Lean manufacturing and socio-technical and ergonomics practices implementation

Guilherme Luz Tortorella, Lizandra Lupi Vergara, Evelise Pereira Ferreira,
and **Carlos Ernani Fries**
Department of Production and Systems Engineering
Federal University of Santa Catarina
Campus Trindade, C.P. 476, Florianópolis, SC 88040-900, Brazil
gtortorella@bol.com.br, l.vergara@ufsc.br, evelliseferreira@gmail.com, carlos.fries@ufsc.br

Abstract

The implementation of Lean Manufacturing (LM) means a systematic approach of various management methods and practices, which may influence individuals' job content and the quality of work. However, research related to Socio-technical and Ergonomics (SE) factors has for a long time solely focused on regular production work to a large extent. This study aims to develop a framework that enables to assess the main LM practices with regard to SE practices implementation within companies undergoing a lean implementation. The proposed method comprises the integration of complementary approaches, which provides a maturity analysis matrix illustrated in a case study, indicating whether the identified LM and SE practices' gaps are systemic or punctual, thus prioritizing the improvements. Further, through the establishment of the degree of criticality of LM practices, our outcomes allow to identify implementation gaps in the lean process that are highly related with the current status of sociotechnical and ergonomics improvements in the company, anticipating problems and developing the practices that converge to them.

Keywords
Lean manufacturing practices; socio-technical and ergonomics practices; maturity analysis.

1. Introduction

Lean Manufacturing (LM) has become popular among manufacturing industries, services and large commercial areas. The implementation of LM means a systematic approach of various management methods and practices (Seppälä and Klemola, 2004). Such approach presents the human element as a fundamental factor for continuous improvement sustainability. Thus, it influences individuals' job content and the quality of work, through the increase of opportunities for participation and learning (Getty, 1999). A LM must develop and consider a set of work features to bring compatibility with workplace ergonomics, namely at a muscular, cognitive and emotional demands level (Arezes et al., 2015). Aligned to this concept, Eklund's (2000) study shows a clear relationship between work demand and quality and productivity performance in lean implementations.

Research related to Socio-technical and Ergonomics (SE) factors has for a long time focused on regular production work to a large extent. However, Backstrand et al. (2013) state that it is important to include such human factors as a part of LM implementation, since LM differs radically from mass production models in terms of the work demands and social aspects. Theoretically, LM may push individual's muscular, cognitive, and emotional resources to the limit. At the same time, it promotes task variety, employment security, financial incentives, development and utilization of skills and knowledge, and knowledge of organizational performance (Seppälä and Klemola, 2004; Toralla et al., 2012). Saurin and Ferreira (2009) reinforce that LM and SE practices are not necessarily in conflict and that there are plenty of opportunities for synergy between both areas.

To better evaluate whether a production system has a proper design and a reasonable work demand, it is necessary to accumulate evidence that is related to both LM and SE practices. Such evidences are obtained from a variety of sources both engineering and human (Macleod, 2003; Lean and Shan, 2012). Literature presents few evidences regarding researches that investigate the potential synergy among LM and SE practices implementation (Zink, 2000; Tortorella et al., 2015). However, there are some data available from researches in developed countries scenario to answer questions about the impact of LM practices on SE practices implementation, in which operational work has been mainly researched in terms of work design (Koukoulaki, 2014; Eklund, 2000). Further, research on SE practices adoption in organizational contexts under LM implementation may have been hampered by the inadequacies of prior studies both from theoretical and methodological standpoints (Genaidy and Karwowski, 2003). In fact, few organizations study their operations in detail as long as they appear to be working satisfactorily (Hagg, 2003). Therefore, a descriptive study that investigates how LM and SE practices may be related in order to mutually converge to a more robust implementation is yet to be established in a company under lean implementation.

This study aims to develop a framework that enables to assess the relationship between LM and SE practices in companies undergoing a lean implementation. The proposed method comprises a combination of techniques that allow the identification of deficiencies related to the adoption of LM practices that may support SE practices implementation, indicating a prioritization of improvements opportunities to better sustain them. Moreover, through the integration of aspects related to SE and LM, whose evidences are scarce in previous studies, the method fills a theoretical gap observed in the literature. The method is based on an adaptation of the process maturity concept, which was extensively applied by Tortorella and Fogliatto (2014) and Fraser et al. (2002). This research is illustrated on a case study carried out in a Brazilian auto parts manufacturer company, which has been implementing LM practices for more than ten years. Despite the fact that this company has been continuously exposed to LM practices and improvement activities, it has not adopted an integrated and sustainable approach, especially regarding SE practices. Thus, with the application of the proposed method, it is expected to understand the existent gaps and critical LM practices, so that the improvement opportunities can be addressed.

The contribution of this research is two-fold. First, academically, it provides a method that combines assessment of LM and SE practices in a unique approach. Such combination fulfils the existent gaps identified in literature, since it integrates lean implementation aspects from an ergonomics standpoint. Moreover, it enables to measure the maturity of LM practices correlated with SE practices, corroborating with the improvement of the involved SE factors under such context. We are not aware of any other available method that is comparable regarding its objectives to the present proposition. Secondly, in terms of managerial implications, the study's outcomes enable the establishment of an improvement portfolio, indicating which LM practices should be reinforced in order to enhance SE aspects within the company. This fact allows companies to address such opportunities and avoid the implementation of divergent or useless approaches, that may demand high levels of effort without contributing to SE practices adoption.

This rest of this paper is structured as follows. Section 2 gives an overview of the literature on LM and SE practices implementation. Section 3 describes the proposed method, with results of its application in a large-sized auto parts manufacturer presented in section 4. Section 5 closes the paper presenting conclusions and future research opportunities.

2. Background

2.1 LM practices

The adoption of lean practices requires a change in the management of workers and in job design. Companies implementing lean need to shift from traditional models of mass production and Tayloristic organization to new models, specifically when organizing their work systems and management practices (Longoni et al., 2013). The challenge lies on justifying and examining why and under which condition the lean practices have competitive value and contextual relevance (Ketokivi and Schroeder, 2004).

Thus, the selection of appropriate practices for process improvement and identification of their applicability in operations feature an additional issue for industrial managers (Herron and Braiden, 2006). This problem is enhanced by the large number of available lean practices, which total over 100 (Pavnascar et al., 2003). However, Bhasin and Burcher (2006) state that companies generally start their lean implementation using one or two lean practices, and implement them throughout the company, realizing soon that such practices do not lead to systemic improvements in the value stream. To promote a wider impact, lean practices must be applied simultaneously at points where the need is greatest. Marodin and Saurin (2013) comment that regardless the fact that LM has been used for decades, generalizable implementation steps have not yet emerged.

In this sense, Table 1 consolidates the most frequent LM practices evidenced in literature. Fifteen widely deemed researches were selected, highlighting nineteen LM practices as the most cited ones. From these, two practices "standardized work" and "problem solving methods" seem to be the most frequently evidenced in the investigated literature. The first one appears to be applied under different motivational reasons: (i) to create basic stability in production processes by mitigating process variability (Doolen and Hacker, 2005; Stentoft and Vagn, 2013), (ii) to balance workload among employees as observed by Shah and Ward (2007) and Bortolotti et al. (2015), and (iii) to emphasize quality procedures and key daily routines (Furlan et al., 2011; Bhamu and Singh Sangwan, 2014). Despite its relevance, the research efforts of the second practice have been recently associated with LM literature (Netland et al., 2015; Marodin et al., 2015). This fact may be justified by the evolutionary comprehension of LM and its practices, which have achieved different patterns of understanding along time (Hines et al., 2004). Overall, all nineteen LM practices have been consistently studied in LM literature and, hence, may be representative to characterize a lean implementation.

Table 1. Appearance of LM practices in literature

LM practices	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	Agreement
1-Flexible manpower	X		X			X		X	X	X	X		X	X	X	67%
2-Pull system	X	X		X		X	X	X	X	X	X	X		X	X	80%
3-Takt time	X	X		X		X		X				X		X	X	53%
4-Continuous flow	X	X		X		X	X	X	X	X	X	X		X	X	80%
5-Material supply	X	X	X	X			X	X	X	X	X	X		X	X	80%
6-Zero defects	X	X			X	X	X	X	X	X				X	X	67%
7-Quality assurance	X	X	X	X				X	X	X				X	X	60%
8-Product / process quality planning	X		X	X	X			X	X	X		X		X	X	67%
9-Standardized work	X	X		X	X		X	X	X	X	X	X	X	X	X	87%
10-Production leveling	X			X	X	X	X	X	X	X	X	X		X	X	80%
11-Maintenance system	X	X		X		X	X	X	X	X	X	X		X	X	80%
12-Workplace organization	X	X					X	X	X	X	X	X	X	X	X	73%
13-Goal oriented teams	X					X	X			X	X		X	X	X	53%
14-Cross functional work		X		X	X					X	X			X		40%
15-Organizational design				X	X					X				X		27%
16-Problem solving methods	X		X		X	X	X	X	X	X	X	X	X	X	X	87%
17-Improvement organization			X	X		X				X	X		X	X		47%
18-Prioritization				X		X	X		X	X	X		X	X	X	60%
19-Improvement approach	X			X			X		X	X			X	X	X	53%

Authors: (1) Shah and Ward, 2003; (2) Doolen and Hacker, 2005; (3) Treville and Antonakis, 2006; (4) Shah and Ward, 2007; (5) Furlan et al., 2011; (6) Stone, 2012; (7) Moyano-Fuentes and Sacristán-Díaz, 2012; (8) Marodin and Saurin, 2013; (9) Stentoft and Vagn, 2013; (10) Netland and Ferdows, 2014; (11) Bhamu and Singh Sangwan, 2014; (12) Jasti and Kodali, 2015; (13) Bortolotti et al., 2015; (14) Netland et al., 2015; (15) Marodin et al., 2015.

2.2 SE practices

Any successful enterprise must possess effective and efficient organization of work at the management level in order to balance the work demands and conditions of the workforce and, subsequently, establish the best socio-technical and ergonomics practices conducive for maximum human health, productivity and quality of work (Karwowski et al., 1994; Genaidy and Karwowski, 2003; Jaworek et al., 2010). Therefore, a holistic view of the process is needed in order to attain not only to machinery and equipment, but also to the involvement of human resources. The underlying concepts to SE practices may be considered into the planning and execution of operational activities, in order to establish proper conditions and better results in the interaction between workers and work environment (Ferreira and Gurgueira, 2013).

Based on our literature review, 22 practices stand out as the most frequent SE practices in a management level of adoption, as shown in Table 2. From these 22, the practice "regulation of technical, organizational and human aspects" appears to be the most cited one in literature. This practice is usually associated with organizations' internal procedures that comprise managerial routines (Dul and Neumann, 2009; Nunes, 2015). These procedures aim to reinforce and provide proper guidance of management expectation with regards to technical, organizational and human aspects on a daily basis for all productive activities within the company (Arezes et al., 2015). It is worthy to notice that a few researchers also relate it with behavioral regulations in a work environment (Koukoulaki, 2010; Camarotto and Vanalle, 2015).

In opposition, "benchmarking for processes innovation" seems to be a practice that has not yet been fully adopted and, in particular, recognized as beneficial for practical implementation of SE factors. However, studies that evidence its application (e.g. Bezerra and Carvalho, 2011; Ferreira and Gurgueira, 2013) report significant advantages in its adoption from the ergonomics perspective. Similarly to the previous practice, "clarity in targets definition" also presents a low agreement percentage among the studied authors. Despite its obvious relevance within an organization context, this practice is rarely denoted as influential for the implementation of SE factors (Koukoulaki, 2010) or even deemed as an SE practice (Saurin and Ferreira, 2009). Thus, it is reasonable to expect that its appearance in the ergonomics literature is less frequent. Overall, these 22 SE practices have been consistently evidenced in literature and may represent, for this study's purpose, the implementation of SE factors within a company.

Table 2. Appearance of SE practices in literature

SE practices	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	Agreement
1- Communication and information system	X		X	X	X			X	X	X					X	53%
2- Problem solving indicators exposure							X			X					X	20%
3- Overload for achievement of goals		X		X	X				X	X	X	X		X	X	60%
4- Management of staff turnover			X			X						X		X	X	33%
5- Ergonomics criteria for workstation design				X	X	X	X	X	X	X	X	X	X	X	X	80%
6- Workstations appropriated to workers				X	X	X	X	X	X	X	X	X	X	X	X	80%
7- Workers' recognition and reward				X	X			X	X				X	X		40%
8- Synergy among functional areas	X		X	X	X		X	X	X	X	X	X	X	X	X	87%
9- Teamwork and coaching	X				X	X		X	X			X	X	X	X	60%
10- Clarity in targets definition					X					X			X			20%
11- Clarity in defining the role of workers				X	X			X					X			27%
12- Risk alerts utilization						X			X		X		X	X	X	40%
13- Search for good organizational climate	X	X	X	X	X			X	X		X	X	X	X	X	80%
14- Search for the health and safety of workers		X	X	X	X	X		X	X	X	X	X	X	X	X	87%
15- Balancing among quality, scope, time and cost			X	X	X	X		X	X	X	X	X	X	X	X	80%
16- Anticipating and reducing the risk of incidents				X	X	X			X		X		X	X	X	53%
17- Appreciation for workers training		X	X	X	X		X	X	X		X	X	X	X	X	80%
18- Ergonomics recommendations as regulations				X	X	X	X			X			X	X	X	53%
19- Clear strategies, symbols and methods		X	X	X	X	X	X		X	X	X		X	X	X	80%
20- Regulation of technical, organizational and human aspects	X	X		X	X	X	X	X	X	X	X	X	X	X	X	93%
21- Meetings for communication of projects					X			X				X		X		27%
22- Benchmarking for processes innovation								X		X						13%

Authors: (1) Nunes, 2015; (2) Arezes et al., 2015; (3) Genaidy and Karwowski, 2003; (4) Dul and Neumann, 2009 ; (5) Saurin and Ferreira, 2009; (6) Womack and Jones, 2005; (7) Silva et al., 2009; (8) Ferreira and Gurgueira, 2013; (9) Guimarães et al., 2015; (10) Bezerra and Carvalho, 2011; (11) Koukoulaki, 2014; (12) Conti et al., 2006; (13) Koukoulaki, 2010; (14) Camarotto and Vanalle, 2015; (15) Santos et al. (2015).

3. Proposed method

The proposed method is comprised of three main steps: (i) determination of LM and SE practices adoption level, (ii) analysis of maturity levels, and (iii) consolidation and prioritization of improvement opportunities. These three sequential steps outlined in Figure 1 are detailed in the sections to follow.

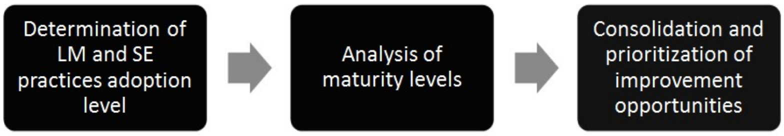

Figure 1. Three sequential steps of the proposed method

3.1 Determination of LM and SE practices adoption level

To determine the adoption level of LM and SE practices in the company, we proposed two questionnaires. The first one intended to identify the adoption level of 19 key practices for lean implementation, as referred in Table 1. The second questionnaire aimed at assessing the adoption level of 22 fundamental SE practices, which were presented in Table 2. Both questionnaires should be applied to individuals from senior management, which are supposed to present a broader organizational perspective and, thus, a more holistic view of these practices' implementation. The adoption level of LM and SE practices are evaluated using a five-point scale, where 1 denotes a practice that has not been implemented, 5 denotes full implementation of the practice and intermediate values denote intermediate situations. For the assessment of LM practices, responses obtained for each question are averaged, rescaled onto a [0,1] continuous scale, and denoted by f_m (m=1,…,19) such that a high value of f_m reinforces a desirable condition. Analogously, responses for SE practices are also averaged, rescaled onto a [0, 1] continuous scale, and denoted by l_n

(n = 1,…, 22). Since the method aims to assess the opportunities for further implementation of LM and SE practices in the company, their gaps for full adoption are given by the complement of f_m and l_n, respectively. Thus, the gaps for full adoption of LM and SE practices in the company are given by g_m and h_n, respectively, using the following expressions:

$$g_m = 1 - f_m, \;\; m = 1, \dots, 19 \quad (1)$$
$$h_n = 1 - l_n, \;\; n = 1, \dots, 22 \quad (2)$$

3.2 Analysis of maturity levels

Values of g_m and h_n are used as input data in the maturity index matrix (**M**) presented in Figure 2. In that matrix, LM practices, denoted by LM_m (m 1,…,19), are related to SE practices, denoted by SE_n (n =1,…,22); intensity of the relationship between LM_m and SE_n is given by r_{mn}, and written in the intersection between row m and column n. The intensity of the relationship quantifies the impact of each LM practice on each SE practice.

		SE practices				
LM practices	Gap for full adoption of LM practices	SE_1	…	SE_{22}	Degree of importance of LM practices	Degree of criticality of LM practices
LM_1	g_1				i_1	c_1
⋮	⋮		r_{mn}		⋮	⋮
LM_{19}	g_{19}				i_{19}	c_{19}
Gap for full adoption of SE practices		h_1	…	h_{22}		

Figure 2. LM and SE practices' relationship matrix **M**

Relationships in **M** were gathered through interviews with six experts. The criteria for experts' selection were lean implementation experience and ergonomics expertise. These experts, with at least 10 years of experience in either LM implementation or ergonomics expertise in large companies located in Brazil, were consulted to answer the following question: 'what is the intensity of the relationship between LM practice m and SE practice n?'.

Responses were given on a continuous scale of nine points, where 0 indicates no relationship and 9 indicates maximum intensity of relationship between m and n. The expert's responses r_{mnk} (k=1,…,6) were averaged and weighted by their years of experience y_k in order to assign higher weights for the most experienced experts, and consolidated in **M**. Since experts' background is influential to establish such relationships intensity, we recommend using **M** for maturity assessment in contexts of large-sized companies, with discrete processes and high volume production. Thus, the relationship intensity r_{mn} is given by Equation (3):

$$r_{mn} = \frac{\sum_{k=1}^{6} r_{mnk} \times y_k}{\sum y_k}, \;\; k = 1, \dots, 6 \quad (3)$$

M is the basis for determining the company's maturity level; for that, information gathering on the gap for full adoption of LM and SE practices in the company given in Equations (1) and (2) are necessary. There are two indicators calculated from the information inputted in **M**; they are:

- Degree of importance of LM practices (i_m): represents the relevance of practice m in the SE practices implementation, and is given by the following expression:
$$i_m = \sum r_{mn} \times h_n \quad (4)$$
- Degree of criticality of LM practices (c_m): given by the product between the importance of practice m and its gap for full adoption in the company; i.e.
$$c_m = i_m \times g_m \quad (5)$$

3.3 Consolidation and prioritization of improvement opportunities

LM practices presenting high c_m values are critical for the company, and should be viewed as improvement opportunities. To best visualize critical practices, we suggest listing them in a table along with c_m values. Although evident from the analysis of c_m values, to better compare criticality values, we created a differentiation index p that gives the number of standard deviations of each individual value with respect to the average of the LM practices.

The standardized *p* scores, usually applied in maturity analysis (Tortorella and Fogliatto, 2014), enable to remove scale effects, and large positive differentiation values indicate the most critical problems. For our purpose, we defined that standardized scores displaying values larger than 1.0 would be considered as the most critical ones, and, thus, prioritized in order to corroborate to SE practices implementation in the company. Finally, c_m values are ordered and an improvement opportunities portfolio is defined. The use of graphic tools such as a Pareto graph is recommended to support the decision-making process.

4. Case study

We now illustrate the application of our propositions in a case study. The company under analysis is an automotive parts manufacturer located in the south of Brazil. Level of product customization is medium, and manufacturing processes are organized in assembly lines and cells. A total of 856 employees work at the company, and the total annual revenue is around US$ 300 million.

Since 2005, the company has made several efforts to implement lean practices. The implementation of LM practices has been facilitated by a continuous improvement department comprised by four members, whose activities are mainly focused on manufacturing processes. At the same time, ergonomics issues have been addressed along time through the continuous adoption of SE practices, which are leaded by the safety department. This department is managed by the company's safety engineer, which is supported by more three safety technicians, whose scope is distributed according to the production areas. Both approaches LM and SE have been independently adopted and deployed within the company's context. The isolated implementation of such practices offered immediate results; however, some limitations are notoriously evidenced. For instance, in interviews with the senior management, its members stated that some practices were not sustained in the long run as initiatives were left aside. Most of the interviewed members attributed the difficulty in sustaining either LM or SE practices to the lack of a complementary approach aimed at promoting a synergic adoption, which may enhance their benefits and provide more robust processes. To address that problem, the proposition in Section 3 was applied in the company with results presented in the following sections.

4.1 Determination of LM and SE practices adoption level

Due to strategic reasons explained in 'section 3.1', both questionnaires were only applied to senior managers, whose sample is represented by 23 individuals. Recall that the adoption levels of LM and SE practices are assessed regarding their implementation level using a one to five scale, where 5 denoted full adoption. Table 3 gives the list of LM practices, the average values from the 23 responses, f_m and g_m values. Analogously, Table 4 presents SE practices and their average responses, with l_n and h_n values. A reliability analysis on collected data indicated a Cronbach's alpha of 0.93 and 0.87 for LM and SE practices questionnaires, respectively. According to Mitchell and Jolley (1996), alpha coefficient values larger than 0.70 are considered acceptable, indicating respondents presenting similar response profiles; Flynn et al. (1990) add that for respondents unfamiliar with the scale, alpha coefficient values equal to 0.60 or larger are deemed acceptable. Since the calculated alphas in this study were higher than these values, respondent's consistency is considered satisfactory. Regarding the LM, the practice LM_{12} (workplace organization) seems to be the most adopted in the company; while practices LM_{13} and LM_{15} ('goal oriented teams' and 'organizational design', respectively) present the lowest level of implementation. For SE practices, SE_{13} (search for good organizational climate) appears as the most implemented practice. On the other hand, company's attention to SE_1 (communication and information system) and SE_8 (synergy among functional areas) seems to be viewed as the least adopted practices.

Table 3. Responses of LM practices questionnaire in the company

	LM practices	Average value of responses	LM practices adoption level in the company (f_m)	Gap for full adoption of LM practices (g_m)
LM1	Flexible Manpower	3.23	0.65	0.35
LM2	Pull system	3.32	0.66	0.34
LM3	Takt time	2.82	0.56	0.44
LM4	Continuous flow	3.00	0.60	0.40
LM5	Material supply	3.09	0.62	0.38
LM6	Zero defects	3.05	0.61	0.39
LM7	Quality assurance	3.55	0.71	0.29
LM8	Product and process quality planning	3.64	0.73	0.27
LM9	Standardized work	3.50	0.70	0.30

LM10	Production leveling	3.18	0.64	0.36
LM11	Maintenance system	3.45	0.69	0.31
LM12	Workplace organization	3.91	0.78	0.22
LM13	Goal oriented teams	2.77	0.55	0.45
LM14	Cross functional work	3.00	0.60	0.40
LM15	Organizational design	2.77	0.55	0.45
LM16	Problem solving methods	3.36	0.67	0.33
LM17	Improvement organization	2.82	0.56	0.44
LM18	Prioritization	3.45	0.69	0.31
LM19	Improvement approach	3.55	0.71	0.29

Table 4. Responses of SE practices questionnaire in the company

SE practices		Average value of responses	SE practices adoption level in the company (l_n)	Gap for full adoption of SE practices (h_n)
SE_1	Communication and information system	2.86	0.57	0.43
SE_2	Problem solving indicators exposure	3.18	0.64	0.36
SE_3	Overload for achievement of goals	2.91	0.58	0.42
SE_4	Management of staff turnover	3.23	0.65	0.35
SE_5	Ergonomics criteria for workstation design	3.32	0.66	0.34
SE_6	Workstations appropriated to workers	3.05	0.61	0.39
SE_7	Workers' recognition and reward	3.18	0.64	0.36
SE_8	Synergy among functional areas	2.86	0.57	0.43
SE_9	Teamwork and coaching	3.05	0.61	0.39
SE_{10}	Clarity in targets definition	3.50	0.70	0.30
SE_{11}	Clarity in defining the role of workers	3.32	0.66	0.34
SE_{12}	Risk alerts utilization	3.55	0.71	0.29
SE_{13}	Search for good organizational climate	3.73	0.75	0.25
SE_{14}	Search for the health and safety of workers	3.55	0.71	0.29
SE_{15}	Balancing among quality, scope, time and cost	3.14	0.63	0.37
SE_{16}	Anticipating and reducing the risk of incidents	3.64	0.73	0.27
SE_{17}	Appreciation for workers training	3.18	0.64	0.36
SE_{18}	Ergonomics recommendations as regulations	3.14	0.63	0.37
SE_{19}	Clear strategies, symbols and methods	3.00	0.60	0.40
SE_{20}	Regulation of technical, organizational and human aspects	3.36	0.67	0.33
SE_{21}	Meetings for communication of projects	3.36	0.67	0.33
SE_{22}	Benchmarking for processes innovation	3.36	0.67	0.33

4.2 Maturity analysis and ranking of improvement opportunities

The relationship intensities between LM and SE practices in **M**, given by r_{mn}, were averaged and weighted by experts' experience, which is presented in Table 5.

Table 5. Experts experience on LM and SE practices implementation

Experts	Years of experience (y_k)	Weight of expert's opinion
1	13	0.14
2	15	0.16
3	10	0.11
4	18	0.19
5	17	0.18
6	22	0.23
Total ($\sum y_k$)	95	

In this step, g_m and h_n values were inputted in **M**, and the criticality of LM practices listed in the matrix was obtained; see Table 2. To better compare criticality values, we created a differentiation index that gives the number of standard deviations of each individual value with respect to the average degree of criticality, being highlighted in Table 2.

LM practices	g_m	SE practices																						i_m	c_m	Diff. Index
		SE_1	SE_2	SE_3	SE_4	SE_5	SE_6	SE_7	SE_8	SE_9	SE_{10}	SE_{11}	SE_{12}	SE_{13}	SE_{14}	SE_{15}	SE_{16}	SE_{17}	SE_{18}	SE_{19}	SE_{20}	SE_{21}	SE22			
LM_1	0.35	4.8	3.5	4.4	8.0	6.4	6.1	6.2	5.4	8.3	7.2	8.7	2.7	6.2	7.4	6.8	6.9	7.3	3.4	6.9	7.3	7.0	3.9	47.0	16.7	0.8
LM_2	0.34	5.4	4.6	6.6	5.4	6.9	2.7	4.4	7.3	5.1	6.7	6.7	2.0	4.1	3.8	6.0	4.2	3.4	4.6	5.4	4.4	2.7	5.6	38.4	12.9	-0.5
LM_3	0.44	4.1	6.1	8.3	5.9	6.6	3.0	2.7	8.3	4.7	8.1	6.4	2.4	3.3	4.1	7.3	4.3	3.7	6.7	5.4	4.8	3.4	3.9	40.5	17.7	1.2
LM_4	0.40	5.2	4.8	8.0	5.7	7.3	3.0	2.7	7.9	6.1	7.7	7.7	3.4	2.9	3.4	7.9	5.9	6.1	7.3	6.1	5.8	3.4	4.6	43.8	17.5	1.1
LM_5	0.38	5.2	4.2	5.9	3.7	8.0	5.9	1.7	5.3	4.1	2.7	3.4	3.0	2.0	4.4	7.4	3.5	4.4	7.7	6.8	3.3	3.4	2.3	35.4	13.5	-0.3
LM_6	0.39	3.8	7.3	3.8	4.4	6.6	5.3	2.7	6.3	4.3	2.0	2.7	3.2	2.4	2.4	6.1	4.9	4.3	6.7	4.7	3.8	2.6	2.7	33.4	13.1	-0.5
LM_7	0.29	5.0	6.2	4.7	4.7	5.3	3.7	4.2	7.1	6.0	6.6	6.6	4.9	4.8	4.4	6.8	2.4	7.2	5.2	6.3	4.4	6.3	4.8	41.6	12.1	-0.8
LM_8	0.27	5.0	6.2	5.7	4.6	5.9	5.9	5.3	7.7	5.7	6.0	7.0	7.6	5.3	5.4	7.6	7.6	5.9	6.7	7.6	6.4	5.9	6.3	48.1	13.1	-0.5
LM_9	0.30	5.1	5.4	6.7	7.7	7.0	7.9	6.4	7.3	7.3	5.9	7.0	6.9	5.8	5.7	7.9	5.8	7.3	5.9	7.9	6.3	5.4	6.9	51.4	15.4	0.4
LM_{10}	0.36	4.4	4.7	7.1	6.9	5.2	5.1	3.2	7.4	4.1	6.0	3.9	3.4	3.7	4.6	6.8	4.2	4.5	4.8	4.2	4.4	3.6	4.9	38.1	13.8	-0.2
LM_{11}	0.31	4.7	5.5	5.6	5.0	5.6	5.3	2.0	6.1	3.1	3.8	2.1	5.2	3.1	4.1	5.7	6.1	3.2	4.6	5.6	5.8	6.1	6.3	36.8	11.4	-1.1
LM_{12}	0.22	6.9	3.7	5.1	5.1	5.0	6.3	5.4	4.5	5.3	4.9	6.0	6.0	5.7	6.0	5.4	6.7	5.0	7.0	4.9	5.4	5.1	6.7	42.7	9.3	-1.8
LM_{13}	0.45	5.9	5.1	5.9	6.2	5.5	3.1	7.9	5.4	7.9	6.9	7.6	3.7	5.8	6.3	4.8	3.9	7.3	5.0	3.7	5.1	5.7	5.3	43.5	19.4	1.8
LM_{14}	0.40	6.9	5.0	6.3	6.1	4.6	4.7	6.3	6.2	6.6	4.2	6.2	4.0	5.3	7.1	5.3	5.4	5.9	5.7	3.7	4.8	5.6	4.4	42.4	17.0	0.9
LM_{15}	0.45	6.1	5.9	5.2	5.3	6.9	6.4	4.1	7.3	6.4	4.1	3.3	2.1	2.1	3.4	5.2	4.7	4.1	5.7	4.1	6.0	5.4	4.7	39.0	17.4	1.1
LM_{16}	0.33	6.1	8.7	4.1	5.8	6.0	5.0	5.8	7.3	7.7	5.8	4.4	5.3	6.4	5.1	5.1	5.0	4.7	4.0	6.1	4.2	7.1	6.8	44.4	14.5	0.1
LM_{17}	0.44	6.8	7.3	5.9	3.1	2.9	4.1	3.7	6.9	3.8	4.8	4.8	2.9	2.7	3.6	5.1	3.6	3.7	3.4	3.7	4.4	5.5	7.0	35.6	15.5	0.4
LM_{18}	0.31	6.1	5.4	7.3	5.8	4.0	3.4	4.8	5.7	6.4	6.4	6.0	3.0	5.6	6.0	5.4	4.4	4.0	2.1	7.4	4.1	4.1	5.4	39.8	12.3	-0.8
LM_{19}	0.29	6.4	5.8	3.8	4.1	5.1	4.5	4.4	6.1	7.7	4.3	5.0	2.4	3.9	3.7	5.0	3.7	3.7	4.1	4.4	2.9	5.4	4.4	36.0	10.5	-1.4
h_n		0.43	0.36	0.42	0.35	0.34	0.39	0.36	0.43	0.39	0.30	0.34	0.29	0.25	0.29	0.37	0.27	0.36	0.37	0.40	0.33	0.33	0.33			

Table 2 - Matrix **M**

Four out of nineteen LM practices stand out as the most critical ones for the company, presenting *p* scores higher than 1.0. Practice LM_{13} (goal oriented teams) appears as the most critical. It is worth to notice that this practice was not considered the most important by the experts; however, the existent gap for its adoption in the studied company enhances its degree of criticality. Further, this LM practice theoretically seems to be highly related with practices SE_7 (workers' recognition and reward), SE_9 (teamwork and coaching) and SE_{11} (clarity in defining the role of workers). Previous studies have pointed the importance of proving autonomy and empowerment for individuals, which may contribute to morale and process ownership, specifically in a lean implementation environment (Seppälä and Klemola, 2004; Toralla et al., 2012). Thus, our finding is aligned with those results.

Practice LM_3 (takt time) is the second most critical one. This finding is coherent with studies from Netland et al. (2015) and Backstrand et al. (2013). Takt time is understood as the customers' demand rate and is used to balance processes' capacities along the value stream. Therefore, it is expected that individuals' work demand is highly influenced by the rhythm imposed by such rate. If properly adopted, it may be helpful for setting the right targets' expectation and, hence, equally distributing and standardizing activities among employees, which avoids overburdens and work fluctuations within the company. Furthermore, experts consider this practice highly related with SE_8 (synergy among functional areas), which denotes its importance in providing means to establish a transparent and cooperative environment among other areas besides manufacturing.

This fact may entail different behaviors. It could positively reinforce the importance of value added definition among the value stream leaders, since problems must be solved in a faster and more robust manner, emphasizing the importance of each individual (Treville and Antonakis, 2006; Marodin et al., 2015). However, inventory represents buffers from these losses and, through its reduction, the pressure for achieving results may also rise, affecting individuals' psychophysical aspects (time pressure) (Babson, 1993; Saurin and Ferreira, 2009). Thus, although deemed as critical for the company, this practice must be carefully adopted in order to avoid side effects on SE practices implementation.

Surprisingly, practice LM_{15} (organizational design) presents the fourth highest criticality value, which can be attributed to the adoption gap within the company, since its degree of importance is relatively low. For our purpose, organizational design is defined as the manner in which a management achieves the right combination of differentiation and integration of the organization's operations. It refers to the structure that fleshes out the organization; i.e. the creation of roles, processes, and formal reporting relationships in an organization (Womack and Jones, 1996; Shah and Ward, 2003; Stone, 2012). This outcome denotes that respondents' perception is that the current company's structure is compromising the achievement of its core qualities across its value stream. Hence, regardless its theoretical relationship intensity with SE practices, the existent potential for this practice reinforcement may feature a systemic improvement over the SE practices implementation.

Finally, the bar graphs in Figure 3 organize improvement opportunities according to their corresponding degree of criticality. Analyzing those results, the company will be able to compose a portfolio of improvement opportunities and focus efforts on LM practices that are critical for SE implementation. A total of four LM practices should be primarily addressed by the studied company in order to corroborate with SE practices implementation. In opposition, practices LM_{12} (workplace organization), LM_{19} (improvement approach) and LM_{11} (maintenance system) display the largest negative standardized p scores, which denotes that they do not represent an issue for the company with regards to SE implementation.

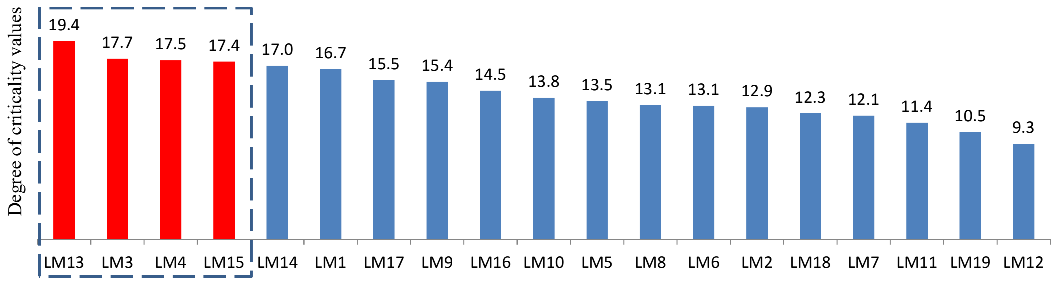

Figure 3. Consolidation of improvement opportunities for LM practices

5. Discussion and conclusion

In this paper, we presented a method for assessing LM and SE practices implementation. The proposed method was illustrated through a case study from a parts manufacturer for the automotive industry.

Two features of the proposed method become evident from its practical implementation. First, the method does not provide an optimal solution, but points at improvement alternatives that may be developed consecutively in the company. Moreover, the method proposes indicators that allow measuring the integration of LM and SE practices represented by degree of importance, which contribute to building a synergic approach that supports the change process and helps improving ergonomics issues in the long run.

Second, through the degree of criticality of LM practices, companies may be able to identify implementation gaps in the lean process that are highly related with the current status of sociotechnical and ergonomics improvements in the company, anticipating problems and developing the practices that converge to them. This fact is quite relevant since changes in organizational practices may take a longer time to be implemented and therefore, it is important to understand these opportunities and have a clear vision of current gaps in lean implementation within the company.

Some limitations in the proposed method are noteworthy and could be viewed as improvement opportunities. Technical aspects concerning LM and SE practices' adoption are not covered in this paper but should be taken into account by companies willing to apply our method. Since lean implementation tends to affect both the technical and socio-cultural factors of an organization, human factors must be intrinsically considered along this change process. This important point however is beyond the scope of traditional lean implementation roadmaps, or treated separately as a secondary approach. That is, companies that want to transform themselves not only must acquire punctual capabilities, but frequently should be able to verify systematic issues in order to address them in a holistic way.

The resulting portfolio represents the beginning of the improvement process, and leaves room for further developments in the method proposed in this paper. We envision the development of a method to guide the adoption of what so called 'lean ergonomics' (Vieira et al., 2012; Koukoulaki, 2014) practices as a valuable addition to the current research. In order to measure and verify any effects of our proposition on key performance indicators, it would be necessary to perform a longitudinal analysis, i.e. to apply the method at different moments and monitor performance indicators as well. The integration of multicriteria decision making methods, such as AHP and its extensions (Allahi et al., 2015; Demitras et al., 2016; Mobin et al., 2014; Mobin et al., 2015) would be another interesting way to strength rationality in the process. In order to capture unsharp and vagueness declarations about human behavior into the decision process, Skeete et al. (2015) and Vafadarnikjo et al. (2015) have proposed some fuzzy logic approaches combined with MCDM can provide effectiveness when evaluating decision makers' judgments. In this paper we present a single application of the method in this paper in which it is used as a diagnosis tool to drive improvements on LM practices within the organization. Another opportunity for further research is to apply the method longitudinally and cross-check it with the evolution of the technical aspects of lean implementation. Based on the collected data, it would be interesting to verify the impact of the evolution of LM and SE practices on organization's performance indicators.

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Biography

Guilherme Luz Tortorella is Associate Professor in the Department of Production and Systems Engineering of the Federal University of Santa Catarina (UFSC), Florianópolis, Brazil. His Master in Production Systems and PhD in Production Engineering were earned from UFRGS. He also has twelve years of experience in the automotive industry with international activities in Mexico, England, USA and Uruguay.

Lizandra Lupi Vergara is Associate Professor in the Department of Production and Systems Engineering at the Federal University of Santa Catarina (UFSC), Florianópolis, Brazil. She is an architect and urban planner and holds a Master's and PhD in Production Engineering from UFSC. She teaches courses related to Ergonomics with focus in Occupational Safety Engineering and Assistive Technologies. She is member of ABERGO (Brazilian Association of Ergonomics).

Evelise Pereira Ferreira is a PhD student in Production Engineering at the Federal University of Santa Catarina (UFSC). She holds a Master's Degree in Production Engineering from UFSC and Bachelor degree in Production Engineering from Federal University of Pampa (UNIPAMPA).

Carlos Ernani Fries is currently Associate Professor in the Department of Production and Systems Engineering at the Federal University of Santa Catarina (UFSC), Florianópolis, Brazil. Mr. Fries holds a Bachelor degree in Civil Engineering as well as a Master and PhD in Production Engineering from UFSC. He has taught courses in Operations Research applied to Manufacturing and Logistics, Decision Theory, Statistics and Forecasting Models among others. His research interests include manufacturing, simulation, optimization, management games, data analysis applied to logistics, and application of big data tools. He is member of IEOM, POMS and INFORMS.