SemeAd 2024
XXVII Seminários em Administração

05, 06, 07 e 08 de novembro de 2024
ISSN 2177-3866

Improving leanness through strategic resources: a case study in a footwear plant

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Agradecimento à orgão de fomento:
Esta pesquisa recebeu apoio financeiro do CNPq Bolsa n. 130551/2012-0.

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1. INTRODUCTION

A number of research papers show improvements provided by Lean Production (LP) systems (Netland, 2013; Shah & Ward, 2003; Chavez et al. 2013; Wickramasinghe and Wickramasinghe 2017). However, most of them focus on the study of the relationship between lean practices and the companies' economic performance, and only recently some researchers started to question the inconsistency of LP implementation results (Habidin, Salleh, Md Latip, Azman, & Mohd Fuzi, 2016). This inconsistency made some authors such as Cooney (2002) and Netland (2013) question the difficulties of general applicability of LP, as much as its whole adoption.

This difficulty can be associated with the lack of several key factors, such as: structured methods that provide a system analysis and an adequate evaluation, and that can be applied to different situations (Wan & Chen, 2009); management and planning, together with an adequate implementation sequence (Åhlström & Karlsson, 2000); adaptation to the organisational context (Lander & Liker, 2007); company's own management principles capable of satisfying its needs Netland (2013); and absence of strategic resources that help the implementation of LP and the development of a sustainable competitive advantage (Gibbons, Kennedy, Burgess, & Godfrey, 2012; Gibbons & Henderson, 2012; Hansen & Møller, 2016; Lewis, 2000; Netland & Aspelund, 2013). Concerning the last factor, differences in performance after the implementation of LP practices can often be explained by internal factors of the organisation, e.g. its resources and capabilities (Forrester, Shimizu, Soriano-Meier, Garza-Reyes, & Basso, 2010; Hansen & Møller, 2016; Lewis, 2000; Parry, Mills, & Turner, 2010)

Lean implementation has become as important as the leanness assessment, which is a theme of recent interest (Almomani, Abdelhadi, Mumani, Momani, & Aladeemy, 2014; Narayanamurthy & Gurumurthy, 2016; Singh, Garg, & Sharma, 2010; Vinodh & Chintha, 2011). The leanness assessment indicates which lean practices should be improved. If the supporting resources of each practice are known, the company could focus its attention and investments in those specific resources that are able to maximise its leanness. Therefore, by recognising its degree of leanness, a company can better allocate its strategic resources, since they are essential to the implementation of LP practices and the development of competitive advantage. However, how can companies allocate their strategic resources efficiently to reach an adequate degree of leanness?

Addressing this question, this work presents a case study of resource allocation to improve the degree of leanness in a footwear plant, relying upon the resource-based view (RBV) of the firm as theoretical background (Barney, 1991). Given the absence of relevant literature for this purpose, the research included a mathematical formulation to determine which resources should receive the largest portion of the company's investment regarding its leanness.

This paper is relevant since it considers that the joint relationships between different types of strategic resources and LP practices are the essential element for a successful implementation, integrating strategic management with the challenges faced by engineering managers to implement LP. The mathematical model proposed in this paper also takes into consideration that besides the fact that companies have different degrees of implementation of each lean practice, they also have different improvement needs for each practice. Thus, the model proposed in this paper can optimally combine a firm-specific bundle of resources with the required lean practice levels. Therefore, it can assists engineering managers in practice regarding the investments that need to be made by the company to improve a bundle of resources and, at the same time, improving the degree of implementation of the LP practices that are associated with these resources.

The remainder of this paper is structured as follows: Section 2 presents a literature review. Sections 3 and 4 present the methodology and findings, including the definition of the relationship between strategic resources and lean practices. The application of a mathematical model to this problem is presented in Section 5, and the last section presents discussion and conclusion.

2. LITERATURE REVIEW

The concept of LP exists at two levels: strategic and operational (Hines, Holweg, & Rich, 2004). At the strategic level, LP is considered a philosophy (Bhasin & Burcher, 2006) supported by principles similar to the ones established by Womack & Jones, (2006): value, value stream, flow, pull, and perfection. At the operational level, LP can be considered as a bundle of complementary and synergic practices responsible for making the lean principles feasible. Thus, Shah & Ward (2007) considered that LP is multifaceted on a bundle of interrelated practices and formulated ten operational constructs that represent fundamental lean practices.

The notion of LP as a bundle of practices has been stressed by several empirical studies (Chavez et al. 2013; Khanchanapong et al. 2014) in which practices represent measurable variables that describe LP. After reviewing the literature on different LP practices, Table 1 shows 12 of them. This selection was made considering only practices related to the shop-floor and considered “internal” (Shah & Ward, 2007; Chavez et al. 2013).

Table 1. LP practices.

Lean practice	Definition	Sources				
		1	2	3	4	5
JIT	Provides inventory reductions by producing and delivering only the necessary amount of the time required.	*	*	*	*	*
Kanban	Pull production mechanism that controls the flow of materials and information using devices that inform the need of parts between two workstations.	*	*	*	*	*
Production levelling	Means levelling the mix and quantity of production over a fixed period in order to reduce the variability of the production schedules.	*	*	*	*	*
Autonomation	Providing operators and machines the ability to detect problems and stop the production process immediately when abnormalities occur.	*	*	*	*	*
Standardised work	Establishment of precise procedures to execute tasks documented and exposed in the workstations.	*	*	*	*	*
Multifunctional teams	Groups of workers trained to perform different tasks, allowing system flexibility to keep the production flow stable.	*	*	*	*	*
Visual management	It suggests the utilisation of visual communication devices installed broadly on the work environment to transmit information about the process and its performance indicators.	*	*	*	*	*
Zero defects quality control	Set of methods that prevent and eliminate defects by identifying and controlling the causes.	*	*	*	*	*
Kaizen	Permanent incremental improvement program that covers the whole organisation and results in a continuous effort to solve problems.		*	*	*	

Lean practice	Definition	Sources				
		1	2	3	4	5
Setup time reduction	Methodology for simplification and improvement of changeover activities to reduce the time spent with them.	*	*	*	*	*
TPM	Structured maintenance approach that gathers a set of techniques that avoid unexpected interruptions on production flow by autonomous and planned maintenance.		*	*	*	
VSM	Support tool for the implementation of LP that maps material and information flows, helping the identification of activities that do not add value and driving the improvement of the value flow.			*	*	

(1) Shingo (1989); (2) Feld (2001); (3) Womack and Jones (1996); (4) Liker (2004); (5) Monden (2012).

The implementation of LP is a long process and companies that already implemented LP may have difficulties in the system maintenance and hence need to monitor their leanness degree periodically. Therefore, leanness assessment is also fundamental to guide the continuous improvement of existing lean systems.

Leanness is the performance measure of lean practices that allows us to compare the degree in which such practices are implemented in different companies (Vinodh & Chintha, 2011). It is worthwhile to mention that LP is not only a bundle of tools, techniques, and practices. However, as the principles that compose the LP philosophy are difficult to measure, lean practices may be used as parameters to define the leanness of a system.

Leanness assessment has been a relevant research theme among several researchers (Narayanamurthy & Gurumurthy, 2016). Soriano-Meier and Forrester (2002) for instance, create an instrument to measure and evaluate a sample of 30 companies of the ceramic industry that identified three groups of companies: “lean”, “in transition” and “traditional”. Similarly, Gurumurthy and Kodali (2009) proposed the utilisation of a benchmarking process based on the comparison of the best industry practices to evaluate the degree of implementation of LP in an appliance manufacturer.

Another research stream proposes the leanness assessment by modelling tools and decision support systems. For instance, Singh, Garg, and Sharma (2010) and (Vinodh, Arvind, & Somanaathan, 2011) used fuzzy logic as a tool to reduce the subjectivity on the evaluation of LP. Wan and Chen (2009) developed a unified leanness measure that evolved from the concept of data envelopment analysis (DEA). Almomani et al. (2014) proposed an integrated model of lean assessment and analytical hierarchy process (AHP), which also traces a roadmap of lean implementation.

The sophistication of an assessment method is not a guarantee of its practical applicability. Wan and Chen (2009) claim that the user-friendliness is a fundamental characteristic of an evaluation method, once it should be applicable by lean practitioners for self-diagnosis. In other words, methods that are sophisticated but too complex to be interpreted by users may have a higher risk of failure. Some assessment models follow this idea, as the ones used by Taj (2008), Wan and Chen (2009) and Bhasin (2011), which provide user-friendliness and practical relevance.

By recognising its degree of leanness, the company can better allocate its strategic resources and direct them to the global improvement of the LP system. By definition, a LP system is constantly evolving (kaizen) and its level of maturity tends to increase with the experience and the development of resources to support the system implementation and maintenance. Thus, besides evaluating the degree of leanness associated to lean practices, it is important to identify which resources support those practices.

2.1 Resources for leanness

The task of identifying the resources that support lean practices may be executed through the theoretical lens of the RBV (Gibbons et al. 2012). According to this theory, resources have a wide definition and refer to all assets (tangible or intangible) that an organisation owns or has access to, including organisational processes, firm attributes, information, knowledge, technologies, and all of the assets that enable the firm to create and implement strategies (Barney, 1991).

Barney (1991) considers a resource strategic when it satisfies four basic requirements, composing what the authors define as "VRIO model": value, rarity, inimitability, and organisation, being the last one related to the company effort to coordinate policies and processes to exploit this resource. The strategic resources are developed through the history of the organisation, under particular circumstances that make them unique and hence difficult to copy (Barney, 1991).

The implementation of LP is path-dependent and its success depends on the disruption with negative past experiences that may disturb the process (Deflorin & Scherrer-Rathje, 2012). Lewis (2000) observed that the trajectory of implementation of LP itself creates a bundle of resources derived from the particular experience of each company, conferring a development potential of valuable, rare and difficult to copy resources. On the other hand, the author notices that the resources already owned by the company may enable the implementation of LP.

The pioneer work of Lewis (2000) related RBV and LP. Although promising, the empirical literature about this research field is still scarce, in which we can cite some works. For example, Forrester et al. (2010) investigate the relation of the adoption of LP with market share and value creation by adopting the RBV. (Parry et al., 2010) developed a methodology for LP implementation that aims to protect the company's key resources. Similarly, Gibbons et al. (2012) proposed a useful framework for identifying the polarisation of resources, defined as a wasted opportunity in resource deployment. By studying the phenomenon of company-specific production systems, Netland and Aspelund (2013) concluded that the implementation of management models based on LP may generate a sustainable competitive advantage as long as the model adjust itself to other strategic resources of the organisation. Khanchanapong et al. (2014) claimed that the complementarity between manufacturing technologies and lean practices, both considered as organisational resources, have positive effects on operational performance.

Unlike lean practices, it is not possible to list a priori a bundle of lean resources. The RBV establishes that strategic resources are unique characteristics of each company. The results of Lewis' (2000) research confirm that even if different companies implement the same lean practices, the specific implementation path can create distinct underpinning resources. Hence, it is important to know the resources that support a company's LP to prioritise investments in resources that have a greater potential for improving the leanness degree.

The literature did not present frameworks that relate leanness assessment to lean resources. Wan and Chen (2009) developed a leanness assessment model that provides a way to guide the lean implementation process through the generation of improvement guidelines, but without linking the proposed improvements to support resources. Almomani et al. (2014) also related the lean assessment to the lean implementation, but their roadmap did not consider lean resources as the true building blocks of the implementation. On the other hand, Parry et al. (2010) included resource analysis in their implementation methodology without using leanness assessment to establish improvement priorities. Similarly, Gibbons et al. (2012) did not consider the leanness degree to identify the lean resources that should be developed.

Once the relationships between leanness assessment and lean resources are defined, resource allocation mathematical models may be used to obtain the combination of investments that optimise the impact on a company's leanness. However, research in this area is scarce. Ramesh & Kodali (2012), for instance, developed a decision framework for the selection of the best sequence of lean tools application to maximise the performance of a manufacturer using an iterative algorithm to solve the prioritised goal optimisation. However, their model ignored the current stage of leanness and the chosen performance metrics were just related the lean outcomes. In a broader context, Safaei (2014) presented a multiobjective programming model to obtain optimal limited resources allocation decisions on supply chains. Although the author used the label "lean supply chain", aspects related LP practices and their support resources, as well as the leanness level, were not included in the model.

3. METHODOLOGY

The study was conducted in a manufacturing plant of a large corporation in the footwear industry. The case was chosen due to the presence of: (i) a well-defined business strategy, with previously established objectives; and (ii) adoption of LP practices. The methodological procedure for data collection and analysis consists of three phases, as described below.

3.1 Identification of lean practices and strategic resources

The first step is to identify lean practices and the strategic resources associated with these practices. Structured and non-structured interviews were the main instruments of data collection. The interviews were conducted with the appropriate staff, as process analysts and engineers. Observations of the process and LP practices were also developed.

Some interviews were conducted in groups of three interviewees, in order to obtain consensus in the assessment. Besides the interviews, documents related to lean practices and strategic resources were analysed; and observations of the process were also developed.

3.2 Leanness assessment and relationship determination

Once lean practices and strategic resources were listed, it was necessary to determine the practice levels and the strength of the relationship between practices and resources. The understanding of these two factors leads to a comprehension of how investments in resources influence lean practices, and which practices require more attention. This phase is conducted through questionnaires applied to the same staff interviewed in the previous phase.

The procedure used to the leanness assessment was developed by Saurin & Ferreira (2008) and adapted to be used in this paper. This procedure was chosen fundamentally due to its easiness of use, also providing immediate feedback during the assessment process. The instrument promotes an individual evaluation of each LP practice, generating grades that represent their implementation degree. After the appropriate adaptations, 55 items representing characteristics related to lean practices were determined.

Each lean practice may be constituted by one or more related items. On the other hand, each item should be related to only one of the 12 lean practices selected for evaluation: just in time (JIT), *kanban* system, production levelling (*heijunka*), autonomation (*jidoka*), standardised work, multifunctional teams, visual management, zero defects quality control, continuous improvement (*kaizen*), setup time reduction, total productive maintenance (TPM) and value stream mapping (VSM). Each item corresponds to one checklist question. Then, each item was discussed in-group interviews in which the staff reached a consensus about the degree of application of that characteristic in the plant. The scale used to evaluate the items is:

- VSA: very strong application (the practice is consolidated).
- SA: strong application (the practice is used in several departments and processes).
- WA: weak application (the practice is rarely used).
- VWA: very weak application (the practice is still in an experimental phase).

- A: absent in the company, but adequate to the production system.
- NA: not applicable, given the characteristics of the production system.

Weights were attributed to each answer: A = 0; VWA = 2.5; WA = 5; SA = 7.5; VSA = 10. For each lean practice, a score is calculated through Equation (1) using the evaluation of the items related to it. In the equation, (T) corresponds to the number of applicable items related to that practice; (B) is the number of items with very weak application; (C) is the number of items with weak application; (D) is the number of items with strong application; and (E) is the number of items with very strong application.

$$Score = \frac{(\mathrm{B} \times 2{,}5) + (\mathrm{C} \times 5{,}0) + (\mathrm{D} \times 7{,}5) + (\mathrm{E} \times 10{,}0)}{\mathrm{T}} \qquad (\mathbf{1})$$

Three levels were used to describe the strength of the relationship between practices and resources: 3 = strong; 2 = moderate; and 1 = weak. When there is no relationship between a practice and a resource, no value is given. The value attributed to each combination of practice and resource is achieved through a consensus among the staff related to the lean implementation.

3.3 Resource allocation model

With the data obtained from the previous steps and data about the cost of investing in strategic resources, it was possible to develop a mathematical model to decide in which resources the company should invest to reach the desired levels of leanness. Several model variations are possible, depending on the company objective: reach for a certain leanness standard, improving leanness as much as possible within a given budget, favouring practices that may be considered more important to the company, etc.

4 RESULTS

The case study was conducted in a plant specialised in the manufacturing of rubber sandals. The plant has currently eight product families separated in four types, each with fifteen combinations of colours and eleven sizes. The main characteristic of the products is their innovative design and durability. The activities of the production process occur in six departments: cut, silk, stitch, injection, kit, and assembly, with an average daily production of 30 thousand pairs of sandals. The factory started the LP implementation project motivated by the headquarters plant that already had the system implemented. Currently, the plant is in a stage of continuous improvement of the lean system.

4.1 Identification of lean practices and support resources

Figure 1 shows the first three years of the lean implementation path. We divided the timeline by semester to better identify the events. For each semester, we identify practices whose implementation had already started and the resources that support the implementation. After the interviews and documents analysis, 12 practices and 17 strategic resources were identified.

4.2 Leanness assessment and relationship determination

Based on the evaluation of the items from the staff, the scores of each practice calculated through Equation (1) are presented in Figure 2. Figure 2 shows that there is a significant difference among the level of practices applications in the plant, with some quite consolidated, as *kaizen* and standardised work, and others still incipient, as autonomation and VSM. The average score of the practices is 5.08, indicating that the general leanness degree of the factory is moderate. This result is expected since the company's concern with leanness is recent and the use of its principles in the plant is still evolving.

Figure 1. Lean practices and support resources identified.

	IMPLEMENTATION TIMELINE					
	1st semester	2nd semester	3rd semester	4th semester	5th semester	6th semester
IMPLEMENTED PRACTICES	Value stream mapping; Standardised work; Production levelling (*heijunka*); Multifunctional teams	Visual management; Zero defects quality control	*Kaizen*	Setup time reduction	Total productive maintenance	Autonomation (*jidoka*); *Kanban* system; Just in time
SUPPORT RESOURCES	• Operational labour; • Qualified managers; • Training; • Heavy machinery; • Support equipment; • Culture; • Outsourced services; • Software.	• Operational labour; • Qualified managers; • Training; • Experience; • Customers; • Raw material; • Heavy machinery; • Support equipment; • Culture; • Organisational climate; • Strategic partnerships and alliances; • Relationship with suppliers; • Brand.	• Operational labour; • Qualified managers; • Training; • Experience; • Culture; • Organisational climate; • Relationship with suppliers.	• Operational labour; • Qualified managers; • Training; • Heavy machinery; • Support equipment; • Culture; • Software.	• Operational labour; • Qualified managers; • Training; • Experience; • Raw material; • Heavy machinery; • Support equipment; • Culture; • Organisational climate.	• Operational labour; • Qualified managers; • Training; • Experience; • Customers data; • Raw material; • Heavy machinery; • Support equipment; • Culture; • Organisational climate; • Strategic partnerships and alliances; • Relationship with suppliers; • Location; • Software.

Figure 2. Assessment of lean practices.

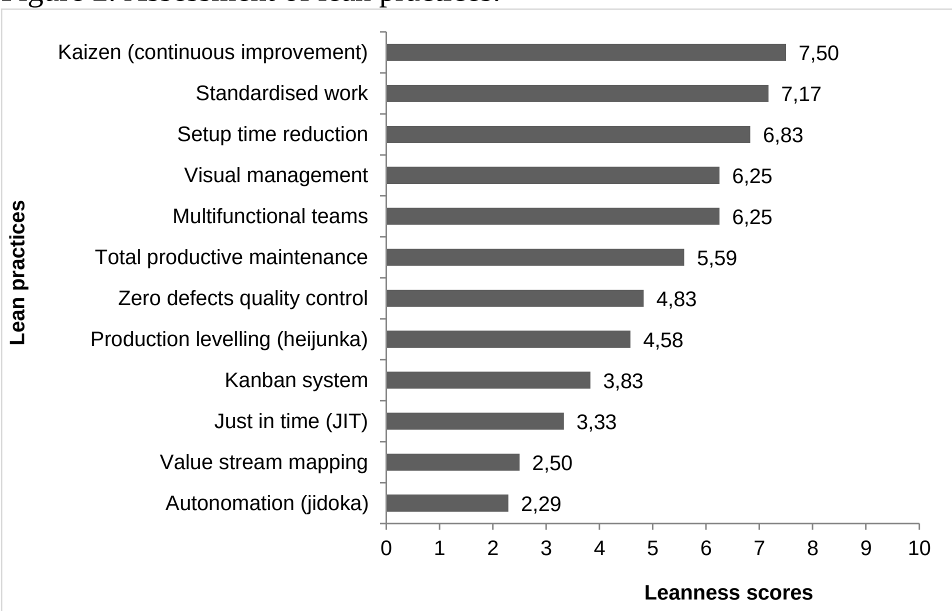

Table 2 presents a matrix with the evaluation of the relationship between practices and resources. Through the sum of the relationships, it is possible to see that Training, Operational labour and Qualified managers are the resources that have the strongest influence on lean practices in general.

Table 2. Relationship between practices and resources.

Lean resources / Lean practices	1 - Operational labour	2 - Qualified managers	3 - Raw material	4 – Customers	5 - Heavy machinery	6 – Location	7 - Support equipment	8 - Culture	9 - Organisational climate	10 - Strategic partnerships and	11 - Training	12 - Brand	13 – Software	14 - Customers data	15 - Relationship with suppliers	16 - Outsourced services	17 - Experience
1 - VSM		2											1			2	
2 - Standardised work	3	3			2			2			3						
3 - Production levelling (*heijunka*)	3	2					1	1			2						
4 - Multifunctional teams	3	2			2		1	3			3						
5 - Visual management	2	3						3	2		3						
6 - Zero defects quality control	2	3	3	1	1		3	2		3	2	1			3		3
7 - Kaizen (continuous improvement)	3	3						3	3		3				3		1
8 - Setup time reduction	2	2			3		1	1			3		1				
9 - TPM	1	2	2		3		1	2	1		3						1
10 - Autonomation	3	3					2	2	2		3						1
11 - *Kanban* system	2	1	2					1			3		1	1	1		1
12 - JIT	2	2	3		2	2	2	2	3	3	3		1	3	1		3
TOTAL	**26**	**28**	**10**	**1**	**13**	**2**	**11**	**22**	**11**	**6**	**31**	**1**	**4**	**4**	**8**	**2**	**10**

Strong relation = 3 Moderate relation = 2 Weak relation = 3

4.3 Resource allocation mathematical model

The choice of in which resources to invest to improve the general leanness degree of the company seems obvious. However, among the three most influent resources, only Qualified managers affect the practice of VSM, which is one of the practices with the lowest scores. Thus, depending on the objectives concerning its leanness degree, the combination of in which resources to invest may become a complex decision for the company.

Once we established a procedure to relate strategic resources to lean practices and to assess the leanness of each practice, we can insert all this information on a mathematical model to optimise the decision of in which resources to invest to achieve an adequate degree of leanness in key practices. Given the amount of data to be processed in real cases, such model can be easily solved using free commercial software, offering an interesting alternative even for companies without a large budget.

We propose a linear programming formulation that supposes the company wishes to use a given budget to improve its lean practices with the smallest scores. It is necessary to estimate some parameters for the model, which can be done using results like the ones presented in Figure 2 and Table 2 , in addition to an estimation of the cost of investing in resources. As such costs were not available for this study, we suppose that investments in some of the resources are available at hypothetical costs to explain how the model works.

The model uses variables x_j, which represents the amount of investment made in resource *j*. One investment in a resource *j* could be for example an overall training program or the purchase of new software, which would improve the resources *training* and *software*, respectively. Each investment is assumed to have a cost and some may allow a partial investment, obtaining in exchange for the improvement in leanness proportionally. For example, if we assume that the cost of a whole training program is $8 (without specifying monetary units), we could invest $4 in a training program with half of the hours of the original one to obtain half of its results regarding leanness. On the other hand, if there is a better computer program that can be bought by $2, it may not be possible to buy "half the program" for $1. In terms of the model, that means that for resource 11 – Training, variable x_{11} could assume any value between 0 and 1 (with 0 meaning no investment at all in training, and 1 meaning investing the cost of the whole program, $8), while for the resource 13 – software, variable x_{13} can only assume the values 0 or 1 (purchase or not the computer program). Values of x_j greater than one can also be considered as long as negative values, representing the possibility of decrease of the current expenses on a resource in order to have more capital to invest in the strategic ones if this view suits the case of the company.

Table 3 shows four resources, which are used as an example. For each of the resources *j*, the Table 3 presents a correspondent cost c_j in monetary units and, if there is the possibility of making an investment as a percentage of the cost, receiving the benefits proportionally.

Table 3. Example of investment options.

Resource	**Cost**	**Does it allow partial investment?**
2 - Qualified managers	10	Yes
5 - Heavy machinery	7	No
11 – Training	8	Yes
13 – Software	3	No

A matrix of relations between strategic resources and lean practices as the one shown in Table 2 is used to establish the intensity of these relationships in the model. It assumes that this intensity is proportional to the increase in the practice level when an investment is made in a given resource. We define the parameter r_{ij} as the degree of improvement of a practice *i* when an investment is made in a resource *j*. When there is no relationship between a practice *i* and a resource *j*, we simply assume $r_{ij} = 0$.

The need of improving a certain practice is given by the difference between its current level and a desired one represented by parameters d_i for each practice *i*. The desired levels of leanness for each practice can vary from case to case, and when the current level of leanness in a certain practice *i* is already the desired one or greater, $d_i = 0$ is defined for that practice. Given the desired levels of each practice for a company, d_i can be calculated from leanness scores given in Figure 2. In summary, the variables and parameters used by the model are:

Variables:
x_j : investments made in a strategic resource *j*
Parameters:
d_i : gap between the score of a given lean practice *i* and its desired level
r_{ij} : degree of improvement of lean practice *i* by investing on strategic resource *j*
c_j : cost of an investment made in a strategic resource *j*

The problem of maximising the benefit of an investment in a lean program emerges when we have a given budget b to be spent on a lean program and we have to decide how much to spend on each resource to bring as much as possible the level of the lean practices to its ideal. The general model is defined as (Equation 2):

$$\text{Maximise } Z = \sum_{i \in P} \left(d_i \sum_{j \in R} r_{ij}\, x_j \right) \qquad (\mathbf{2})$$

$$\text{subject to } \sum_{j \in R} c_j x_j \leq b$$

$$0 \leq x_j \leq 1 \text{ or } x_j \in \{0,1\}$$

In the objective function, $\sum_{j \in R} r_{ij}\, x_j$ calculates the improvement on each practice resulting of the investment in resources j, given the intensity of their relationship. It then maximises the improvement over all practices weighted by the difference of their current level and the desired one, in order to give preference to practices whose level are farther to the ideal one. The constraint limits the total investment in resources by the budget available.

Suppose we have a budget of \$15 and choose to focus our investments in practices whose score is smaller than 4.0. By substituting the values of the parameters in the general model presented before, we achieve the following model:

$$\text{Maximise Z}=1.52x_2+x_{13}+1.73x_2+3x_{11}+0.2x_2+3x_{11}+x_{13}+0.7(2x_2+2x_5+3x_{11}+x_{13}) \qquad (\mathbf{3})$$

$$\text{subject to } \quad 10x_2 + 7x_5 + 8x_{11} + 3x_{13} \leq 15$$

$$x_2 \leq 1$$

$$x_{11} \leq 1$$

$$x_2, x_{11} \geq 0; x_5, x_{13} \in \{0,1\}$$

The values outside the parenthesis on the objective function correspond to the difference between the "critical score" of 4.0 and the current score of each practice. The model does not consider practices with a score larger than or equal to 4.0. Note that it is possible to determine different scores for each of the practices according to the needs and interests of the company. The value determination is not such an important factor since it can be easily changed and recalculated given its size. It is important to notice that most of the information is based on a subjective analysis, hence, the results should be used as a guideline and not treated as an absolute decision.

Inserting the model into an optimisation software, we obtain the following optimal solution: $x_2 = 1, x_{11} = 0.625, x_5 = x_{13} = 0$, which means we should invest \$10 to perform the whole manager qualification program and 62.5% of the training program, at a cost of \$5. Although Software has the lowest cost and is related to three among the four practices considered, the strength of the relationship among Training the practices resulted in the choice of only two resources.

5. Conclusions

This paper analysed the relationship between lean practices and strategic resources. Through a case study, we proposed a quali-quantitative methodology to determine the influence of each resource into each practice and used a mathematical model to support decision making in different scenarios. Besides the fact that relating lean practices to strategic resources is a new procedure in LP subject, its applicability with simple optimisation methods as linear programming provides a useful tool for engineering managers in companies interested in invest to improve their degree of leanness.

This paper presents some theoretical and managerial implications. First, it brings together leanness and the RBV and, in a broader sense, it addresses the often missing link between LP and strategic management literature. Secondly, it provides a rational tool to support the decision faced by top and engineering managers about the investment in a lean program. Even though literature stresses the importance of top management commitment for successful lean implementation, top managers are generally apart from the shop-floor trying to decide how to allocate restricted resources among dozens of business opportunities and improvement initiatives. For those managers, LP may be just another one issue about their operations and the economic justification may be more meaningful for them than any other argument.

Therefore, through analysing the influence of a set of resources in the implementation of specific LP practices, and adopting the mathematical model, engineering managers inform top management of the improvement and the necessary investments in these resources. Consequently, it is possible to increase the level of implementation of LP practices, also contributing to the strategic management and the competitive advantage of the organization.

Some limitations in the application of the proposed approach are noteworthy. Due to the lean implementation is very recent in the studied case, the data collection was a very hard task since even today the plant managers are still learning about LP. Considering the limited potential of generalisation of a single case study, we recommend applying the approach in other real cases. It is important to test the approach in different companies, with different lean experiences, and from different industries. Another recommendation is to test the proposed mathematical model with real financial data, and not only with hypothetical data. Although hypothetical data had been enough to reach our research objectives, it would be useful to evaluate the applicability of the model in real decision-making processes about lean investments.

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