reduced waste. Therefore, blending Lean PLM could only be beneficial. This article presents an analysis and a model to support companies in the implementation of Lean PLM.

This article has allowed us to extract the 14 main CSF to be used when implementing Lean PLM. To achieve this, the ISM method is the most appropriate, in order to determine the correlation between the different factors and finally develop an ISM model that will be a guide to any company wishing to implement Lean PLM. This analysis showed that “Top management support and commitment”, “Proper

PLM selection and good Lean tools" and "Interdepartmental cooperation" are important for the successful implementation of Lean PLM. In order to help decision makers develop a Lean PLM implementation strategy, it was necessary to use the MICMAC analysis to identify the driving and dependencies of the variables and classify the factors into four groups.

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