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Integration Between Lean Manufacturing and Other Quality Tools: A Scale Development

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Abstract

In order to improve organization's performance, both in quality and productivity, several quality programs were created and implemented, with recent highlight to Lean Manufacturing (LM). All these initiatives are based on the involvement of employees, managers and organizational procedures, and it is expected that there will be some interaction between them. This paper describes the development and validation of a multi-item scale, an instrument which measures how employees perceive the integration between a production system based on the principles of Lean Manufacturing with other quality tools already used in the companies. The method included analyzes related to apparent validity, content validity, total item correlations, factor analysis and reliability. A questionnaire submitted to 317 respondents from a population of 1,699 employees of a metal-mechanic company included a proposed scale of 10 items to evaluate the integration between LM and other quality tools. After the analysis of the data, two questions were excluded because they did not present relevant factor loadings and the other eight questions resulted in two factors (Structure of integration of SP with other tools and Results in integration between SP and other tools). Confirmatory factor analysis confirmed that these factors constituted a model with good fit.

Keywords: Lean Manufacturing; Quality; Integration; Measuring Scales.

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1. Introduction

In order to improve quality and productivity, several quality programs were created and implemented in companies. Among these methodologies, we can mention Total Quality Control, Quality Control Circles, PDCA or PDCA Cycle, ISO 9000, Poka Yoke, Kanban, Just in time, Kaizen, Lean Manufacturing [[1], [2], [3], [4]]. Along the same lines, Lean Manufacturing (LM) is a methodology that has been developed in companies, with the goal of improving their performance, using a series of well-defined and organized tools. Companies have implemented different initiatives that may conflict internally or otherwise leverage each other. In addition, all have at their base the group of employees, the involvement of the group of managers and the organizational procedures. In this way, it is estimated that there is some interaction between the initiatives. The barriers hampering the implementation of successful Lean Manufacturing and the interactions among them, are often the same as those observed in quality programs [[5]]. The starting point of this study is the idea that, since there is a history in organizations of quality programs that comes from decades, how does the implementation of lean philosophy behave? Will there be overlaps? Will there be counterpoints? How do company employees see the complementarity of these approaches? In a literature search [[6]] shown that the LM philosophy and the six sigma steps are essentially the same due to a Japanese Total Quality Management (TQM) practices. The roadmap of LM is an example of new alternative TQM roadmaps. The effectiveness of the LM is assured by focusing on training people in tools and techniques and at the same time to little focus on understanding the human factor, i.e., how to build the right company culture. Managers need to be aware of the cultural characteristics of their organization before adopting quality techniques. Implementing quality tools appropriate to the company's culture enhances their effectiveness in order to increase the benefit from the use of these techniques [[7], [8]]. While looking for relationship between organizational culture and the use of quality techniques, and its impact on operational performance, the organizational culture does not appear to be an unequivocal predictor of the use of quality techniques [[7]].

To examine if the organizational cultural variations have correlation with the success and effectiveness of lean manufacturing [[9]] analyzed the literature in the area of LM and lean management. It was developed a model to describe the interaction between cultural dimensions and their supposed effect on lean implementation and sustainability. Future research directions should include the measurement of organizational culture in firms that have implemented lean processes by using the different quadrants in the Competing Values Framework [[10]]. Knowing which dimensions influence lean effectiveness and the way that they exert that influence allows managers to develop the firm's organizational culture to one that will support implementing and sustaining lean efforts [[9]].

The degree of implementation of LM practices in rigid continuous processes has a positive effect on organizational performance. Role of training, communication and empowerment are important antecedents of LM. It helps to reflect on the contextual determinants that can keep rewards systems from acting as antecedents of LM. LM depends on employees' involvement in lean activities, which is produced by giving them more empowerment, training, information and new forms of compensation [[11]]. Employee involvement through different concepts such as training, communication, empowerment and rewards and recognition has a positive impact on the implementation of process approach, system approach to management, continual improvement and factual approach to decision-making [[12]]. The success of the LM implementation finds a stumbling block in the lack of understanding of lean precepts [[13]]. Companies focus on the application of tools rather than a LM approach with a cultural view. In addition, conflicts between implementation strategies and the selection of appropriate LM tools are observed [[14]]. Improper implementation of the strategy can lead to increased costs and reduced productivity, disrupting improvement processes. Lean Production (LP) was first introduced in Womack's book The Machine That Changed the World in 1990. Lean was so named because it allows producing and conducting a business with minimal use of resources while if you get the maximum results possible, that is, do more with less, reducing anything that is surplus and that does not add value to the product. The Lean concept was originally created with the purpose of minimizing losses in production processes and increasing customer value [[18]].

Lean Manufacturing has been treated as the most efficient way of production of the present times [[19]] and the implementation of LM results in greater organizational performance compared to other practices called flexible manufacturing systems and computer-integrated manufacturing systems [[20]]. The improvement of processes and business through the reduction of losses has been developed since the late 19th century with Gilbert and his time study, later with Taylor and his work at the Ford Motor Company [[18]]. However, it intensified from the 1970s, following the development of the Toyota Production System and Just in Time logic, with Taiichi Ohno and Eiji Toyoda. At that time the focus was restricted to the production area. Today concepts are applied in all areas, so that he family of topics encompasses Lean Enterprise, Lean Business System, Lean Production, Lean Manufacturing, Lean Supply Chain (LSC) management, Lean Product Development (LPD), among others. There are prevalence of Lean studies in recent years in the manufacturing sector, however, applications in the public services, tourism and hospitality, health and other sectors are also observed [[21]]. Lean Manufacturing (LM) seeks to improve organizational performance in both financial and non-financial terms. LM is considered a manufacturing philosophy, which will be used as a long-term tool [[22]]. It is about doing more with less, that is, it seeks to reduce waste in activities that do not generate value. The LM has the capacity, when appropriately adapted to the organization, to strengthen the organization's competitiveness in the marketplace substantially by reducing wastes and improving product quality and efficiency of production [[23]]. Lean Manufacturing leads to better quality, visual and easy management, greater efficiency, reduced workforce, total company involvement, elimination of problems, reduced space, greater safety in the workplace and improved employee morale [[18], [24]]. Meeting the expectations and needs of customers requires establishing a system that integrates the different business processes, such as marketing, sales, development and manufacturing of products. Both the implementation and the integration of these processes must follow a methodology that reduces the risks and increases the efficiency of the results. For each process defined in the Manufacturing System, there is a set of tools appropriate to its realization. Each type of process can be designed and executed with the support of specific tools. Quality tools should be used in the integration, monitoring and optimization of processes. In management models par excellence, the tools play a key role. They ensure the minimization of the risks due to the uncertainties of the inputs and sources of the processes [[25]].

The use of tools should be based on the objectives of each process. The objectives are expressed in tangible characteristics, measurable quantitatively or qualitatively, by means of expected performance factors. The use of the tools should allow the evaluation of the performance of the process and, consequently, of the Manufacturing

System. Benchmarking, Value Chain Mapping, Thinking Design, and Business Process Management or BPM are key tools for organizing processes. For the definition of the product development process, it is possible to use the PDP Reference Models, which include Quality Function Deployment, Cause and Effect Diagrams, Analysis of Potential Failure Modes and Effects, Statistical Process Control and Regression Analysis. The use of tools or methods to improve quality and productivity essentially depends on people. The goal is to change the way people work in organizations, especially in studying and changing processes. In this way, it is estimated to exist some interaction between people and improvement tools. In addition, interaction between the different methods is also expected. These interactions can be beneficial, since the methodologies can be complementary and the result more robust. However, one can expect some redundancy or duplicity between them. In extreme and undesirable cases, the positive effect of one tool can be nullified by another [[15], [16]]. Thus, we intend to analyze the integration between production systems based on the principles of Lean Manufacturing (PSLM) and quality tools already used in companies. Studying the literature, there were no studies that presented scales of data collection involving this relation. So, an instrument, based on multi-item scales, that relates both approaches, needed to be developed. In this way, the objective of this work is to validate a scale that analyzes the integration between production systems based on the principles of Lean Manufacturing and quality tools. Proper scale development and validation provide the necessary foundation to facilitate future quantitative research in the organizational sciences [[17]]. For the development of the work were following the steps suggested in the literature that are presented in the sequence.

2. Method

To develop the scale, items were constructed according to the study's framework. These items underwent expert analysis for content validity and then subjected to exploratory factor analysis, confirmatory factor analysis and reliability studies. The psychometric characteristics of the scale were analyzed through unidimensionality, reliability and validity. Unidimensionality is obtained when a set of items has statistical properties that demonstrate that their items constitute a single factor [[26]]. The factor analysis is used to verify if the items have high loadings in only one factor [[27]].

Reliability represents the degree to which a set of items are consistent when measuring the same construct. The most common ways of assessing the reliability of a scale are through reliability of alternative forms, test-retest reliability, medium-to-medium reliability, and reliability of internal consistency [[28], [29], [27]].

After confirming that the scale is in agreement with the conceptual definition, it is one-dimensional and meets the levels of reliability, the next investigation is about its validity (Hair and his colleagues 2010), which represents the capacity that the scale possesses in fact, reflect the concept being measured, that is, the scale is free of measurement or systematic errors, generated by the observer, instrument or both, that could compromise all the results. The validity can be obtained through content validity, construct and criterion approaches [[29], [27]].

In the validation process, the apparent validity, which searches for the best form of the instrument and vocabulary and content validity, is used to evaluate whether the instrument actually measures what one wants to measure.

3. Results

3.1. Exploratory phase

The exploratory stage of scale elaboration aimed to provide a better understanding of the theme and context, to examine the feasibility of the study and to identify its relevance [[27]]. In the first stage of this phase the literature review was carried out, where the dimensions of the construct were defined, based on the theoretical principles of production systems and other quality tools. Subsequently, the individual items were generated, which were derived from the theoretical framework and from interviews with three specialists. The configuration of the group of specialists was characterized by professionals in the area of Business, Quality and Industrial Engineering, who could analyze the question and problematize the set of generated items, thus contributing to ensure content validity. These steps allowed the development of the individual items, which, because they were aspects of evaluation of the respondents' perception, needed to be operationalized in multi-item scales. This situation occurs whenever there is a need for several aspects to be evaluated simultaneously to arrive at a common goal, which is the evaluation of the construct itself [[29], [30]]. Thus, a total of ten items (the questions of the instrument) were returned, which were again submitted to expert analysis, following the indication of [[31]], which suggests that a group of specialists review the set of items generated to "confirm or invalidate its definition of the phenomenon".

The ten questions resulting from the experts' analysis were:

- The PSLM and the other tools are integrated in this company;
- There is confusion between PSLM and other tools;
- This company benefits from both PSLM and other tools;
- It is a correct decision for this company to invest in PSLM and other tools as well;
- The other tools interfere in the PSLM implementation;
- The success of this company is due to the investment in tools of control and improvement;
- The implemented tools contribute to improve the company´s image vis-à-vis clients;
- The implementation of the PSLM and other tools contribute to the competitiveness of this company;
- The implementation of control and continuous improvement tools contribute to employee satisfaction;
- The tools of control and continuous improvement are real opportunities for the employee to participate in the decisions in this company.

3.2. Measurement purification

The measurement purification is to understand the structure of the instrument so that it is possible to really establish which items will be kept in the instrument and which do not add value to the evaluation process of the construct, that is, it seeks to eliminate redundant items or with low power of explanation [[32]]. Initially, 20 undergraduate students of Business Administration and Industrial Engineering from a private university answered the questions. The purpose of this step was to verify a proper adequacy of language and layout of the instrument. After minor adjustments, the instrument was applied to a group of 317 employees of a metal-mechanic company that has more than 1,600 employees and has a history of more than 30 years of investments in Quality Tools and Lean Manufacturing. The sample size was obtained by calculating the simple random sample, considering a 95% confidence level and a maximum sampling error of 0.05. The calculation resulted in a minimum sample of 314 respondents. The sample used in this study was composed of 317 employees, who were randomly selected. For the draw, a report was used with the name of all the employees that form the study population (1,699 shop floor employees), generated by the Human Resources Department. The items were rated on a five-point Likert scale (strongly disagree, disagree, neutral, agree and strongly agree), with an initial text explaining the purpose of the research, guiding the respondent and ensuring confidentiality of information presented. In the data preparation stage, questions of reverse items were reversed. Eight questionnaires were discarded because they used only two points on the scale, and one questionnaire that presented missing values of more than 10% of the questionnaire [[33]]. Others presented two or less omission cases, distributed randomly between the cases and variables, thus allowing their replacement by the mean of the item [[27]]. After this step, a final sample of 308 valid questionnaires with missing values replaced by the average of each item was reached. After this first cleaning, the validity and reliability analyses of the scales were carried out. An exploratory factor analysis was performed and its results compared to those of internal consistency and correlations (item-item and item-total) [[34]]. The use of exploratory factor analysis is also useful at this time to verify / confirm if the number of dimensions obtained with the data collected is similar to that derived from the theory. Thus, the factors underlying the constructs evaluated in the scale were defined and explain the correlations between them of the set of items studied. There were some measures related to the factor analysis, which sought to evaluate its relevance. Bartlett's sphericity test analyzes the association between variables and is used to test the null hypothesis that the variables in the population correlation matrix are not correlated [[27]]. The Kaiser-Mayer-Olkin (KMO) sample adequacy measure analyzes whether the sample is suitable for analysis by comparing the magnitudes of the observed correlation coefficients and the partial correlation coefficients [[27]]. High values for the KMO indicate that the factor analysis is adequate. As a reference, Malhotra (2010) indicates that the KMO measure must be greater than 0.5 and the closer to 1 the value, the better the adequacy. The value obtained for KMO was 0.832 for all ten items. The Bartlett sphericity test rejected the null hypothesis that there was no significant correlation between the variables of the sample studied and the analyses of the commonalities of the variables also showed satisfactory values. One item (The success of this company is due to the investment in tools of control and improvement) presented low commonality (0.42) and was withdrawn from the set. Number of factors' determination occurred through the eigenvalue criterion greater than 1.0 and the use of the main component technique with varimax orthogonal rotation [[27]]. Two questions did not present relevant factor loadings and were removed from the set: "There is confusion between PSLM and other tools" and "The other tools interfere in the PSLM implementation". The results indicated the formation of two factors that explain 68.8% of the variability (higher than 30% is considered to be sufficient [[35]], with KMO value of 0.832 and Bartlett sphericity test with significance $p < 0.001$. The topics were grouped as follows: (i) \Structural integration between PSLM and other tools; and (ii) Results of the PSLM integration with other tools. The reliability analysis was performed for each of the factors, using the calculation of Cronbach's alpha coefficient. This coefficient measures the reliability of the internal consistency, that is, the degree to which the answers are consistent among the items of the same measure [[36]], and is formed by the average of all the half-to-half coefficients that result from different ways of dividing the scale items (Malhotra 2010). A scale whose items have a low alpha coefficient indicates a "weak" scale in capturing the construct. Hair and his colleagues (2010) state that the lower limit for Cronbach's alpha generally accepted is 0.70, although it may decrease to 0.60 in exploratory research - similar to the value indicated by [[29], [37]]. It was also verified the maximum item-total correlation of 0.8 for each variable, ensuring that there is no multicollinearity [[36]]. The first factor obtained in the analysis was called the “PSLM Integration Framework with other tools”. This factor was composed of four questions, explained 54.4% of the data variability and presented Cronbach's alpha of 0.831, very good according to [[38]]. Factor loadings are shown in Table 1.

The second factor that emerged from the scale indicators of PSLM integration with other tools was “Results of the PSLM integration with other tools”, composed of three items. It presented Cronbach's alpha 0.717 (Table 2), considered good [[38]].

Table 1: Rotated factor loadings “PSLM Integration Framework with other tools”

Items	Rotated factor loadings	Mean	Standard Deviation
The implementation of tools of control and continuous improvement contribute to employee satisfaction	0.870	3.93	0.775
The tools of control and continuous improvement are real opportunities for the employee to participate in the decisions in this company	0.840	3.81	0.847
The implemented tools contribute to improve the company's image vis-à-vis clients	0.625	4.13	0.704
The PSLM and the other tools are integrated in this company	0.607	4.03	0.743

Table 2: Rotated factor loadings “Results of the PSLM integration with other tools”

Items	Rotated factor loadings	Mean	Standard Deviation
This company benefits from both the PSLM and the other tools	0.832	3.87	0.761
It is a correct decision for this company to invest in PSLM and other tools as well	0.813	3.97	0.738
The implementation of the PSLM and other tools contribute to the competitiveness of this company	0.527	4.13	0.700

When Tables 1 and 2 are examined, it has been revealed that the averages for all the expressions ranged from 3.87 to 4.13. Since the general average of all the items for this scale is 3.83, it can be said that workers tend to agree weakly that there is integration between the quality tools already in place in the company and lean production initiatives (PSLM).

3.3. Confirmatory factor analysis

Exploratory factor analysis is useful as a technique for developing scales in the initial stage, phase of reducing a large number of indicators to a more parsimonious set. It is particularly useful as a preliminary analysis, in the absence of relationships between indicators of a construct [[39]]. However, several authors suggest the use of confirmatory factor analysis, since this procedure provides sufficient information about the unidimensionality, reliability, convergent validity and discriminant validity [[39], [40], [41], [42], [27], [43]]. Following this indication, a confirmatory factor analysis was performed for the structure suggested in the previous step, using the same sample of respondents. The first step in the evaluation process is unidimensionality analysis [[43]]. Once it is obtained, then the reliability can be analyzed. When scales are one-dimensional and reliable, then validity can be analyzed. Unidimensionality was analyzed through the parameters of the items related to the construct. The parameters sign, magnitude and statistical significance indicates whether the set of items is one-dimensional or not [[43]]. In this analysis, it was observed that the structure proposed by the confirmatory factor analysis was maintained, with all indicators showing significant relationship with each of the constructs. In the sequence, the reliability analysis was performed through the construct reliability and extracted variance calculations. The composite reliability of a construct can be calculated by CR=(□□□□□□□□□□□□□□□□□□j□□□, where □ is the standardized parameter estimate. In many cases the value approaches Cronbach's alpha and is suggested to be greater than or equal to 0.7 [[43]], although lower values are accepted if the research is exploratory [[27]]. Extracted variance reflects the general amount of variance in the indicators explained by the latent construct. It can be calculated by AVE=□□□□□□□□□□□□□□□□j□□□, where □ is the standardized parameter estimate. AVE values should be equal to or greater than 0.5 [[43]]. The factor "Structural integration between PSLM and other tools" presented CR = 0.8346 and AVE = 0.5604, while the factor "Results of the PSLM integration with other tools" presented CR = 0.7297 and AVE = 0.4774, slightly below that suggested by [[43]], indicating modest convergent validity for this construct. Although the AVE value for the factor "Results of the PSLM integration with other tools" was below the threshold of .50, the CR value was higher than the minimum indicated.

4. Conclusions

The use of multi-item scales in research is very common. The constructs in general are already defined and the use of these scales favors the advancement of science. On the other hand, although it is common for organizations to implement continuous improvement methodologies, little is known about the integration between them, nor there is a scale that evaluates their integration from the point of view of those involved. Thus, the present research offers a contribution to deepen the understanding of the integration between quality tools and production systems based on Lean Manufacturing. The field of application for scale validation was a company with decades of experience in implementing these methodologies and the sample had 308 employees from the productive sector involved with both Quality and Lean. It is believed that, in this way, the traditional procedures for the development and evaluation of scales of measures, which are the study of the total item correlations, exploratory factor analysis and reliability (Cronbach's alpha), in addition to the procedures suggested by the confirmatory factor analysis. The results suggest that the integration between production systems based on Lean Manufacturing and quality tools can be seen in two dimensions: structure and results. While the structure assesses aspects such as satisfaction, employee involvement and company image, the results dimension addresses the benefits and competitiveness of the organization. We suggest the continuation of the research with the application of the scale proposed in other organizations and the comparison between the results obtained in this company and the others.

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