Readiness level assessment for lean Six Sigma implementation in the healthcare sector

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Abstract

Purpose – The purpose of this study is to identify the critical readiness factors (CRFs) that mainly affect the implementation of Lean Six Sigma (LSS) in an organization and their interactions, and to develop a model that allows the management to assess the Lean Implementation Readiness Level.

Design/methodology/approach – The methodology is separated into two main parts: the literature review and the assessment model development. In the literature review, the main CRFs and their interactions for LSS implementation in Scopus Data Base were identified. The second part of the methodology is the model development. It was built on a stepwise framework that considers the relations among the CRFs and their importance. Moreover, it was used fuzzy-based linguistic variables given by the experts working in the company to consider the actual performance rating of each CRF. The model has been validated in the healthcare sector in nine hospitals.

Findings – From the model application, it is possible to note that the most frequent level among the nine hospitals interviewed is "Average Ready". Also, the most extreme level of readiness occurred ones while the most extreme level of not readiness never occurred. Results show that in 78% of the cases, there would have been a high probability of implementation failure. Also, it was possible to identify for each hospital if the CRFs are good, if they are weak and need to change or if another factor needs to be improved before it and what this factor is.

Originality/value – This work proposes a new methodology that eliminates the negative aspects and limitations of the total interpretive structural modeling methodology and the fuzzy logic approach currently applied to evaluate the LSS readiness of a company. The present methodology lies in the fact that it provides a solution not only by defining the weak CRFs but also by giving an indication of priority as it identifies the weak antecedent factors that inhibit the preparedness of the depending factors.

Keywords Lean Six Sigma, Readiness level, Critical readiness factors, Healthcare, Fuzzy logic

Paper type Research paper

1. Introduction

Lean Six Sigma (LSS) is one of the most applied techniques in organizations in recent years. This technique combines Lean and Six Sigma, bringing their benefits and overcoming their deficiencies (Patel and Patel, 2021). In fact, Six Sigma complements Lean philosophy by providing statistical tools and know-how to improve performances by focusing on limiting mistakes or defects (Muraliraj *et al.*, 2018). On the other side, Lean approach pursues a cultural change in the organization, and its main goal is to identify and eliminate the wastes

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while always focusing on customers' requirements and without making it just a cost-saving exercise (Antony *et al.*, 2019).

According to some authors, the failure rate of LSS improvement projects is considered high, around 70% (Albliwi *et al.*, 2014; Pedersen and Huniche, 2011). Despite the strong interest and importance of the LSS implementation, the literature lacks to adequately address the problem of high failure rate encountered, and it neglects to provide companies with tools to assess and prevent the failure risk. Indeed, few papers discuss the readiness of a company to undertake LSS improvement projects. Some works suggest a checklist of aspects that the management must evaluate for assessing the preparedness of its company for the LSS implementation. Others propose a theoretical or quantitative model to measure the readiness level (Raju and Antony, 2019). Among the cases of company's preparedness analysis, the methodologies mainly used are based on the total interpretive structural modeling (TISM) or fuzzy logic approach (Jena *et al.*, 2017; Swarnakar *et al.*, 2020; Vaishnavi and Suresh, 2020; Yadav *et al.*, 2017; Narayanamurthy *et al.*, 2018). However, the models are lacking in considering all the aspects necessary to perform a correct evaluation of the LSS implementation organization readiness level, as well as the interactions between the main critical readiness factors (CRFs).

Thus, the following research questions were formulated:

RQ1. What are the critical factors affecting the organization readiness level for LSS implementation? What are their interactions?

RQ2. How to assess the organization readiness level for LSS implementation?

Therefore, the objectives of this article are to identify the CRFs that mainly affect the implementation of LSS in an organization and their interactions, and to develop a model to assess the lean implementation readiness level (LIRL). This work presents relevance both in theoretical and in practical terms. In theoretical terms, this work proposes a new methodology using new criteria for the interactions between the CRF and the LIRL. In practical terms, the assessment model allows managers from organizations to make more assertive decisions aligned with their goals, considering the current LIRL and the situation of each organization.

In addition to this introductory section, the article is structured as follows: Section 2 presents a theoretical review of LSS and healthcare. In Section 3, the methodology is presented, and Section 4 presents results and discussions. Finally, Section 5 presents the conclusions, limitations and suggestions for future works.

2. Theoretical review

2.1 Lean Six Sigma and healthcare

When Lean and Six Sigma are implemented in isolation, it may be that neither has effective results, limited by each other's needs in the organization (Pepper and Spedding, 2010). In this way, the concept of LSS emerged, and the combination of these two ideas has many benefits. LSS can be defined as: "an organized strategy from a business perspective that enables industries to effectively recognize the customer desires, eliminates the variability within the production, and reduces all non-value-added activities" (Singh and Rathi, 2018). Though both the approaches evolved primarily in the manufacturing domain, the application has expanded into service sectors such as the healthcare sector (Patel and Patel, 2021).

Hagan (2011) stated that 95% of activities carried out in healthcare sector do not add value, neither to the customers nor to the process outcome, leaving enough space for improvements. This means that, from an organizational point of view, the need for more flexible solutions as LSS has arisen (Tlapa *et al.*, 2020). In the literature, most of the papers focus on case studies of LSS implementation in hospitals, principally in emergency departments, presenting the benefits and the results achieved through the projects (Furterer, 2018). The main achievements are the reduction of patients' waiting time, the improvement of the patients' flow that reduces overcrowding and the reduction of costs (Daly *et al.*, 2021). There are also some unmeasurable objectives often targeted, such as the improvement of staff and patients' satisfaction, as well as the improvement of teamwork and cooperation between different functions.

Even if many papers present positive implications for LSS improvement projects, it is reported that 70% of LSS implementation projects fail (Albliwi *et al.*, 2014; Pedersen and Huniche, 2011). This data is also confirmed in the healthcare sector, where the LSS initiatives fail in two cases out of three (Leite *et al.*, 2020). Moreover, it is stated that about 70% of the LSS implementation failures are due to the fact that the organization is not ready for the application of the project (Antony *et al.*, 2020; Leite *et al.*, 2020). Indeed, the companies' readiness to implement LSS techniques is rarely evaluated before proceeding with the actual implementation. Thus, more in-depth studies related to the readiness of LSS implementation in the healthcare sector are needed.

3. Methodology

The description of the methodology is separated into two main parts: the literature review and the assessment model development.

3.1 Literature review

To identify the main CRFs and their interactions, a literature review was performed. The literature review was conducted following some steps. Firstly, a database was selected. The database considered was Scopus, which was chosen to access a broader number of academic papers. Secondly, keywords were carefully chosen according to two research axes: lean system and critical factors affecting LSS implementation. The research string, limited to the articles' keywords, was: {[(lean six sigma) OR (six sigma) OR lean OR (lean healthcare) OR (lean system) OR (continuous improvement)] AND [(success factors) OR (critical factors) OR (failure factors) OR readiness OR (readiness factors) OR (readiness index) OR leanness OR barriers OR healthcare OR change)]}. The research resulted in 2,873 articles. In total, 10 papers were randomly selected among the results obtained to check the accuracy of the chosen keywords. The analysis confirmed the rightness of the search string, as it was verified that the keywords of these articles matched the search keywords. Subsequently, articles with document typology corresponding to "conference paper" were excluded, and only articles written in English were retained in the search. Moreover, articles with titles and abstracts not relevant to the scope of the research were discarded. Finally, the remaining papers were read, and they led to the identification of additional articles, included in the total number of 89 papers reviewed.

Through the analysis of the literature, the CRFs were defined by summarizing, translating and reworking not only the readiness factors adopted in the reference papers but also the critical factors, failure factors, success factors and barriers to LSS implementation that emerged in the literature.

Also, during the literature review, it was found that there was often an impact between two factors. Indeed, in many descriptions of critical failure or success factors, it was indicated that the lack of that aspect was going to affect another one. Therefore, it is essential to consider not only each CRF but also the impacts that one factor can have on the others. Only significant influences have been considered and described underneath. The influence of factor A on factor B is meant in a unidirectional direction; thus, the impact of A on B does not imply that B affects A.

According to their nature, the CRFs are grouped into seven categories: management and leadership, operational and strategy, organizational, effective communication, LSS knowledge and approach, tools and external aspects. The CRFs and their impacts are summarized in Table 1, along with some of the references of literature review.

3.2 Proposed lean implementation readiness model

The second part of the methodology is the model development. The lean implementation readiness model (LIRM) is based on the 30 variables, corresponding to the CRFs previously identified through the literature review. The model is an approach used to assess the LIRL of an organization for LSS implementation and to identify the weak CRFs to be addressed by the organization, whether it is not ready.

In general, the LIRL is computed using two values for each CRF: importance weighting of CRF and performance rating of CRF. The importance weighting of CRF is a value objectively obtained by analyzing the interactions between factors extracted from the literature, and it refers to the importance of one factor over another and to the attention that must be placed on this factor during the implementation of LSS. The performance rating of CRF is a value that refers to how the organization considered performs from that point of view, and it is collected from the experts that directly work in the analyzed organization.

The step-by-step model development will be demonstrated in the following subsections.

3.2.1 Development of reachability matrix. In consonance with the work of Jena *et al.* (2017), a reachability matrix was developed as a representation of the interactions between the CRFs. The reachability matrix translates the previously identified interactions into a matrix that has on the axes the CRFs ordered numerically from top to bottom and from left to right. In the matrix obtained, only binary numbers (0 or 1) are inserted. If the CRF_i impacts on CRF_j, "1" is entered in the cell (i,j). Whether CRF_i does not influence CRF_j, "0" is entered in the intersection cell (i,j). By convention, the "1" has always been inserted on the diagonal because each factor impacts on itself.

Also, the transitivity check was added. The transitivity check allows us to analyze the interrelationship between CRFs by applying the transitivity logic: if factor "a" impacts on factor "b" and factor "b" impacts on factor "c", then factor "a" impacts on factor "c" (Vaishnavi *et al.*, 2019). The transitivity analysis is carried out on two levels, considering also when factor "a" impacts on factor "b", factor "b" impacts on factor "c" and factor "c" impacts on factor "d". Therefore, it is stated that factor "a" impacts on factor "d" with a second level transitivity. If any interrelation between CRFs occur, the "0" is replaced by 1* or 1**; otherwise, no changes happen. The first level transitivity is translated into 1*, while the second level transitivity is 1** (Vaishnavi and Suresh, 2020). Therefore, the reachability matrix with the transitivity analysis is shown in Table 2. The first row and the first column represent the 30 CRFs.

3.2.2 Driving power, dependence power and importance weighting of critical readiness factors. The driving power and the dependence power of each CRF are calculated to assess the nature of CRFs in terms of their importance during the implementation stage compared to the others. Indeed, the driving power represents how one CRF impacts others, and the dependence power represents how one CRF is affected by other CRFs (Swarnakar *et al.*, 2020). The driving $power_i$ is the sum of all the factors impacted by CRF_i. The dependence $power_i$ is the sum of all the factors that influence CRF_i. To determine the weight of each CRF, the ratio between driving power and dependence power is initially calculated, and then this

Table 1. CRFs From literature review

	CRFs		Definition	Impact	Some references
Management and leadership	CRF1	Management leadership	Team leaders and senior managers are inclined to change, lead the improvement project and motivate the whole organization, and they act as role models	CRF2, CRF3, CRF4, CFR7, CRF8, CRF11, CRF19, CRF23	Al-Balushi *et al.* (2014), Antony *et al.* (2012), Ben-Tovim *et al.* (2007)
	CRF2	Management commitment and involvement	Managers are committed and personally involved in the implementation of LSS in the company	CRF1, CRF4, CRF5, CRF9, CRF13, CRF19, CRF20, CRF21, CRF23	Al-Balushi *et al.* (2014), Albliwi *et al.* (2014), Alnajem *et al.* (2019), Arumugam *et al.* (2012), de Souza and Pidd (2011)
	CRF3	Teamwork	Group members work together and with teamwork spirt	CRF18, CRF23	Alnajem *et al.* (2019), Al-Balushi *et al.* (2014), Delgado *et al.* (2010)
Operational and strategy	CRF4	Costs analysis and resources allocation	The costs have been properly analyzed and the resources (technological, financial, human and temporal) made widely available	CRF5, CRF16, CRF17, CRF20, CRF21, CRF24	Holden (2011), Hussain *et al.* (2019), Jayaraman *et al.* (2012), Mozammel and Mapa (2011; Psychogios and Tsironis (2012)
	CRF5	Implementation plan	A detailed and structured implementation plan is written and available	CRF7	Aij *et al.* (2013), Albliwi *et al.* (2014), Alnajem *et al.* (2019), Bhasin (2012)
	CRF6	Process ownership	Management has defined who is in charge of the progress and implementation of each task and it has promptly communicated this to each process owner	CRF21	Albliwi *et al.* (2014), Bhasin (2012), de Souza and Pidd (2011), Hilton and Sohal (2012)
	CRF7	Long term strategy	The strategy and implementation plan are defined with a long-term approach and a goal of continuous improvement	CRF21	Aij *et al.* (2013), Al-Balushi *et al.* (2014), Albliwi *et al.* (2014), Chakravorty and Shah (2012)
Organizational	CRF8	Spread of LSS culture	Cultural change in the company has occurred and employees have embraced the LSS and organization culture and changed their attitudes	CRF11	Bhasin (2012), de Souza and Pidd (2011), Holden (2011), Jeyaraman and Kee Teo (2010), Narayanamurthy *et al.* (2018)
	CRF9	Organizational approach	The implementation of LSS is a goal pursued by the whole organization, it is coordinated by the organization and it is supported by the cooperation between different departments without individualistic competition	CRF7, CRF10, CRF18, CRF22	Albliwi *et al.* (2014), Arumugam *et al.* (2012), de Souza and Pidd (2011), Hilton and Sohal (2012), Jeyaraman and Kee Teo (2010), Rees (2014), Yadav *et al.* (2018)
	CRF10	Customized methodology	The methodology applied in the company is based on generic lean concepts, but it is adapted to the organizational characteristics and its needs	CRF2, CRF22	Albliwi *et al.* (2014), Bhasin (2012), de Souza and Pidd (2011), Holden (2011), Vaishnavi *et al.* (2019)
	CRF11	Inclination to change	The employees are willing to accept the change that the implementation of LSS implies	CRF5, CRF7, CRF23	Coronado and Antony (2002), de Souza and Pidd (2011), Glasgow *et al.* (2010)

(*continued*)

Table 1.

	CRFs		Definition	Impact	Some references
Effective Communication	CRF12	Transparent communication	Employees are provided with clear and comprehensive information about the LSS process, the long-term organization goals within the organization's strategic agenda, the implications this implementation brings, and the effort required to each person	CRF11, CRF19	Albliwi *et al.* (2014), Arumugam *et al.* (2012), Andersen *et al.* (2014), Antony *et al.* (2007), de Souza and Pidd (2011), Hilton and Sohal (2012)
	CRF13	Communication from management to employees	Management frequently communicates with employees about goals and reasons for adopting LSS approach, the implementation progress and the decisions taken	CRF8, CRF11, CRF15, CRF19	Coronado and Antony (2002), Delgado *et al.* (2010), Dickson *et al.* (2009), Fine *et al.* (2009), Jayaraman *et al.* (2012)
	CRF14	Communication from employees to management	Employees are encouraged to communicate with the management and to constantly report the problems they encounter in the workplace	CRF21, CRF23	Alnajem *et al.* (2019), de Souza and Pidd (2011), Vaishnavi *et al.* (2019), Vaishnavi and Suresh (2020)
	CRF15	Communication and trust between employees	Employees trust each other and their management	CRF11	Antony *et al.* (2007), Delgado *et al.* (2010), Narayanamurthy *et al.* (2018), Vinodh and Chintha (2011)
LSS knowledge and approach	CRF16	Management training	All managers attended training courses on LSS methodology and techniques and use of digital technologies	CRF5, CRF7, CRF8, CRF9, CRF10, CRF19, CRF28	Alnajem *et al.* (2019), Aij *et al.* (2013), de Souza and Pidd (2011)
	CRF17	Employees training	All employees attended training courses on LSS methodology and techniques and use of digital technologies	CRF3, CRF5, CRF8, CRF11, CRF13, CR19, CRF23, CRF28, CRF29	Al-Balushi *et al.* (2014), Aij *et al.* (2013), Alnajem *et al.* (2019), Andersen *et al.* (2014)
	CRF18	Cross-functional teams	Team members are selected from different departments, functional silos, professional silos and organizational levels	CRF5 CRF8, CRF9, CRF12, CRF14, CRF15, CRF19, CRF22, CRF29	Albliwi *et al.* (2014), Alnajem *et al.* (2019), de Souza and Pidd (2011), Delgado *et al.* (2010), Desai *et al.* (2012)
	CRF19	Employees involvement and empowerment	Employees are empowered, encouraged to actively participate in the decision-making and directly involved in implementation process	CRF11, CRF14, CRF22	Aij *et al.* (2013), Al-Balushi *et al.* (2014), Dickson *et al.* (2009), Hussain and Malik (2016)
	CRF20	Reward system	A reward system aligned with objectives is used to give monetary bonuses to employees based on their performances	CRF8, CRF11, CRF15, CRF19, CRF23, CRF26	Al-Balushi *et al.* (2014), Albliwi *et al.* (2014), Desai *et al.* (2012), Papadopoulos *et al.* (2011)
	CRF21	Decision making aligned with LSS	Every person at every organizational level involved in the LSS implementation knows the organization	CRF5, CRF7, CRF23, CRF30	Coronado and Antony (2002), Jeyaraman and Kee Teo (2010), Vaishnavi and Suresh (2020)

(*continued*)

	CRFs		Definition	Impact	Some references
		and organization goals	and LSS objectives and his decision-making is consistent with these goals		
	CRF22	Goals and mission definition	Organizational goals and mission are defined, aligned with the LSS objectives, and clearly communicated with the organization	CRF6, CRF11, CRF19, CRF21	Yadav and Desai (2017), Yadav *et al.* (2018), Alnajem *et al.* (2019), de Souza and Pidd (2011)
	CRF23	CI and monitoring	The performances are periodically monitored, and there is an approach of continuous improvement of the results over time	CRF7	Alnajem *et al.* (2019), Al-Balushi *et al.* (2014), de Souza and Pidd (2011)
Tools	CRF24	IT infrastructure	The IT infrastructure is developed and strengthened	CRF21, CRF25, CRF27, CRF28	Albliwi *et al.* (2014), Yadav and Desai (2017), Snee (2010)
	CRF25	Measurement system	A measurement system based on a set of indicators and measures is available, and it has been defined together with the groups involved in the LSS implementation	CRF26	de Souza and Pidd (2011), Kumar *et al.* (2007), Fillingham (2007), Jeyaraman and Kee Teo (2010), Karim and Arif-Uz-Zaman (2013)
	CRF26	Performance management	Employees' performances are assessed and analyzed with a performance management system	CRF20, CRF30	de Souza and Pidd (2011), Leite *et al.* (2016), Al-Balushi *et al.* (2014)
	CRF27	Data collection	Data is continuously collected for each process, and it is stored in a database available for use	CRF26	Al-Balushi *et al.* (2014), Leite *et al.* (2016), Narayanamurthy and Gurumurthy (2018)
	CRF28	Effective use of technology	Management exploits the available technologies, and the employees effectively use it	CRF12, CRF13, CRF14,	Stanton *et al.* (2014), Vaishnavi *et al.* (2019)
External	CRF29	Customer analysis	Customers were analyzed, divided into groups, and needs and value were identified for each customer group	CRF10, CRF21, CRF30	Al-Balushi *et al.* (2014), Narayanamurthy *et al.* (2018), Papadopoulos *et al.* (2011)
	CRF30	Supplier selection	Suppliers are properly selected based on requirements of customers and LSS technique: high quality, low cost and quick delivery	CRF7, CRF23	Albliwi *et al.* (2014), Narayanamurthy *et al.* (2018), Vaishnavi and Suresh (2020c), Vinodh and Chintha (2011), Vinodh and Vimal (2012)

Table 1.

Table 2. Reachability matrix with transitivity analysis

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	1	1	1	1*	1**	1	1	1*	1**	1	1**	1*	1*	1**	1*	1*	1*	1	1*	1*	1*	1	1*	1**	1**	1**	1**	1**	1**
2	1	1	1*	1	1	1**	1*	1*	1	1*	1*	1**	1	1*	1*	1*	1*	1*	1	1	1	1*	1	1*	1**	1*	1**	1**	1**	1*
3	0	0	1	0	1*	1**	1*	1*	1*	1**	1**	1*	0	1*	1*	0	0	1	1*	0	1**	1*	1	0	0	0	0	0	1*	1**
4	0	0	1*	1	1	1**	1*	1*	1*	1*	1*	1**	1*	1**	1*	1	1	1**	1*	1	1	1**	1*	1	1*	1*	1*	1*	1*	1*
5	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	1**	0	0	0	0	0	0	1**
6	0	0	0	0	1	1	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1*	0	0	0	0	0	0	1*
7	0	0	0	0	1*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1*	0	0	0	0	0	0	1*
8	0	0	0	0	1*	0	1*	1	0	0	1	0	0	0	0	0	0	0	0	0	1**	0	1*	0	0	0	0	0	0	1**
9	0	0	0	0	1*	1*	1	1*	1	1	1*	1*	0	1*	1*	0	0	1	1*	0	1*	1	1**	0	0	0	0	0	1*	1**
10	0	0	0	0	1	1*	1*	0	0	1	1*	0	0	1**	0	0	0	0	1*	0	1*	1	1**	0	0	0	0	0	0	1**
11	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1*	0	1	0	0	0	0	0	0	1**
12	0	0	0	0	1*	1**	1*	0	0	0	1	1	0	1*	0	0	0	0	1	0	1**	1*	1*	0	0	0	0	0	0	1**
13	0	0	0	0	1*	1**	1*	1	0	0	1	0	1	1*	1	0	0	0	1	0	1**	1*	1*	0	0	0	0	0	0	1**
14	0	0	0	0	1*	0	1*	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1*
15	0	0	0	0	1*	0	1*	0	0	0	1	0	0	0	1	0	0	0	0	0	1**	0	1*	0	0	0	0	0	0	1**
16	0	0	0	0	1	1**	1	1	1	1	1*	1*	1*	1*	1**	1	0	1*	1	0	1*	1*	1**	0	0	0	0	1	1**	1**
17	0	0	1	0	1	1**	1*	1	1**	1*	1	1*	1	1*	1*	0	1	1*	1	0	1*	1*	1	0	0	0	0	1	1	1*
18	0	0	0	0	1	1*	1*	1	1	1*	1*	1	0	1	1	0	0	1	1	0	1*	1	1*	0	0	0	0	0	1	1*
19	0	0	0	0	1*	1*	1*	0	0	0	1	0	0	1	0	0	0	0	1	0	1*	1	1*	0	0	0	0	0	0	1**
20	0	0	0	0	1*	1**	1*	1	0	0	1	0	0	1*	1	0	0	0	1	1	1**	1*	1	0	0	1	0	0	0	1**
21	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1
22	0	0	0	0	1*	1	1*	0	0	0	1	0	0	1*	0	0	0	0	1	0	1	1	1*	0	0	0	0	0	0	1*
23	0	0	0	0	1**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	1	0	0	0	0	0	0	1**
24	0	0	0	0	1*	0	1*	1**	0	0	1**	1*	1*	1*	1**	0	0	0	1**	1**	1	1**	1*	1	1	1*	1	1	0	1*
25	0	0	0	0	1**	0	1**	1**	0	0	1**	0	0	1**	1**	0	0	0	1**	1*	1**	1**	1*	0	1	1	0	0	0	0
26	0	0	0	0	1**	1**	1*	1*	0	0	1*	0	0	1**	1*	0	0	0	1*	1	1**	1**	1	0	0	1	0	0	0	1**
27	0	0	0	0	1**	0	1**	1**	0	0	1**	0	0	1**	1**	0	0	0	1**	1*	1**	1**	1*	0	0	1	1	0	0	0
28	0	0	0	0	1**	1**	1**	1*	0	0	1*	1	1	1	1*	0	0	0	1*	0	1*	1**	1*	0	0	0	0	1	0	1**
29	0	0	0	0	1*	1**	1*	0	0	1	1**	0	0	1**	0	0	0	0	1**	0	1	1*	1*	0	0	0	0	0	1	1
30	0	0	0	0	1**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	1	0	0	0	0	0	0	1

ratio is divided by the sum of all the ratios. The driving and dependence power are calculated, and they are presented in Table 3.

3.2.3 Level partition of the reachability matrix. The partition is an activity that allows to organize all the CRFs on different levels, considering not only the dependence power and the driving power but also the relationships of influence existing between the factors. For each CRF_i, three sets must be defined (Jena *et al.*, 2017):

- *Reachability*: it is the group of the factors on which the CRF_i impacts. Therefore, taking the i-row in the reachability matrix as reference, the reachability set is composed of those CRFs positioned in columns in whose intersection cell there is 1 or 1* or 1**;
- *Antecedent*: it is the group of the factors that influence the CRF_i. Therefore, the intersection set is composed of those CRFs positioned in rows that have 1 or 1* or 1** in the i-column of the reachability matrix; and
- *Intersection*: it is given by the intersection between the reachability set and the antecedent set.

Firstly, the reachability set is compared with the intersection set. If the CRFs contained in the two sets correspond to each other's exactly, the CRF is associated with the n-level

	Driving power	Dependence power	Driving power/dependence power	Weight
CRF1	30	2	15.00	0.184
CRF2	30	2	15.00	0.184
CRF3	18	5	3.60	0.044
CRF4	28	3	9.33	0.114
CRF5	5	30	0.17	0.002
CRF6	6	18	0.33	0.004
CRF7	5	30	0.17	0.002
CRF8	7	16	0.44	0.005
CRF9	17	8	2.13	0.026
CRF10	11	10	1.10	0.013
CRF11	6	23	0.26	0.003
CRF12	11	11	1.00	0.012
CRF13	13	8	1.63	0.020
CRF14	6	21	0.29	0.003
CRF15	7	16	0.44	0.005
CRF16	20	4	5.00	0.061
CRF17	21	4	5.25	0.064
CRF18	17	8	2.13	0.026
CRF19	10	20	0.50	0.006
CRF20	14	8	1.75	0.021
CRF21	5	30	0.17	0.002
CRF22	10	20	0.50	0.006
CRF23	5	30	0.17	0.002
CRF24	19	4	4.75	0.058
CRF25	13	5	2.60	0.032
CRF26	14	8	1.75	0.021
CRF27	13	5	2.60	0.032
CRF28	15	7	2.14	0.026
CRF29	12	9	1.33	0.016
CRF30	5	28	0.18	0.002

Table 3. Driving power, dependence power and weight W_i of each CRF

corresponding to the number of interactions made. When a CRF is assigned to a partition level, this factor is removed from reachability set of all CRFs for which the partition level has not yet been found. The algorithm continues until all CRFs are associated with a partition level. The algorithm was implemented considering the reachability matrix and the 30 CRFs were divided into 10 partition levels. A diagraph has been developed, and it is illustrated in Figure 1.

3.2.4 Linguistic assessment of critical readiness factors performance rating by experts. Linguistic terms are used to obtain, through survey, the performance rating of CRFs for the LSS implementation in the company. They are preferred to numerical grades because they allow a better understanding and evaluation of the answer as they are more explanatory than numbers. The linguistic terms used are: strongly disagree (SD), disagree (D), partially disagree (PD), neither agree nor disagree (NN), partially agree (PA), agree (A) and strongly agree (SA) (Lin *et al.*, 2006; Liou and Chen, 2006).

The performance ratings must be collected for each CRF. This value refers to the organization's readiness level in each specific aspect. It is necessary to collect the opinion of the experts who work in the company to have an overall view of the situation in the structure and to be able to proceed with a correct assessment of the LIRL. Therefore, the rating must be collected by interviewing the managers who work in the organization in position with decision-making capabilities and process improvement power. For this, a questionnaire was formulated in multiple-choice format, and the selectable answers correspond to the linguistic terms. Each point in the questionnaire corresponds to a CFR.

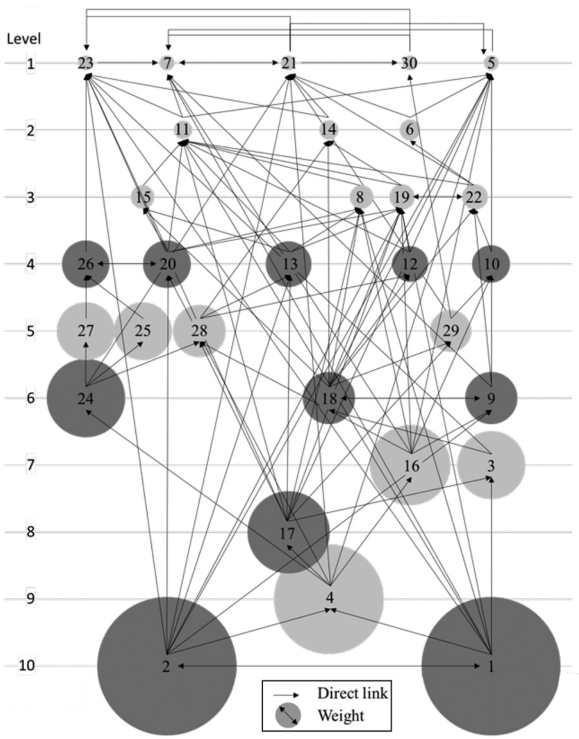

Figure 1.
Partitions Levels

3.2.5 Performance rating of critical readiness factors: conversion of linguistic terms using fuzzy logic approach. The linguistic performance ratings collected through the survey need to be converted into numeric terms. The approach adopted is using triangular fuzzy numbers, as they allow for easy translation of a linguistic expression into numbers while considering the variation of a subjective answer and simply performing operations to compute the desired result. Triangular fuzzy numbers (a,b,c) are defined with their membership functions [$f_A(x)$] described in equation (1) (Lin *et al.*, 2006):

$$f_A(x) = \begin{cases} \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{x-c}{c-b}, & b \le x \le c, \\ 0, & otherwise. \end{cases} \tag{1}$$

A set fuzzy number corresponding to each linguistic term is used to evaluate the rating of each CRF (Lin *et al.*, 2006; Sreedharan and Sunder, 2018). These linguistic ratings are expressed by triangular fuzzy numbers using a 0–10-point scale, as shown in Table 4.

Whether more people from the same company are interviewed, the answers must be averaged, and the LIRL is computed by applying equation (2) (Chen and Hwang, 1992). This formula must be used to reduce the votes of individual respondents to a single average performance rating for each CRF:

$$\begin{aligned} Average &= (a_1 b_1 c_1)+, \quad \ldots, + \quad (a_n b_n c_n) \\ &= \left(\frac{a_1+, \quad \ldots, \quad + \quad a_n}{n}, \frac{b_1+, \quad \ldots, \quad + \quad b_n}{n}, \frac{c_1+, \quad \ldots, \quad + \quad c_n}{n} \right) \end{aligned} \tag{2}$$

3.2.6 Lean implementation readiness level. The LIRL is an indicator obtained by reducing the importance weighting and the performance rating of all the CRFs into a single number that represents the organization's overall readiness level for LSS implementation. The LIRL is computed using equation (3) (Lin *et al.*, 2006; Vinodh and Vimal, 2012):

$$LIRL = \frac{\sum_{i=1}^{I} (W_i \otimes R_i)}{\sum_{i=1}^{I} (W_i)} \tag{3}$$

Linguistic variable	Fuzzy no.
Strongly disagree (SD)	(0,0.5,1.5)
Disagree (D)	(1,2,3)
Partially disagree (PD)	(2,3.5,5)
Neither agree nor disagree (NN)	(3,5,7)
Partially agree (PA)	(5,6.5,8)
Agree (A),	(7,8,9)
Strongly agree (SA)	(8.5,9.5,10)

Table 4. Linguistic terms and appropriate fuzzy numbers for CRFs rating for LSS implementation

where R_i: fuzzy performance rating for readiness for the implementation of LSS of i-th CRF; W_i: fuzzy importance weighting for readiness for the implementation of LSS of i-th CRF; I: total number of CRFs.

Triangular fuzzy numbers are then used to translate the number obtained into a linguistic term so that experts can understand more clearly the level of their organization. The most widely used way to deal with the translation of a triangular fuzzy number into linguistic terms is the Euclidean distance (Chen *et al.*, 2006). The linguistic term with the minimum distance is the one chosen to translate the LIRL into words. The set of natural-language expressions selected for labelling the LIRL is: not ready (NR), low ready (LR), average ready (AR), close to ready (CR) and ready (R). The correspondence between the chosen linguistic variables and the fuzzy numbers is shown in Table 5.

3.2.7 Rank fuzzy performance importance index (FPII). It is necessary to understand which factors have affected an organization when it was not "ready" to identify where to intervene to increase the score. To achieve this goal, two aspects have been considered: the rank of the fuzzy performance importance index (FPII) obtained from the answers given in the questionnaire, their relative weight, and the hierarchy of the factors, and thus the relations each one has with each other. To obtain the ranking score of the FPII, it is needed to compute the FPII number first for each CRF_i, given by equation (5):

$$FPII_i = U_i \otimes R_i \tag{5}$$

where $U_i = 1 - W_i$ (Lin *et al.*, 2006; Vinodh and Vimal, 2012); W_i is the fuzzy importance weight of CRF_i and R_i the performance rating of CRF_i.

The next step is to compute the ranking score of each factor, computed through the centroid method as equation (6):

$$Ranking\ \ score = \frac{a + 4b + c}{6} \tag{6}$$

where a, b and c are the lower, middle and upper numbers of the triangular fuzzy one (Lin *et al.*, 2006; Vinodh and Vimal, 2012).

Once all the fuzzy numbers are converted into single ones, it is possible to rank them from the highest value to the lowest. It is important to note that the factors which has high values of FPII are the one that are performing well, while low values of FPII are associated with factors that are acknowledged as underperforming by the model according to their importance.

3.2.8 Matching FPII with level partition. Nevertheless, identifying the weak CRFs is not enough. Indeed, since the factors could have impact on one another, it is better to focus on few implementations that have an impact on most of the hierarchy than on each single one,

Table 5. Linguistic terms and appropriate fuzzy numbers for lean implementation readiness level for implementation of LSS

Linguistic variable	Fuzzy no.
Ready (R)	(7, 8.5, 10)
Close to ready (CR)	(5.5, 7, 8.5)
Average ready (AR)	(3.5, 5, 6.5)
Low ready (LR)	(1.5, 3, 4.5)
Not ready (NR)	(0, 1.5, 3)

both in time and monetary terms. Moreover, by focusing on less implementation, it would be easier to achieve better results and assess them.

A Visual Basic for Applications code in Excel has been implemented that automatically checks if any weak CRF has direct links with some other weak factor with higher partition level. If any correspondence is found, then it will look for a link with other weak CRFs with even higher partition level, up to two times, since too many iterations would lead to marginal improvements on the weak factor under consideration.

The algorithm loops for each weak CRF "x" searching if any higher-level weak CRF "z" that has a direct link to the starting CRF is present. Thus, for each weak CRF, a reference factor is identified, which could be the CRF itself or an antecedent. The result of this algorithm will determine on which factors to focus first and on which it is possible to impact acting on the first ones.

The purpose of this algorithm is to make the management focus on correcting a few CFRs with higher impact on the others. Indeed, it is useless to let the experts focus on a factor that has weak antecedent factors because it is necessary that the organization has correctly implemented the factors positioned further down in the diagraph to be sure that it is correctly performing in that CRF.

3.2.9 Suggested corrective actions to improve weak critical readiness factors. At this point, an algorithm will propose suggested corrective actions according to the "weakness" of the factor:

- if the CRF is not weak, then it will be displayed "no corrective actions required" for that factor;
- if the CRF has been classified as weak but has some weak antecedents, the model will suggest focusing on the antecedent CRF. In this case, the algorithm identifies the weak CRF, and it searches if it has any weak antecedents. Then, it searches if the weak antecedent has any weak antecedents too. The iteration is carried out maximum twice, thus the algorithm goes up the diagram by a maximum of two antecedents; and
- to conclude, if the CRF has been classified as weak but it has no weak antecedents, the model will propose only a corrective action designed for the factor. These factors are called the weakest CRFs.

A graphical description of the result has also been implemented. Indeed, the final output of the LIRM is a diagraph automatically generated that highlights which CRFs are not critical, those that have weak CRFs as antecedents and eventually their interconnection, and those that are the weakest CRFs.

4. Results

To properly identify the suitable healthcare organizations for the model application, an analysis of the most appropriate hospitals was carried out. After the selection, the respondents must have a managerial role with decision-making power and be connected to the improvement processes of the organization.

The survey was submitted to senior members of several hospitals, and 13 responses from nine different hospitals have been collected. The interviewees cover managerial roles such as CEO, facility manager and operations manager. The respondents work in nine different hospitals. This means that for three structures, multiple answers were received. Hospitals *H3*, *H4* and *H5* received responses from multiple managers working in the same healthcare structure. Instead, hospitals *H1*, *H2*, *H6* and *H7* received a single response each. Moreover, for healthcare organization *H4*, managers who work in three different unities answered.

Table 6 shows the answers collected from the survey. The answers were given in linguistic terms, according to Table 4. The experts interviewed are indicated as E_i, as their names have not been reported for privacy. Similarly, the healthcare organizations' names are replaced by H_i.

To perform an accurate analysis, the answers of the 13 experts have not been considered as independent when they work in the same healthcare structure. Therefore, the following analysis is based on nine hospitals, thus aggregating the experts' answers as to whether they belong to the same H_i. Aggregating the answers obtained in the same hospital makes the results more attentive and less subjective, as they are based on multiple opinions. The aggregated Lean Healthcare Readiness Level for hospitals is reported in Table 7.

From the results, it is possible to note that the most frequent level is "average ready". Also, the most extreme level of readiness occurred ones, while the most extreme level of not readiness never occurred. From the analysis of the results obtained with the surveys, it emerges that seven times out of nine the implementation of LSS in a healthcare organization would have been done with a level of readiness far from being ready or closed to ready, thus in 78% of the cases there would have been a high probability of implementation failure.

Table 6.
Survey answers by 13 experts

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}
	H1	*H2*	*H3*	*H3*	*H4A*	*H4A*	*H4A*	*H4B*	*H4C*	*H5*	*H5*	*H6*	*H7*
CRF1	SA	PA	NN	D	SA	SA	NN	PA	PA	SA	A	A	SA
CRF2	A	D	SD	SD	D	A	NN	SD	D	SA	D	SD	NN
CRF3	SA	D	SD	SD	NN	SD	SD	SD	D	A	PA	SD	NN
CRF4	SA	PD	NN	SD	NN	NN	SD	SD	PA	A	A	NN	SA
CRF5	SA	PA	NN	SD	NN	NN	SD	SD	NN	A	SA	NN	SA
CRF6	SA	A	NN	SD	NN	A	NN	SD	NN	A	SA	NN	A
CRF7	SA	A	NN	SD	NN	NN	PA	PA	A	SA	SA	NN	A
CRF8	SA	D	SD	SD	NN	A	D	SD	NN	A	PA	SD	NN
CRF9	A	PD	SD	SD	NN	NN	D	SD	NN	A	PA	SD	D
CRF10	A	A	NN	SD	NN	A	PA	SD	A	A	SA	A	SA
CRF11	PA	PA	NN	NN	PA	SA	D	PA	PA	PA	PA	A	SA
CRF12	PA	D	SD	SD	NN	NN	SD	SD	D	A	A	D	NN
CRF13	PA	A	SD	SD	A	SA	PA	PA	NN	A	PA	PA	SA
CRF14	A	PA	NN	SD	PA	SA	A	A	A	A	NN	PA	D
CRF15	A	PA	D	SD	PA	A	NN	PA	PA	PA	PD	A	NN
CRF16	A	SD	NN	SD	NN	NN	SD	SD	D	PD	SD	D	SD
CRF17	PA	SD	SD	SD	D	NN	SD	SD	D	PD	SD	D	SD
CRF18	SA	SD	SD	SD	NN	NN	SD	SD	D	PA	D	SD	SD
CRF19	SA	NN	NN	SD	PA	SA	D	NN	PA	PA	NN	A	SA
CRF20	SA	A	A	SA	PA	PA	D	SD	D	D	PA	SA	SD
CRF21	NN	SD	SD	SD	NN	NN	NN	SD	PD	A	PD	NN	D
CRF22	NN	PD	NN	SD	PA	NN	SD	SD	D	A	SA	NN	NN
CRF23	A	PA	PA	SD	PA	A	D	NN	D	A	A	A	SA
CRF24	SA	PA	D	SD	SD	D	PD	PD	PA	PA	SD	SA	PA
CRF25	A	NN	PA	A	D	NN	NN	SD	NN	PA	A	NN	A
CRF26	SA	A	NN	A	D	NN	PD	SD	NN	NN	PA	SA	NN
CRF27	SA	PA	D	A	NN	PD	D	PD	NN	PA	A	SA	A
CRF28	A	PA	NN	SD	D	NN	NN	NN	PA	PA	A	A	SA
CRF29	A	PA	NN	SD	NN	NN	NN	SD	PA	PD	PA	PA	SA
CRF30	NN	PA	NN	NN	NN	NN	NN	AA	PD	NN	PA	A	SD

Moreover, these results demonstrate how effective and necessary the developed model is to control if a hospital structure can proceed with the LSS implementation and intercept any critical points to be improved.

Since eight out of nine hospitals were found to have a level different from being "ready", the LIRM model expressed a second output in addition to the LIRL. Indeed, the weak factors for each hospital were identified.

The identification of the weak factors is done with the FPII, which is computed by matching the performance rating obtained with the questionnaire and the importance weighting of each CRF. Then, the weakest factors have been identified by matching the FPII with the level partitions and interactions between factors.

To exemplify, the answers of one expert of Hospital *H2* are shown in Table 8. As reported, 13 factors have been identified as weak: CRF2, CRF3, CRF4, CRF8, CRF9, CRF12, CRF16, CRF17, CRF18, CRF19, CRF21, CRF22 and CRF25.

In turn, Table 9 shows for each hospital if the factors are good, if they are weak and need to change, or if another factor needs to be improved before it, and what this factor is. In other words, a tick indicates if the factor has not been identified as weak for that hospital; the word "Weak" for the weakest factors. The remaining factors are those identified as weak but without the prior importance. Indeed, for those factors, there is the reference of the factor that must be improved beforehand. Therefore, all the CRFs without ticks are the weak factors, but only those with "Weak" indicated are those on which the manager must focus in the first instance.

The percentage of weakest factors to focus on was therefore reduced to a range between 3% and 20%, leading experts to concentrate on maximum six CRFs per time. The application of the model and its ability to identify the most critical CRFs allows to considerably reduce the group of factors on which to concentrate.

Going into detail, the CRF11 was never identified as weak. This result could be judged as unexpected, and it appears inconsistent with what is stated in the literature. However, looking at it from another viewpoint, this may explain why it is often mentioned as a failure factor in the literature; indeed, resistance to change is an aspect that leaders and management underestimate, and it could often not be correctly addressed. Moreover, the results obtained are given by the combination of the performance rating provided by the experts in the surveys and the specific importance weight of each CRF. The weight of the CRF11 is low because it has a lot of antecedents and few dependent factors; indeed, it is positioned at the second level of the diagraph. Therefore, the LIRM coherently does not identify this factor as critical because, even if it were an actually weak aspect for a hospital, its performance could be indirectly improved thanks to the countermeasures implemented on its antecedents.

Similarly, the result obtained for CRF7, CRF14, CRF19 and CRF23 can be described, as these factors are at low levels and have low importance weight. Another factor that is always classified as not critical is CRF1. Conversely to what previously stated for the other factors, CRF1 is very important, and it is positioned on the bottom of the diagraph. This

Table 7. Aggregated lean implementation readiness level results

Expert Hospital	E_1 *H1*	E_2 *H2*	Mean *H3*	Mean *H4a*	E_8 *H4b*	E_9 *H4c*	Mean *H5*	E_{12} *H6*	E_{13} *H7*
LHRL	Ready	Average ready	Low ready	Low ready	Low ready	Average ready	Close to ready	Average ready	Close to ready

CRF	FRLSSI	Ri			Wi			Ui			FPIIi			Ranking	Weak	Proposed solution
CRF1	PA	5	6.5	8	0.184	0.184	0.184	0.82	0.82	0.82	4.08	5.31	6.53	5.31	–	–
CRF2	D	1	2	3	0.184	0.184	0.184	0.82	0.82	0.82	0.82	1.63	2.45	1.63	Weak	Weak
CRF3	D	1	2	3	0.044	0.044	0.044	0.96	0.96	0.96	0.96	1.91	2.87	1.91	Weak	Focus on CRF4
CRF4	PD	2	3.5	5	0.114	0.114	0.114	0.89	0.89	0.89	1.77	3.10	4.43	3.10	Weak	Focus on CRF2
CRF5	PA	5	6.5	8	0.002	0.002	0.002	1.00	1.00	1.00	4.99	6.49	7.98	6.49	–	–
CRF6	A	7	8	9	0.004	0.004	0.004	1.00	1.00	1.00	6.97	7.97	8.96	7.97	–	–
CRF7	A	7	8	9	0.002	0.002	0.002	1.00	1.00	1.00	6.99	7.98	8.98	7.98	–	–
CRF8	D	1	2	3	0.005	0.005	0.005	0.99	0.99	0.99	0.99	1.99	2.98	1.99	Weak	Focus on CRF4
CRF9	PD	2	3.5	5	0.026	0.026	0.026	0.97	0.97	0.97	1.95	3.41	4.87	3.41	Weak	Focus on CRF2
CRF10	A	7	8	9	0.013	0.013	0.013	0.99	0.99	0.99	6.91	7.89	8.88	7.89	–	–
CRF11	PA	5	6.5	8	0.003	0.003	0.003	1.00	1.00	1.00	4.98	6.48	7.97	6.48	–	–
CRF12	D	1	2	3	0.012	0.012	0.012	0.99	0.99	0.99	0.99	1.98	2.96	1.98	Weak	Focus on CRF3
CRF13	A	7	8	9	0.020	0.020	0.020	0.98	0.98	0.98	6.86	7.84	8.82	7.84	–	–
CRF14	PA	5	6.5	8	0.003	0.003	0.003	1.00	1.00	1.00	4.98	6.48	7.97	6.48	–	–
CRF15	PA	5	6.5	8	0.005	0.005	0.005	0.99	0.99	0.99	4.97	6.47	7.96	6.47	–	–
CRF16	SD	0	0.5	1.5	0.061	0.061	0.061	0.94	0.94	0.94	0.00	0.47	1.41	0.47	Weak	Focus on CRF2
CRF17	SD	0	0.5	1.5	0.064	0.064	0.064	0.94	0.94	0.94	0.00	0.47	1.40	0.47	Weak	Focus on CRF2
CRF18	SD	0	0.5	1.5	0.026	0.026	0.026	0.97	0.97	0.97	0.00	0.49	1.46	0.57	Weak	Focus on CRF17
CRF19	NN	3	5	7	0.006	0.006	0.006	0.99	0.99	0.99	2.98	4.97	6.96	4.97	Weak	Focus on CRF2
CRF20	A	7	8	9	0.021	0.021	0.021	0.98	0.98	0.98	6.85	7.83	8.81	7.83	–	–
CRF21	SD	0	0.5	1.5	0.002	0.002	0.002	1.00	1.00	1.00	0.00	0.50	1.50	0.50	Weak	Focus on CRF2
CRF22	PD	2	3.5	5	0.006	0.006	0.006	0.99	0.99	0.99	1.99	3.48	4.97	3.48	Weak	Focus on CRF2
CRF23	PA	5	6.5	8	0.002	0.002	0.002	1.00	1.00	1.00	4.99	6.49	7.98	6.49	–	–
CRF24	PA	5	6.5	8	0.058	0.058	0.058	0.94	0.94	0.94	4.71	6.12	7.53	6.12	–	–
CRF25	NN	3	5	7	0.032	0.032	0.032	0.97	0.97	0.97	2.90	4.84	6.78	4.84	Weak	Weak
CRF26	A	7	8	9	0.021	0.021	0.021	0.98	0.98	0.98	6.85	7.83	8.81	7.83	–	–
CRF27	PA	5	6.5	8	0.032	0.032	0.032	0.97	0.97	0.97	4.84	6.29	7.75	6.29	–	–
CRF28	PA	5	6.5	8	0.026	0.026	0.026	0.97	0.97	0.97	4.87	6.33	7.79	6.33	–	–
CRF29	PA	5	6.5	8	0.016	0.016	0.016	0.98	0.98	0.98	4.92	6.39	7.87	6.39	–	–
CRF30	PA	5	6.5	8	0.002	0.002	0.002	1.00	1.00	1.00	4.99	6.49	7.98	6.49	–	–

Table 8. Calculation for LIRL (H_2) computation and identification of weak CRFs

result could be due to the fact that, being the interviewees who cover roles that require leadership, they tend to not judge themselves as not good leaders.

Despite being at the minimum level, CRF21 is identified six times out of nine weak. This may be since all the organizations interviewed do not have any ongoing LSS implementation plans, so their decisions are also not made on the basis of the LSS principles. Instead, the CRF30 is classified twice as weak, and in both cases, it was identified as a solution by itself. This is because it has few antecedents, and when it is weak, it can only be improved by acting directly on the direct implementation of corrective actions for better selecting the suppliers.

The most frequently weak and weakest CRFs are located in the higher levels. This can be partially explained by the nature of the LIRM; the CRFs with higher weight are located at the bottom of the diagraph, and the FPII is computed considering both the importance weighting and the performance rating. However, it is interesting to note how the training, cross-functional teams and transparent communication are significantly more critical than the other factors at the same level.

Also, when the model is launched, it automatically gives also the diagraph. The diagraph shows in a graphical way the output obtained with the LIRM and the links between the weak factors and the factors proposed to them as a strong solution.

The diagraph is generated and automatically colored by the model. The bubbles represent the CRFs; their position on the different lines is relative to the level partition and

Table 9. LIRM results

	E_1	E_2	Mean	Mean	E_8	E_9	Mean	E_{12}	E_{13}
	H1	*H2*	*H3*	*H4a*	*H4b*	*H4c*	*H5*	*H6*	*H7*
LHRL	Ready	Average ready	Low ready	Low ready	Low ready	Average ready	Close to ready	Average ready	Close to ready
Weak factors	0	13	15	10	20	12	10	13	14
Weakest factors	0	2	1	2	1	5	6	2	5
CRF1	✓	✓	✓	✓	✓	✓	✓	✓	✓
CRF2	Improve	Weak	Weak	Weak	Weak	Weak	Weak	Weak	Weak
CRF3	✓	CRF4	CRF4	CRF4	CRF4	CRF17	✓	CRF4	CRF17
CRF4	✓	CRF2	CRF2	CRF2	CRF2	✓	✓	CRF2	✓
CRF5	✓	✓	✓	CRF2	CRF2	✓	✓	✓	✓
CRF6	✓	✓	✓	✓	CRF9	✓	✓	CRF9	✓
CRF7	✓	✓	✓	✓	✓	✓	✓	✓	✓
CRF8	✓	CRF4	CRF2	✓	CRF4	✓	✓	CRF4	✓
CRF9	✓	CRF2	CRF2	✓	CRF2	✓	✓	CRF2	CRF2
CRF10	✓	✓	✓	✓	CRF2	✓	✓	✓	✓
CRF11	✓	✓	✓	✓	✓	✓	✓	✓	✓
CRF12	✓	CRF3	CRF3	CRF3	CRF3	CRF3	✓	CRF3	CRF3
CRF13	✓	✓	CRF2	✓	✓	✓	CRF2	✓	✓
CRF14	✓	✓	✓	✓	✓	✓	✓	✓	CRF3
CRF15	✓	✓	CRF2	✓	✓	✓	CRF2	✓	CRF3
CRF16	Improve	CRF2	CRF2	CRF2	CRF2	Weak	Weak	CRF2	Weak
CRF17	Improve	CRF2	CRF2	CRF2	CRF2	Weak	Weak	CRF2	Weak
CRF18	✓	CRF17	CRF17	CRF17	CRF17	CRF17	Weak	CRF17	CRF17
CRF19	✓	CRF2	✓	✓	✓	✓	✓	✓	✓
CRF20	✓	✓	✓	✓	CRF2	CRF2	CRF2	✓	CRF2
CRF21	✓	CRF2	CRF2	✓	CRF2	CRF2	✓	CRF2	CRF2
CRF22	✓	CRF2	✓	✓	CRF2	CRF3	✓	CRF2	CRF2
CRF23	✓	✓	✓	✓	✓	CRF2	✓	✓	✓
CRF24	✓	✓	CRF2	CRF2	CRF2	✓	Weak	✓	✓
CRF25	✓	Weak	✓	✓	CRF4	✓	✓	Weak	✓
CRF26	✓	✓	✓	Weak	CRF24	✓	Weak	✓	Weak
CRF27	✓	✓	✓	✓	CRF4	Weak	✓	✓	✓
CRF28	✓	✓	CRF4	✓	✓	✓	✓	✓	✓
CRF29	✓	✓	CRF4	✓	CRF4	✓	CRF17	✓	✓
CRF30	✓	✓	✓	✓	✓	Weak	✓	✓	Weak

Source: All figures and tables are authors' own work their size to importance weighting of each CRF. The CRFs are connected by a grey arrow from CRF_i to CRF_j when CRF_i impacts on CRF_j, and all the arrows are ascending. The colouring instead varies according to the results obtained by the LIRM implementation to the specific hospital: all factors that are not weak are coloured green; weak factors instead are divided into three different colours: red if it is a weakest, therefore a CRF that has itself as a strong solution; yellow if it is a CRF that has a strong solution to focus on another factor; and finally, yellow-red hybrid colour if the CRF has a strong solution to focus on another CRF, but at the same time it is proposed as a strong solution to at least one of its depending CRFs. Moreover, the arrows that directly connect two weak CRFs are highlighted in yellow to allow the user to easily identify which is the weak antecedent of a weak CRF that is intercepted by the model. To illustrate, the diagraph obtained with the LIRM implementation for *H2* is shown in Figure 2.

5. Conclusion

The purpose of this work was to identify the CRFs that mainly affect the implementation of LSS in an organization and their interactions, and to develop a model that allows the

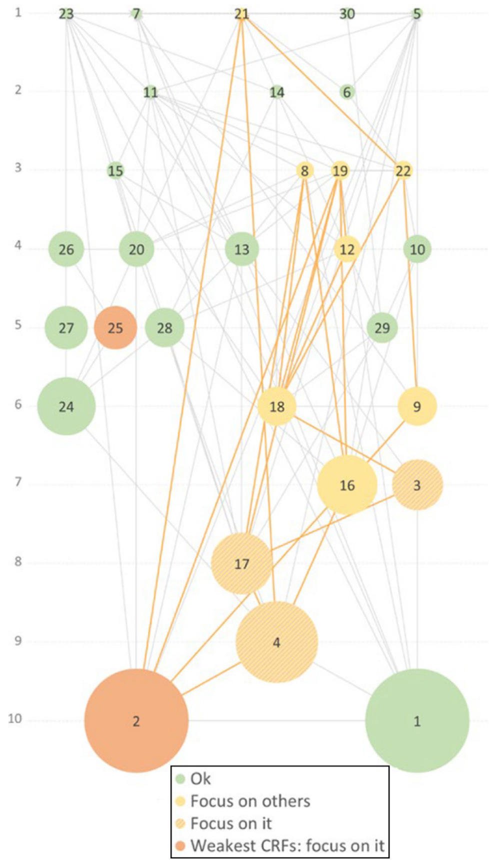

Figure 2.
Hierarchical diagraph with LIRM output indication for H_2

management to assess the LIRL of its company and to intercept possible causes of implementation failure.

This work has theoretical implications as it proposes a new methodology that eliminates the negative aspects and limitations of the TISM methodology and the fuzzy logic approach currently applied to evaluate the LSS readiness of a company. The novelty of the LIRM is that the TISM approach is advanced by adopting the fuzzy logic approach to include the actual performance of the company to evaluate the readiness level. Further, the implication of the present methodology lies in the fact that it provides a solution not only by defining the weak CRFs but also by giving an indication of priority as it identifies the weak antecedent factors that inhibit the preparedness of the depending factors.

Regarding practical implications, the work provides a generic model applicable to any company in any sector that wishes to apply LSS or that has already applied it. It is a 360-degree model, as it not only assesses the LIRL of the company but also identifies the causes of failure. The advantage of this methodology is that it is not fixed, it considers the current situation of each company according to the performance through a survey, and it guides the management in the implementation. Moreover, the LIRM assists the management during the whole implementation period, as it should be applied iteratively throughout the implementation period to monitor the maintenance of the LIRL and to intercept possible causes of failure.

The validation in a limited group of hospitals and by interviewing 13 experts working in the healthcare sector was a limitation of the work. Therefore, tree research directions are proposed. Firstly, the model can be empirically validated by examining the applicability over a larger sample of healthcare organizations and in other geographic areas. Secondly, the model could be analysed in other industry sectors. Finally, the model could be longitudinally validated to follow a company during the LSS implementation process and to assess whether the model was effectively able to avoid the LSS implementation project failure.

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