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Lean manufacturing implementation: An exploratory study of Brazilian companies

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Abstract: This paper surveys 79 Brazilian companies following their implementation of lean manufacturing (LM) practices. This analysis is based on 37 indicators which are divided into four important variables, including demand, product, production planning and control (PCC), and shop floor. We identified a strong correlation between practice and expected performance such that an increase in lean manufacturing practices positively corresponds to an increase in production performance. We also found that lean manufacturing achieves better results when implemented by large companies, although lean manufacturing can also work well for medium- and small-sized companies. In order to highlight differences in the analysis, we compared results between a group of 36 companies termed the Group of Backward Companies (GBC) and another 24 companies termed the Group of Lean Companies (GLC). We also discuss the differences in each variable leading to greater success for the GLC group in implementing LM.

Keywords: Lean Manufacturing, Benchmarking, Best Practices and Performance

1. Introduction

Based on the increased implementation of Lean Manufacturing (LM) as a production strategy, it is appropriate to investigate its level of maturity in companies. Yet, little attention has been given to the establishment of evaluation standards in the literature, thus making it difficult for those concerned about the potential deployment of LM in their own production systems (Wan and Chen, 2008).

Over the last decade, the impact of LM post-implementation has been a growing concern. White et al. (1999) investigated the existence of ten LM practices at 454 small and large companies in the United States. Sánchez and Pérez (2001) applied a checklist for 107 companies in Spain to assess the influence of their objectives in the context of lean indicators. Goodson (2002) evaluated the implementation of lean manufacturing in more than 150 companies. Shah and Ward (2003) analyzed the correlations between the levels of LM practices implemented in 1,757 companies from various sectors. To measure the degree of adoption of LM, Kaplinski and Kojima (2004) developed an index that was applied to 50 manufacturers of automotive components in South Africa. Also, in the United States, Doolen and Hacker (2005) evaluated the level of adoption of lean practices implemented in 27 companies that manufacture electronic products. Shah and Ward (2007) developed scales that were applied to 280 companies at different stages of implementation of LM. In China, Taj (2008) investigated the adaptation of lean manufacturing practices (LMP) in 65 companies from various sectors. Rahman et al. (2010) applied part

of Shah and Ward's (2003) instrument, which collected data in 187 Thailand companies, to examine the extent to which lean practices have been adopted and their impact on operational performance.

Despite widespread of knowledge on the topic, many companies experience difficulty implementing LMP. Some authors suggest that the success of LM depends on the unique characteristics of each company (Nightingale and Mize, 2002; Hines et al., 2004; Saurin et al., 2010) and that each one must find its own manner of implementing LM because there is no universal way that applies to all companies (Taj, 2005).

When taken together, these findings suggest that there is a range of opinion about how LM practices work and the best way to implement them (Staats et al., 2011). One way to address these challenges would be to select a set of practices known to be lean and evaluate the effects of their implementation on a given production system. Such analysis would provide information pointing out strengths and weakness in the process, indicating where to give special attention for effective implementation, and recommending steps to facilitate and improve the implementation process. To accomplish these goals, we present a survey that quantifies the status of LM practices and procedures, as implemented by large, medium and small Brazilian companies. We collected a total of 112 questionnaires from among various departments and sectors at different periods of LMP implementation in a total of 79 companies. This analysis takes into account 37 indicators of established practices and respective performances achieved, divided into four groups of variables important to lean manufacturing: demand, product, production planning and control (PPC), and shop floor, which all belong to the Lean Benchmarking (LBM) method developed by Andrade (2006).

2. Research Method

The data collection instrument of this research provides a benchmark for the comparison of a series of indicators based on the four variables of demand, product, PPC and shop floor, as well as a means of verifying the performance achieved with the implementation of these practices. The indicators to be measured within each of the variables are divided into practices and respective performance, as shown in Figure 1. The variables of demand and product have eight indicators each. The variable PPC has nine indicators, and the shop floor variable has 11 indicators. Each of these indicators will be presented in this paper.

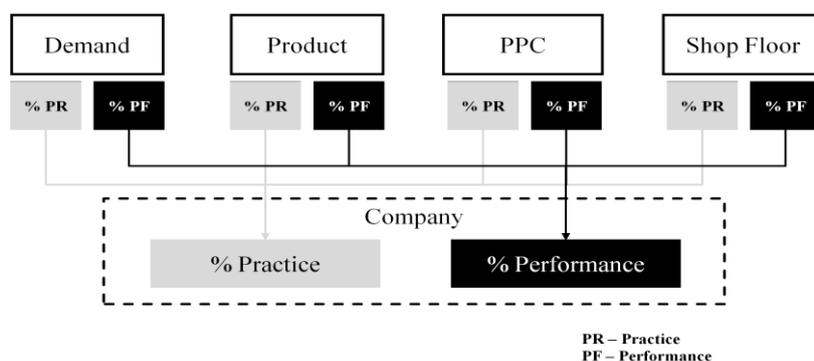


Figure 1. Questionnaire variables (Andrade, 2006).

The answers to the questions were tabulated into a scale of integer scores from 1 to 5, where 1 (20%) is equivalent to a basic level of application of a practice or obtained performance, 3 (60%) is equivalent to an intermediate level, and 5 (100%) means excellence in practice or performance. Scores 2 (40%) or 4 (80%) are intermediate positions. For example, one key shop floor indicator is termed Single Minute Exchange of Dies (SMED) practice (SFL-02). A score of five (5) indicates that the company has a formal group which carries out systematic reviews of the setups of the machines guided by goals of continued reduction of setup times. On the other hand, a score of three (3) indicates that a company has a formal group that eventually undertakes a review of machine preparation, and a score of one (1) indicates that the company has no formal critical review of machine setups. Correspondingly, there is a SMED performance indicator based on the shop floor variable, which is noted as a percentage of setup. Thus, the score will be five (5) if setup time is less than 5% of production time, three (3) if setup time takes between 10 and 20% of production time, and one (1) if setup time exceeds 30% of production time. Based on the questionnaire, which is presented in Appendix A, we have a consolidated score of practice and performance for each variable based on the average of the scores, as well as a final score of practice and performance for the entire company or department analyzed, allowing comparison with other applications from the database (Fig. 1).

For our exploratory survey in this research, we used the most common type of non-probabilistic sample, where the researcher is interested in the opinions and actions of certain population elements, but it is not representative in statistical terms. In selecting the sample, we used the criterion of convenience because we believe that the surveyed companies were reliable sources of information. Once the sample is characterized as “intentional nonrandom,” the selection of elements depends partly on the opinion of the investigator. The data collection was obtained from 2006 to 2011 by members of the Laboratory of Simulation of Production Systems (LSSP) from the Department of Production Engineering and Systems (DEPS) of the Federal University of Santa Catarina (UFSC), Brazil, to support each company’s implementation of lean manufacturing, assisted by postgraduate students and two doctoral candidates (Andrade, 2006; Silva, 2009).

The reliability of the results of this research was based on Cronbach's α . Leontitsis and Paggi (2007) argue that the higher the result of this ratio, the greater the reliability. The reliability of the results of this study was calculated with R software (R Development Core Team, 2011) through the R Commander GUI interface (Fox, 2005), resulting in $\alpha = 0.88$, which is above the acceptable range. It is also consistent with Cronbach (1951), who indicates a value of $\alpha \geq 0.55$ for responses to be considered consistent, and it is close to values found in similar surveys (Shah and Ward, 2007).

3. Results and Discussion

The 79 companies are distributed among seven Brazilian states, specifically, Santa Catarina (54%), Goiás (23%), Minas Gerais (8%), Ceará (7%), Paraná (6%), Mato Grosso do Sul (1%) and Rio Grande do Sul (1%). Regarding the size[1] of the surveyed companies, 48.2% are large, 27.7% medium,

and 24.1% are small companies. The industrial sectors of economic activity[2] from companies are presented in Table 1.

Table 1. Sectors of economic activity of the companies.

Sector of economic activity	Applications	Percentage (%)
Apparel and Accessories	43	38.39
Machines and equipment	14	12.50
Automobiles	7	6.25
Electrical machines, appliances and materials	8	7.14
Non-metallic minerals	1	0.89
Textiles	20	17.86
Wood	3	2.68
Metallurgy	3	2.68
Computer equipment, electronic and optical products	5	4.46
Rubber and plastic material	1	0.89
Various products	5	4.46
Food	2	1.79
Total	112	100,00

3.1 General database analysis

The first analyses correspond to the practices versus performance general graph, as presented in Figure 2. To achieve the objectives proposed in this article, the sample was divided into three groups of companies. Those having less than 50% in practices were termed the Group of Backward Companies (GBC), while those with 70% or above in practices were identified as the Group of Lean Companies (GLC). A third group of practices between 50% and 70% were identified as the neutral group. The general graph suggests a correlation between practice and performance; thus, as the implementation of practices increases, performances correspondingly increase within the production system.

According to the literature, deployment of LM is more likely to get better results when applied to large companies (Sánchez and Pérez, 2001; Shah and Ward, 2003; Doolen and Hacker, 2005). As seen in Figure 2, the GLC is mostly composed of large companies, i.e., within the 24 companies, 20 (83.3%) are large. Otherwise, out of 36 GBC companies, 15 (41.7%) are small, and another 14 (38.9%) are medium-sized companies with a low level of implemented practices. Some of them can actually perform well, but without the appropriate practices, they are very dependent on the experience and knowledge of key employees, which is not a proper substitute for the implementation of lean management practices.

However, while attribution of success or failure of LMP implementation by the size of a given company can be an easy answer, it is not the complete one, simply because large companies have more human and capital resources to invest. Therefore, irrespective of company size, the aim of this paper is to identify and discuss how and where the process of LM implementation occurs, focusing on the variables of demand, product development, PPC and shop floor, as described above. As can be seen in Figure 2, among the GBC, there are large companies, while within the GLC, we also find medium-sized (three) companies and one small company.

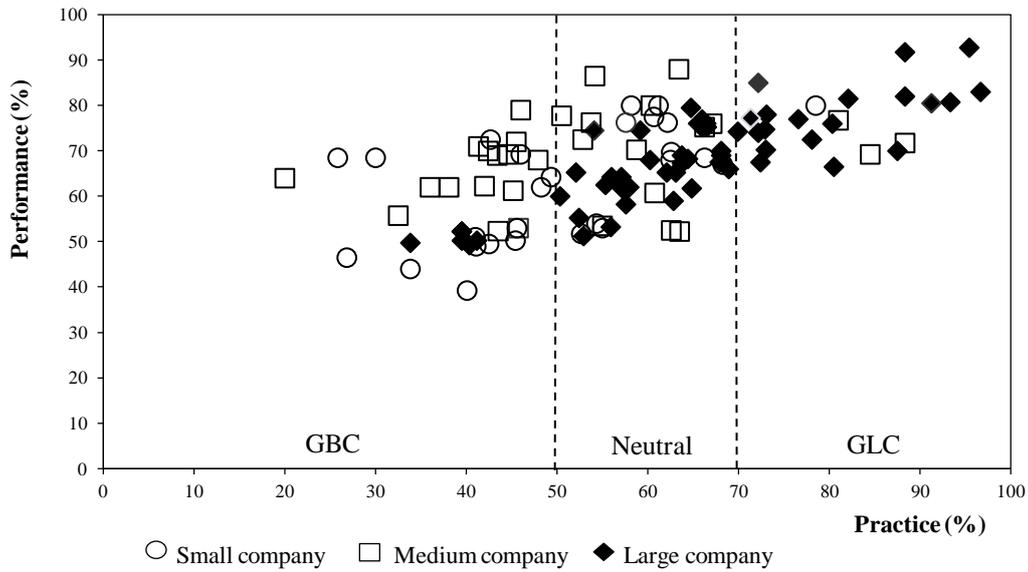


Figure 2. General graph of practice versus performance.

Next, we present a detailed analysis of the 37 indicators of practice and performance from the four studied variables. Aiming to better identify the differences, we worked with two groups at the extremes: i) companies that have a practical level of LM over 70% (GLC) and those with a level of practices below 50% (GBC). The goal, as stated, is to identify where the competitive edge is and which aspects can speed up the deployment process of LM implementation, as well as challenges that confront lean manufacturing implementation.

3.2 Demand Analysis

According to Shingo (1989), analysis of production systems necessarily involves understanding the basic demand characteristics the company attends. Stabilizing the cycle of planning and production and lowering waste associated with buffer stocks in a lean production system depend on matching the level of production to demand and demand forecasting. For the analysis of the demand variable, we proposed eight indicators, three for practices and five for performance, as listed in Figure 3. These indicators are general in nature because they are the same for any industry or any department within a company. For example, the indicator termed “DEM-03 - Market Analysis” is a general practice for any company because the demand for finished products is the same for the entire company, but the indicator termed “DEM-02 - ABC Management of Demand” is specific to each department, since this indicator may apply to one sector, but not the entire company.

Practices		Type
DEM-01	Demand forecast model	General
DEM-02	ABC management of demand	Specific
DEM-03	Market analysis	General
Performances		Type
DEM-04	Forecast reliability	General
DEM-05	Concentration degree	Specific
DEM-06	Frequency degree	Specific
DEM-07	Confirmed demand degree	General
DEM-08	Demand response	General

Figure 3. Practices and performance indicators of demand variable.

The scored results of the demand variable for GBC are shown in Figure 4, and the results for GLC are shown in Figure 5.

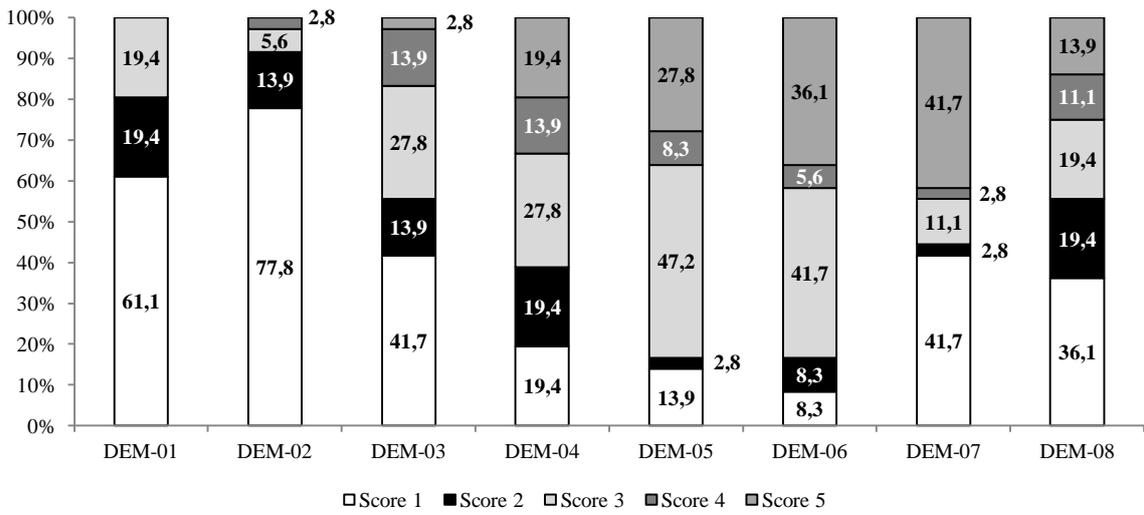


Figure 4. Frequency distribution graph of scores from GBC’s demand variable.

Initially, we evaluated whether the sampled company presents a structured way of making a demand forecast and whether the forecast, formal or not, is effective. For the GBC, 80.5% (scores 1 and 2 at DEM-01) do not have a formal model to forecast demand, and these companies use only the experience of the sales staff to forecast the main items. Consequently, 66.6% (scores 1, 2 and 3 at DEM-04) of the companies miss this forecast above 20%, and 19.4% miss it more than 40%, results which affect both capacity planning and pulled production programming, which are important issues in lean manufacturing.

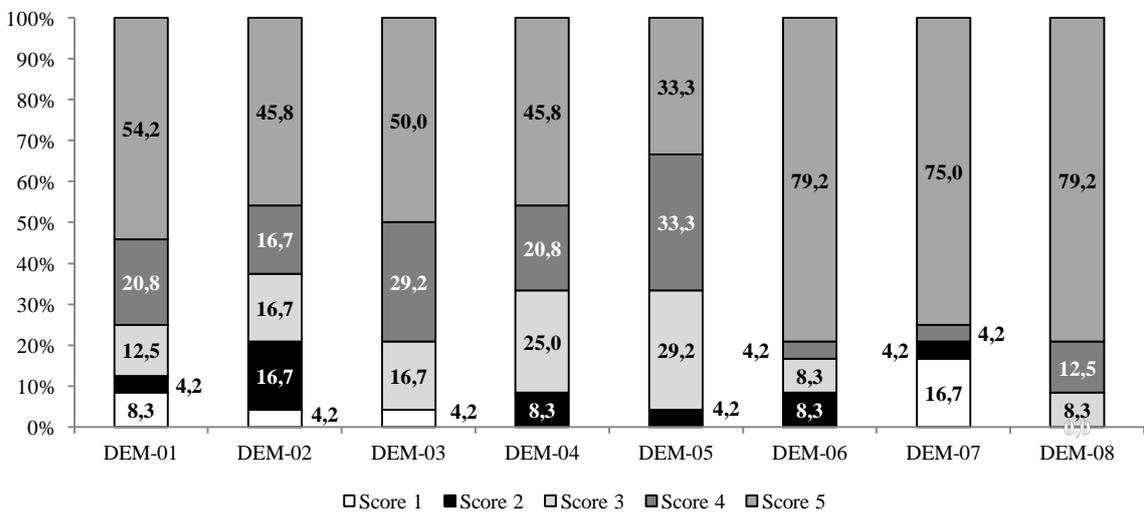


Figure 5. Frequency distribution graph of scores from GLC’s demand variable.

Comparing the values of GLC companies, we see that 87.5% (scores 3, 4 and 5 at DEM-1) have, and use, a formal forecast model with software support, which results in an error below 20% for 66.6% (scores 4 and 5 at DEM-4) of companies, and 45.8% (score 5 at DEM-04) of them miss less than 10%, which allows both effective capacity planning of production resources and appropriate pulled programming.

The second demand variable indicator, ABC Management of Demand, is related to the practice of assessing the volume and frequency of product demand in order to identify the level of repetitiveness and concentration of production. This indicator allows companies to identify different ways to manage production of items and to orientate the implementation of pulled or pushed flows for groups of items in terms of their demand characteristics.

For the GBC, 80.5% (scores 1 and 2 at DEM-02) of companies do not have an understanding of ABC Management of Demand. Therefore, as expected, 83.3% (scores 3, 4 and 5 at DEM-05) have 50% of demand concentration at less than 30% of items and 27.8% (score 5 at DEM-05) have concentration at less than 10% of items. Likewise, the demand occurs with monthly, or greater, frequency in 50%, or more, items for 41.7% (scores 4 and 5 at DEM-06) of these companies. Thus, by not using the practice of demand concentration and frequency, this group is missing an opportunity to organize and focus their resources in a more lean way. On the other hand, this indicator for GLC is an actual practice for 79.2% (scores 3, 4 and 5 at DEM-02) of the companies, since 95.8% (scores 3, 4, and 5 at DEM-05) have 50%, or more, concentrated demand in less than 30% of items, and 33.3% (score 5 at DEM-05) of them have concentration in less than 10% of the items. Likewise, the demand occurs with monthly, or greater, frequency at 50%, or more, items for 83.4% (scores 4 and 5 at DEM-06) of these companies.

What is striking about the GLC with a high level of lean implementation is the fact that 20.9% (scores 1 and 2 at DEM-02) of them do not take advantage of the concentration and frequency of demand. Otherwise, ABC management would lead to an increase in the expected results of these practices because a high degree of concentration and frequency of demand in a few items, called A-class, have the potential to build a focused system on productive resources, thus facilitating the introduction of a supermarket run by a pulled flow. This is a favorable situation in which one can manage most of the production through pulled flow, releasing those charged with PPC for other duties in planning and more accurate control of made-to-order or pushed items, which usually have higher contribution margins.

Finally, we have indicators related to the issue of customer relations. These indicators aim to assess how distant the market is from the production system and evaluate evidence of actions established to accelerate communication and contact between the internal environment of the company and the events and variables of the marketplace that influence customers. This assessment is needed to better understand market behavior and establish a communication channel between the decision makers who plan and schedule and the external sources of demand. This practice is called “market analysis”, and the related performances are termed “Confirmed demand degree” and “Demand response”.

For the GBC, only 2.8% (score 5 at DEM-03) have a formal model and use it with software and technical support to create a communication channel with key customers, while 55.6% do not take any action in this regard. For the GLC, in contrast, 50.0% (score 5 at DEM-03) of companies make use of this formal communication channel, and only 4.2% (score 1 and 2 at DEM-03) have taken no steps in this regard. Quite possibly, the answer to the lack of solid customer relations is rooted in the fact that 41.7%

(score 5 at DEM-07) of the GBC and 75.0% of the GLC have more than 50% of confirmed demand before the start of production, which may seem comfortable for them. However, only 13.9% (score 5 at DEM-08) of the GBC have demand forecasting access or have previously confirmed a promised delivery date, while for the GLC, this indicator goes up to 79.2%, allowing LMP to be properly executed on the shop floor.

3.3 Product Analysis

In addition to demand features, the process of new product development also exerts a strong influence on production performance, since the majority of waste arises from product design. Moreover, the production of samples and prototypes during the development test phases, in parallel with the current production of products, generates a higher number of cross orders and machine setups. Designing products with predefined schedules facilitates the manufacturing process and meets the requirements for a lean manufacturing strategy by the continuous improvement and reduction in overall waste.

Lean product development must simultaneously seek to meet demand for variety without, however, generating an undue increase in the number of different product components and should also involve different participants of the production chain by applying the concurrent engineering concept, a lean management practice defined and illustrated below. Within the lean strategy, flexibility of the production system and product differentiation techniques will enable companies to meet the demand of variety in a standardized way and with controlled design parameters, which will reduce the disorganized development of components and final products to be planned and scheduled.

Because of the importance of lean product development, we proposed eight indicators to evaluate the product variable, within which four are practices and four are performances, as described in Figure 6. The results of the applications for the GBC are shown in Figure 7, and the results for the GLC are presented in Figure 8.

Practices		Type
PRO-01	Concurrent Engineering	General
PRO-02	Parameter setting design	General
PRO-03	Calendar of development	General
PRO-04	Special order negotiation	General
Performances		Type
PRO-05	Internal defects percentage	Specific
PRO-06	Variety degree	General
PRO-07	Life cycle	General
PRO-08	Leftover percentage	General

Figure 6. Practices and performance indicators of product variable.

The first indicator aims to measure how the company applies the principles of concurrent engineering such that all those impacted by the development of new product production are included, even primary suppliers and end users. For the GBC, 77.7% (scores 1 and 2 at PRO-01) do not have a multifunctional process of developing new products, nor do they have an effective communication structure, while all GLC companies have this process. However, 37.5% (score 3 at PRO-01) of them have not included suppliers and customers.

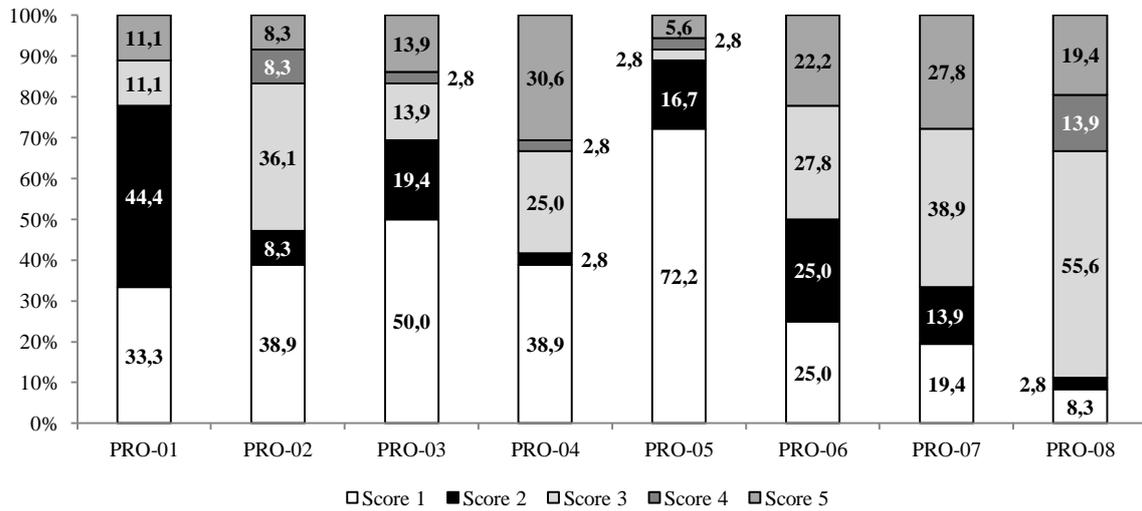


Figure 7. Frequency distribution graph of scores from GBC's product variables.

The second product variable indicator aims to determine whether the process of product design involves the practice of setting limits. The idea here is to determine whether the company can impose limits on the creative process in order to avoid the excessive growth of new items, but without affecting the perceived value of products by the end customers. The difference between the two groups is significant. While only 16.6% (scores 4 and 5 at PRO-02) of GBC companies systematically use the application of design parameters during the process of new product development, this statistic grows to 79.1% for the GLC. It should be noted that none (score 1 at PRO-02) of the companies from the GLC group lacks the use of design parameters for new product development, while 38.9% of GBC companies are in this situation. Therefore, it is not surprising that these GBC companies have difficulty implementing lean practices at the shop floor level.

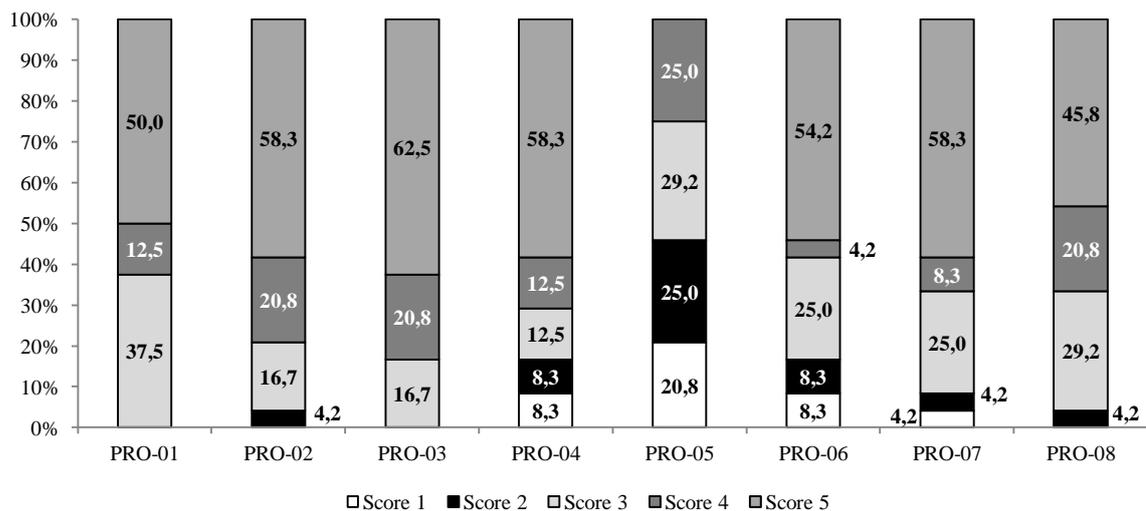


Figure 8. Frequency distribution graph of scores from GLC's product variables.

A third practice indicator aims to measure the existence of a planned and organized development process with an activities schedule. Only 16.7% (scores 4 and 5 at PRO-03) of GBC companies have implemented this process, while for the GLC, this number increased to 83.3%. No

(scores 1 and 2 at PRO-03) GLC company has failed to implement practices that develop products in a planned way, while more than half of GBC companies do not have such practices.

To complete the analysis of the product variable practices, we sought to assess the design of customized products, which are crossed with other products in the production process, usually with specifications set by client. Such product requests are developed in partnership with the factory within the parameters negotiated for product design, not simply imposed by market forces. For GBC companies, 41.7% (scores 1 and 2 at PRO-04) accept special requests for independent parameterizations of a given project, which complicates production resource scheduling as a whole, while for GLC, this number reduces to 16.6%.

The first product performance indicator is defects percentage. Most defects result from the failure to apply proper practices in lean product design, which result in new products that are difficult to produce on the shop floor. For GBC companies, 88.9% (scores 1 and 2 at PRO-05) have more than 0.1% of internal defects, whereas for GLC companies, this statistic reduces to 45.8%. It should be noted that each kind of industry has its standards with respect to acceptable levels of defects, i.e., in the metal-mechanics industry it is easier to get a part per million (ppm) evaluation (0.000001%), whereas the value of 0.1% defects is considered a good indicator in the textile industry, which covers 51.8% of the applications, as shown in Table 1.

When LM practices are not followed in the context of product design, a large inventory of variety items can result, as the life cycle of these products tends to be short. Since GBC companies generally ignore factors which impact product design and production, half (scores 1 and 2 at PRO-06) of them exceed the limits of variety, while the number is reduced to only 16.6% for the GLC. Regarding the life cycle of products, only 27.8% (scores 4 and 5 at PRO-07) of GBC companies have scheduled production of new products more than ten times during that product's life cycle, while for GLC, 66.6% of the companies are in this situation, with plans to repeat production schedules for small lots of the same item, thus increasing inventory turnover.

To complete the product variable analysis, we sought to evaluate the level of obsolete inventory against the provisioning of products that meet actual market needs, not only for finished products, but also specific components. Thus, assessing the percentage of leftovers in inventory is a good indicator of efficiency in the context of LM implementation, since LM requires a planned inventory turnover. For the GLC, 66.6% (scores 1 and 2 at PRO-08) have just 1%, or less, of leftover inventory at the end of product life, while only 33.3% of GBC companies are in the same situation. We should note that 55.6% (score 3 at PRO-08) of GBC companies have up to 10% of leftover, which translates into very high waste.

3.4 Planning and production control analysis (PPC)

The practices of planning, scheduling and controlling production in a company provide the conditions necessary to support the decision-making process in terms of what, how much, when, where and how to produce or buy the inputs and products processed in the production system. In a broad way,

one can understand the dynamics of PPC as the brain of manufacturing management, since the final settings that determine the process of transforming raw material into finished goods is the result of intentional reasoning.

PPC performance has strong impact on the competitiveness of a company, as well as the successful implementation of lean manufacturing. The quality, final cost, flexibility and delivery performance of products offered in the marketplace are positively influenced by an effective management in terms of planning, programming and production control. A lean PPC seeks to use company resources to meet market demands. In general, seasonality and such external factors as the overall economic outlook reflect demand characteristics. Therefore, to better meet competitive criteria, PPC should establish simultaneous pulled and pushed flows.

To evaluate PPC, we proposed ten indicators, out of which five represent practices and five represent performances, as described in Figure 9.

Practices		Type
PPC-01	Master production planning (MPP)	General
PPC-02	Material Requirement Planning (MRP)	General
PPC-03	Production capacity analysis	Specific
PPC-04	Departmental PPC	General
PPC-05	Integrated schedule system	General
Performances		Type
PPC-06	Plan and Schedule cycle	General
PPC-07	On time delivery percentage	Specific
PPC-08	Value aggregation percentage	Specific
PPC-09	Stock turnover	Specific
PPC-10	Extra time percentage	Specific

Figure 9. Practices and performance indicators of the PPC variable.

The results for the GBC group are shown in Figure 10, and those of the GLC are shown in Figure 11. In a general way, PPC practices are related to the existence of software support, which relates strongly to company size. Most GBC companies are medium or small in size. Consequently, PPC practices are weak or nonexistent. GLC companies, however, are mostly large, and such practices are easily consolidated. To the extent that software is used, there is a direct correlation with performance indicators. The details of the practices with respective performance of the PPC variable are discussed below.

Master production planning (MPP) involves establishing a short-term production plan based on sales forecasts or confirmed orders. MPP sets the conditions for all other planning and programming activities; therefore, its existence is essential for PPC and lean manufacturing. As such, the PPC-01 indicator evaluates whether a company has and uses a software system on a weekly basis to support an integrated business system (ERP) for master production planning. Such is the case for 79.2% (score 5 at PPC-01) of GLC companies, while for GBC companies, 72.2% (score 1 and 2 at PPC-01) do not have a formal MPP model.

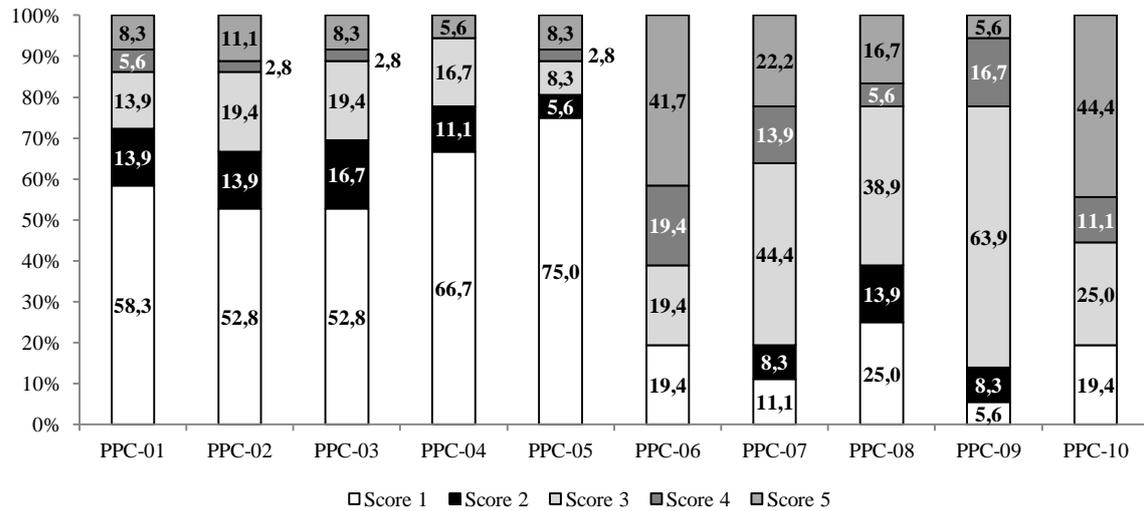


Figure 10. Frequency distribution graph of scores from GBC’s PPC variable.

MPP determines the requirements of finished products, which, in PPC dynamics, are used to calculate Material Requirements Planning (MRP). MRP, in turn, scales up the needed components and raw materials. Thus, the second indicator assesses whether PPC is able to rapidly calculate the required materials. As a requirement for both pushed and pulled programming, MRP uses forecast demand to dimension supermarkets. Again, 66.7% (scores 1 and 2 at PPC-02) of GBC companies do not use an MRP system, while this value is just 4.2% for the GLC. At the other extreme, 79.2% (score 5 at PPC-02) of GLC companies have implemented both MPP and the MRP and integrated them into a corporate ERP system, a situation considered ideal for lean management.

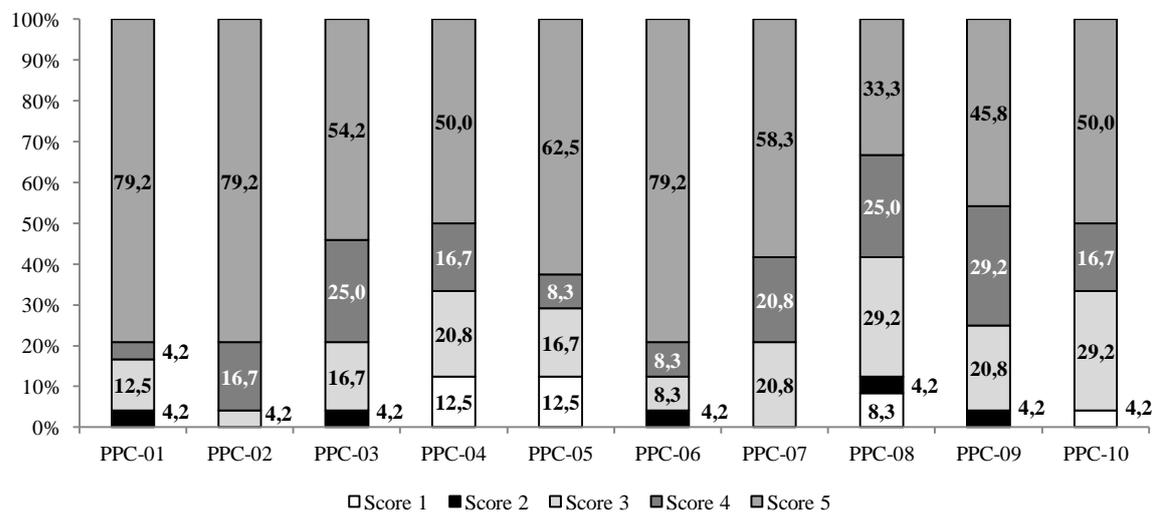


Figure 11. Frequency distribution graph of scores from GLC’s PPC variable.

The third indicator is productive capacity analysis. As a PPC tool, the analysis of production capacity to meet the company's forecasts should be performed using MPP in order to avoid bottlenecks. For a lean production system with the characteristics of many items and shared streams, short-term capacity analysis is an essential practice of PPC to focus and organize resources. Even where it is possible to pull the production, analysis of short-term capacity is required to balance resources and supermarkets. Only 11.1% (scores 4 and 5 at PPC-03) of GBC companies have a capacity planning system, as an adjunct

to MPP, to design cycle times and levels of inventory (supermarkets), while this statistic rises to 79.2% for GLC companies.

Once a production schedule is issued, it is necessary to monitor resources and rapidly reallocate them if a problem arises within the planning horizon. Thus, in the fourth PPC variable indicator, we seek to assess how close PPC is from the production process. In decentralized PPC, there are extensions from main PPC, as found in different departmental settings; therefore, the time between identification and correction of problems is effectively reduced. Thus, this indicator aims to measure the level of centralization of planning, programming and production control decisions. For the GBC, we find that 5.6% (scores 4 and 5 at PPC-04) of companies have a semi-decentralized system where extensions of the main PPC can be found within departments and connected by a loose communications network. However, for the GLC, 66.7% have departments with their own PPCs and are thus more decentralized. Such departmental decision-making allows for better short-term implementation and monitoring of productive resources, in addition to facilitating the deployment process of new practices related to manufacturing management.

The last practice indicator, integrated schedule system, aims to investigate whether production planning, programming and control are structured in a way that can manage hybrid production flow by both pulled and pushed systems. According to the precepts of LM, the pulled system must be applied for items with repetitive demand, while pushed system logic focuses on customized items for which demand is generally low. Our results show that 75.0% (score 1 at PPC-05) of GBC companies are not prepared to simultaneously manage both pushed and pulled flows, while companies at GLC 70.8% (scores 4 and 5 at PPC-05) already employ pulled programming that runs parallel to pushed programming.

The first performance indicator is the planning and programming cycle. We sought to evaluate the frequency given to the cycles of planning and production programming, or, more specifically, which periods of time (days, weeks or months) are adopted for PPC. It is understood that weekly planning and scheduling cycles are sufficient to manage LM and adjust cycle times and supermarkets. In general, this is already an industry standard. For GBC, this performance indicator can be identified in 61.1% (scores 4 and 5 at PPC-06) of companies, while GLC companies, at 87.5%, perform this practice with employees on a weekly basis, or less. Still, GBC companies, despite apparent appropriate planning and programming cycles, are not using it to expand LM practices.

The second PPC performance indicator, on-time delivery percentage, compares the time between orders taken and orders processed in order to establish on-time delivery. Since a high service level here is indicative of competitive advantage, this performance indicator is measured on the basis of finished orders within the original deadline. We found that only 36.1% (scores 4 and 5 at PPC-07) of GBC companies have a punctuality rate of over 90%, while for the GLC, this grows to 79.1% of companies, and 19.4% (scores 1 and 2 at PPC-07) of GBC companies do not even have 40% of punctuality.

The third performance indicator seeks to measure the percentage of aggregate value. To explain, production lead time is the sum of waiting, processing, inspection and transportation times at each stage of manufacturing. Thus, the measurement of how much time the products accrue in added value by this indicator is an essential measurement of PPC efficiency, since, for example, much of the responsibility for wait-time waste results from queuing and scheduling problems. Only 22.3% (scores 4 and 5 at PPC-08) of GBC companies are sufficiently agile to have an average production lead time up to 5 times the standard engineering lead time, but GLC, with a leaner and planned shop floor, reaches this value in 58.3% of companies.

Another performance indicator is inventory turnover as the main source of waste within the factory. To determine this index, we measure how many times the inventory of items and finished products revolve in relation to the average monthly demand. Results show that 22.3% (scores 4 and 5 at PPC-09) of GBC companies keep under one month's inventory, while this statistic grows to 75.0% of GLC firms, with 45.8% (score 5 at PPC-09) of them having under one week's inventory.

The last PPC performance indicator measures the percentage of unplanned overtime necessary to enforce the monthly production program. Last minute changes in production schedules cause imbalances and delivery delays. This indicator is measured by relating the amount of unplanned overtime during a monthly period to total hours of production in the same period. For GBC, 44.4% (scores 1, 2 and 3 at PPC-10) of companies use more than 10% of unplanned overtime on average to meet deadlines. This is expected given that only 11.1% (scores 4 and 5 at PPC-03) have a capacity analysis system. Considering that 79.2% (scores 4 and 5 at PPC-03) of GLC companies have a capacity analysis system in place and noting that this indicator assesses unplanned overtime, it was unexpected that 33.4% (scores 1, 2 and 3 at PPC-10) of GLC companies were using more than 10% of unplanned overtime.

3.5 Shop floor analysis

For the shop floor variable, we sought to investigate structures present in the company, or department, to enable the effective transformation of primary inputs into semi-finished and finished products. Thus, the study focuses on the analysis of how human resources and physical infrastructure are being applied to achieve the desired outcomes. This variable seeks to investigate the degree to which lean practices meet competitive demands. In this investigation, we proposed eleven indicators, five of which are practices and six of which are performances, as described in Figure 12.

The results of the applications are shown in Figure 13 for the GBC, and the results for GLC are shown in Figure 14. In a general way, most GBC companies are deficient in shop floor lean manufacturing practices, and, consequently, shop floor performance. In fact, GLC companies equal the poor performance of GBC companies in the practice of Total Productive Maintenance, with high rates of unplanned downtime, as well as the issue of polyvalence, both in practice and in performance. The details of the practices and performances of shop floor variable are shown below.

Practice		Type
SHF-01	Volume flexibility	Specific
SHF-02	Single Minute Exchange of Dies (SMED)	Specific
SHF-03	Focused production	Specific
SHF-04	Total Productive Maintenance	General
SHF-05	Polyvalence program	Specific
SHF-06	Standard routine	Specific
Performance		Type
SHF-07	Leveling degree	Specific
SHF-08	Setup percentage	Specific
SHF-09	Productive indices	Specific
SHF-10	Non-planned breakdown indices	Specific
SHF-11	Polyvalence indices	Specific

Figure 12. Practices and performance indicators of the shop floor variable

The first shop floor practice indicator, volume flexibility, aims to investigate how flexible the production system can be in meeting demand in a cost-effective manner in relation to the variety of the mix and structure of machines and equipment present in the company. Volume flexibility enables the adjustment of production according to the current needs of the market. With this indicator, is hoped that the configuration of resources would provide flexibility in production volume and facilitate the leveling of production batches according to demand, with minimum surplus inventory. One way to assess this feature is to verify in each sector the existence of different types and sizes of equipment in proportion to the average demand requested. The degree of leveling is the practical result of implementing volume flexibility, and it is measured by the ratio between the average production lots and the average lots of customer requests. The closer the production lot is to the demand order, the better.

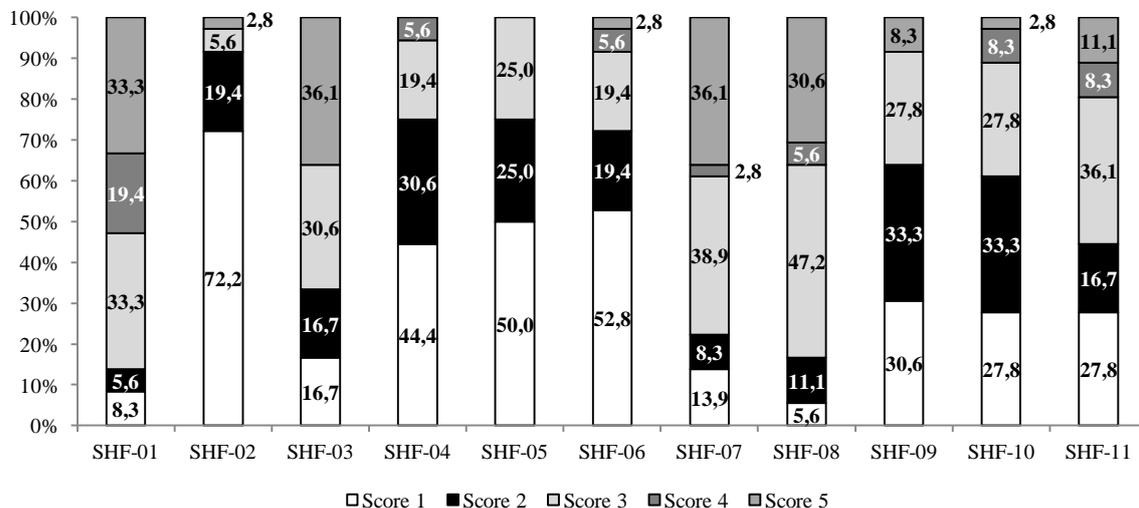


Figure 13. Frequency distribution graph of scores from GBC's shop floor variable.

We found that only 33.3% (score 5 at SHF-01) of GBC companies were not required to use equipment larger than necessary, which means 61.1% (scores 1, 2 and 3 at SHF-07) of companies had production batches above 30% of customer orders. Up to 66.7% (score 5 at SHF-01) of GLC companies have an inverse relationship of volume flexibility, and only 37.6% (scores 1, 2 and 3 at SHF-07) of them have batch production 30% higher than the customer needs.

Single Minute Exchange of Dies (SMED), the second indicator, presupposes the implementation of teams guided by goals of continued reduction of time to do a systematic review of machine

preparation. Thus, SMED seeks to identify whether the company has such permanent teams in place in relation to the progressive reduction of time spent on machine preparation for the exchange of batch production, thus having adequate performance for equipment setup time. Results show that 91.6% (scores 1 and 2 at SHF-02) of GBC companies have no formal setup review, while this percentage is just 25.0% for GLC companies. The percentage of GLC companies having a formal SMED team is 37.5% (scores 4 and 5 at SHF-02), while this figure is only 2.8% for GBC companies.

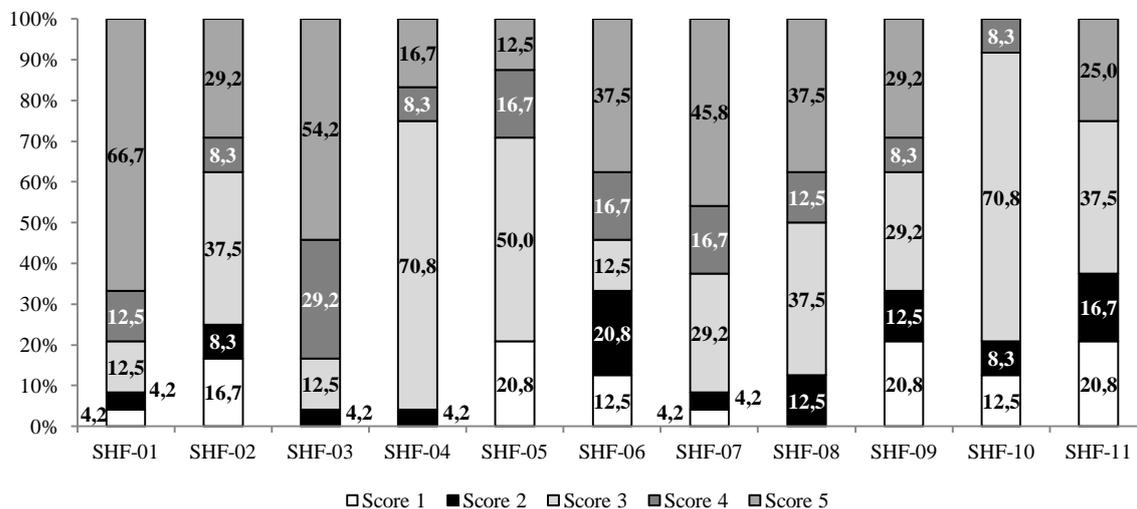


Figure 14. Frequency distribution graph of scores from GLC’s shop floor variable.

Despite the large difference in the use of SMED teams, no significant performance difference exists compared to the length of setup time. For GBC and GLC companies, 30.6% (score 5 at SHF-08) and 37.5%, respectively, have setup times less than 5% of production time, while for GBC and GLC companies, 47.2% (score 3 at SHF-08) and 37.5%, respectively, have setup times between 10 and 20% of productive time. Perhaps the issue of setup time is more closely related to the type of equipment than the existence of SMED teams, or these teams are not being used effectively.

The third indicator aims to determine the degree of focused production in the company. This indicator verifies if equipment has previously been prepared for lots of a particular item, or if the equipment is prepared coincident with the input of production lots, resulting in increased machine downtime for tool change. Since “A class” items have a high concentration and frequency of repetition, focused production is justified by the high volumes involved, but other items should not have a focus on a specific item; rather, similar items in an order should be grouped to make fast exchanges between them. Focused production is measured in percentage terms and lists among all devices available in the shop the percentage dedicated to the production of a specific family of items. The corresponding performance indicator measures production rate efficiency compared with the nominal average rate for the resource. As expected, given the size difference of companies from both studied groups, only 36.1% (scores 4 and 5 at SHF-03) of GBC companies have more than 50% of installed capacity focused on a specific family of items, while for the GLC, this percentage grows to 83.4%. As a result, since focused production leads

to increased productivity, 66.7% (scores 3, 4 and 5 at SHF-09) of GLC companies have a real productive rate equal to, or above, the expected one, while for the GBC, this percentage is only 36.1%.

The fourth indicator aims to identify the practice of Total Productive Maintenance (TPM) within the company. Such program includes formal preventive maintenance planning for different resources with scheduled dates to perform maintenance activities of equipment and an education and training program for operators. Results show that 75.0% (scores 1 and 2 at SHF-04) of GBC companies work only with corrective maintenance, with only 5.6% (scores 4 and 5 at SHF-04) of them applying TPM. For the GLC, although the percentage of companies that work only with the corrective maintenance is just 4.2% (scores 1 and 2 at SHF-04), the percentage of companies applying TPM is still low, 25.0% (scores 4 and 5 at SHF-04), and the most (score 3 at SHF-04) companies perform just preventive maintenance, but lack a broader TPM program.

The performance indicator is proposed to assess how often production is interrupted as a result of breakage problems work stoppages that impede production. Since most GBC companies only provide for corrective maintenance, 61.1% (scores 1 and 2 at SHF-10) experience interruption of production from equipment breakdowns, whereas only 20.8% of GLC companies experience this. Out of GLC companies that have preventive maintenance, but no broader TPM program, 70.8% (score 3 at SHF-10) have rare interruptions of production for equipment breakdown, but eventually require emergency maintenance before complete breakdown, which is not a solution expected of companies that practice LM.

The last set of practices and performance indicators are related to polyvalence (multipurpose operators) and people management. These indicators assess whether there is an effective program to stimulate polyvalence within the company, given that lean manufacturing promotes flexibility of the workforce as an important means of absorbing variations in demand by the shift of functions among operators, but also to ensure the standard and quality of production. Our survey showed that 75.0% (scores 1 and 2 at SHF-05) of GBC companies have no formal program to encourage polyvalence for technical training of operators, whereas this statistic is only 20.8% for GLC companies, and 79.2% (scores 3, 4 and 5 at SHF-05) of GLC companies have formal programs to stimulate polyvalence through continual training for operators.

There is also a significant difference between the percentages of polyvalent, or multipurpose, collaborators. Results show that 44.5% (scores 1 and 2 at SHF-11) of GBC companies have less than 20% of polyvalent operators; while for the GLC, this value is about 37.5%. At the other extreme, only 19.4% (scores 4 and 5 at SHF-11) of GLC companies have more than 80% of polyvalent operators, while this value is slightly higher at 25.0% for GLC companies.

With the lack of polyvalence, it is not surprising that 72.2% (scores 1 and 2 at SHF-06) of GBC companies do not use the concept of cycle time and standard routine with polyvalent operators. For the GLC, this value is also high, at least for lean companies, amounting to 33.3%, which is justified by the fact that 37.5% (scores 1 and 2 at SHF-11) of them have less than 20% of polyvalent operators. On the

other hand, while 54.2% (scores 4 and 5 at SHF-06) of GLC companies use standard routines for the operations which are balanced by a given cycle time, with multipurpose operators both in assembly lines and in manufacturing cells, and provide shop floor standard routine updates, a practice which would be expected from a lean company, this figure is only 8.4% for GBC companies.

4. Conclusions

Despite the evolving deployment of lean manufacturing in Brazilian companies, little is known about the effectiveness of these deployments and the enabling or restrictive factors in the process. Using the benchmarking method for our survey of LM practices and procedures implemented in 79 Brazilian companies, we found a direct correlation between practice and expected performance and that performance is enhanced by the addition of more LM practices. We also found that the implementation of LM is more likely to have better results when implemented in large companies, even though small- and medium-sized companies could also benefit from LMP. Finally, within each analyzed variable (demand, product, PPC, and shop-floor), we identified and discussed the majors differences which make GLC more successful in the implementation of lean practices in comparison to the GBC.

Notes

1. According to the Brazilian Service of Support to Micro and Small Enterprises criteria (small companies: 20 to 99 employees; medium companies: 100 to 499 employees; and large companies: over 500 employees).
2. According to the criteria of the National Classification of Economic Activities, developed by the National Classification.

Appendix A.

Demand indicator		Description of the scores
DEM-01	Demand forecast model	Score 1 Company does not have a formal model to forecast demand and uses only the experience of the sales staff to forecast main items.
		Score 3 Company has a formal model to forecast demand, with software, but only makes the forecast for main items.
		Score 5 Company has a formal model to forecast demand, with software, and makes the forecast for all items.
DEM-02	ABC management of demand	Score 1 Company does not have a formal model for ABC management of demand.
		Score 3 Company has, and eventually uses, a formal model for ABC management of demand, with software.
		Score 5 Company has, and always uses, a formal model for ABC management of demand, with software.
DEM-03	Market analysis	Score 1 Company does not have a formal model for communication channel with the main customers.
		Score 3 Company has, and eventually uses, a formal model for communication channel, with software and other techniques, for the main customers.
		Score 5 Company has, and always uses, a formal model for communication channel, with software and other techniques, for the main customer.
DEM-04	Forecast reliability	Score 1 Company misses more than 40% of demand forecast.
		Score 3 Company misses between 20% and 30% of demand forecast.
		Score 5 Company misses less than 10% of demand forecast.
DEM-05	Concentration degree	Score 1 Company does not have demand concentration.
		Score 3 Company has more than 50% of the demand at less than 30% of items.
		Score 5 Company has more than 50% of the demand at less than 10% of items.
DEM-06	Frequency degree	Score 1 Company has less than 20% of items with monthly sales frequency.
		Score 3 Company has between 30% and 40% of items with monthly sales frequency.
		Score 5 Company has more than 50% of items with monthly sales frequency.
DEM-07	Confirmed demand degree	Score 1 Company has less than 20% of confirmed demand before beginning production.
		Score 3 Company has between 40% and 30% of confirmed demand before beginning production.
		Score 5 Company has more than 50% of confirmed demand before beginning production.

DEM-08	Demand response	Score 1 PPC of company accesses the information of demand forecast, or confirmed orders in advance of the promised delivery date.
		Score 3 PPC of company accesses the information of demand forecast, or confirmed orders, in advance of, or equal to, the promised delivery date.
		Score 5 PPC of company accesses the information of demand forecast, or confirmed orders, after the promised delivery date.

Product indicators		Description of the scores
PRO-01	Concurrent Engineering	Score 1 Company does not have a formal multifunctional model to design new products.
		Score 3 Company has a formal multifunctional model to design new products, supported by an efficient communication channel.
		Score 5 Company has a formal multifunctional model to design new products, supported by an efficient communication channel, which involves suppliers and final consumers.
PRO-02	Parameter setting of design	Score 1 Company does not use parameter setting of design.
		Score 3 Company uses parameter setting of design for a few product families.
		Score 5 Company systematically uses parameter setting of design for all product families.
PRO-03	Calendar of product development	Score 1 Company does not have a calendar of product development.
		Score 3 Company has a calendar of product development for a few items.
		Score 3 Company has a calendar of product development for all items.
PRO-04	Special order negotiation	Score 1 Company accepts special orders, despite parameter setting of design.
		Score 3 Company accepts special orders, if they partially adhere to the parameter setting of design.
		Score 5 Company accepts special orders, if they totally adhere to the parameter setting of design.
PRO-05	Internal defects percentage	Score 1 Company has, on average, more than 0.1% defects, which means more than 10,000 parts per million.
		Score 3 Company has, on average, less than 0.1% defects, which means less than 1,000 parts per million.
		Score 5 Company has, on average, less than 0.1% defects, which means less than 1,000 parts per million.
PRO-06	Variety degree	Score 1 In the portfolio of the company, the average ratio between the number of families and the number of items within these families is greater than 100.
		Score 3 In the portfolio of the company, the average ratio between the number of families and the number of items within these families is between 50 and 100.
		Score 5 In the portfolio of the company, the average ratio between the number of families and the number of items within these families is lower than 100.
PRO-07	Life cycle	Score 1 If the rate between the portfolio lifetime and its programming cycle is lower than 4.
		Score 3 If the rate between the portfolio lifetime and its programming cycle is between 6 and 10.
		Score 5 If the rate between the portfolio lifetime and its programming cycle is greater than 10.
PRO-08	Leftover percentage	Score 1 If the leftover percentage of the portfolio items is greater than 20%.
		Score 3 If the leftover percentage of the portfolio items is between 5% and 10%.
		Score 5 If the leftover percentage of the portfolio items is lower than 1%.

PPC indicators		Description of the scores
PPC-01	Master Production Planning (MPP)	Score 1 Company does not have a formal Master Production Planning (MPP) model.
		Score 3 Company has, and uses monthly, a formal Master Production Planning (MPP) model with software.
		Score 5 Company has, and uses weekly, a formal Master Production Planning (MPP) model integrated to the Enterprise Resource Planning (ERP).
PPC-02	Material Requirement Planning (MRP)	Score 1 Company does not have an MRP integrated system, but works with spreadsheets or isolated systems.
		Score 3 Company has, and uses monthly, an MRP integrated system, with software.
		Score 5 Company has, and uses weekly, a formal MRP system integrated to the Enterprise Resource Planning (ERP).
PPC-03	Production capacity analysis	Score 1 Company does not have a capacity planning system.
		Score 3 Company has a capacity planning system with no MPP integration.
		Score 5 Company has a capacity planning system with MPP integration, and cycle time, production rate and stock level calculation.
PPC-04	Departmental PPC	Score 1 Company does not have PPC for departments.
		Score 3 Company has central PPC bases for the departments with periodic communication.
		Score 5 Company has PPC bases for the departments linked by a communication channel, within which flows all the necessary information.
PPC-05	Integrated schedule system	Score 1 Company does not have a PPC system to manage pulled flows.
		Score 3 Company has two distinct PPC systems to manage pulled and pushed flows.
		Score 5 Company has two integrated PPC systems to manage pulled and pushed flows.
PPC-06	Plan and Schedule cycle	Score 1 Company has a plan and schedule cycle with monthly, or greater, frequency.
		Score 3 Company has a plan and schedule cycle with half a month frequency.
		Score 5 Company has a plan and schedule cycle with weekly, or lower, frequency.
PPC-07	On time delivery percentage	Score 1 Company has on-time delivery at lower than 40% of the orders.
		Score 3 Company has on-time delivery at between 60% and 80% of the orders.
		Score 5 Company has on-time delivery at greater than 90% of the orders.
PPC-08	Value aggregation percentage	Score 1 Company has production lead time 30 times greater than standard lead time from engineering.
		Score 3 Company has production lead time between 10 and 20 times the standard lead time from engineering.
		Score 5 Company has production lead time lower than 5 times the standard lead time from engineering.
PPC-09	Inventory	Score 1 Company has three months, or greater, inventory turnover.

	turnover	Score 3 Company has a month's inventory turnover. Score 5 Company has a week's turnover, or lower.
PPC-10	Extra time percentage	Score 1 Company uses 20%, or greater, of unplanned extra time to meet the delivery dates.
		Score 3 Company uses between 10% and 20% of unplanned extra time to meet the delivery dates.
		Score 5 Company uses 5%, or lower, of unplanned extra time to meet the delivery dates.
Shop floor indicators		Description of the scores
SHF-01	Volume flexibility	Score 1 Company does not have varied sizes of equipment and must use larger equipment to produce more than the customer needs.
		Score 3 Company has small, medium, and large sizes of equipment, but must use bigger equipment to produce more than the customer needs.
		Score 5 Company has small, medium, and large sizes of equipment and use equipment in proportion to customer needs.
SHF-02	Single Minute Exchange of Dies (SMED)	Score 1 Company does not have a formal process of critical analysis for machine setup.
		Score 3 Company has a formal group that eventually makes the critical analysis of the machine setup.
		Score 5 Company has a formal group guided by goals of continuous reduction of machine setup times, which results in a critical analysis of setup times.
SHF-03	Focused production	Score 1 Company has less than 10% of capacity focused on specific family items.
		Score 3 Company has between 20% and 30% of capacity focused on specific family items.
		Score 5 Company has more than 50% of capacity focused on specific family items.
SHF-04	Total Productive Maintenance	Score 1 Company only makes corrective maintenance.
		Score 3 Company makes preventive maintenance, but lacks a broader maintenance program.
		Score 5 Company has a Total Productive Maintenance program and continually trains technicians.
SHF-05	Polyvalence program	Score 1 Company does not have a formal polyvalence program for technical training of employees.
		Score 3 Company has a partial polyvalence program for technical training of employees.
		Score 5 Company has a polyvalence program for technical training of all employees.
SHF-06	Standard routine	Score 1 Company does not use standard routine.
		Score 3 Company uses standard routine, balanced with the cycle time, only for the assembly line.
		Score 5 Company uses standard routine, with polyvalent employees, balanced with the cycle time for the assembly line and manufacturing cells and keeps standard routine sheets available at the shop floor.
SHF-07	Leveling degree	Score 1 Company has the leveling factor $(\text{average production lot size} / \text{average order size}) > 2$.
		Score 3 Company has the leveling factor $1.3 < (\text{average production lot size} / \text{average order size}) > 1.5$.
		Score 5 Company has the leveling factor $(\text{average production lot size} / \text{average order size}) < 1.1$.
SHF-08	Setup percentage	Score 1 Company has setup time 30% greater than production time.
		Score 3 Company has setup time between 10% and 20% of production time.
		Score 5 Company has setup time lower than 5% of production time.
SHF-09	Productive indices	Score 1 Company has a real productivity lower than planned productivity.
		Score 3 Company has a real productivity equal to planned productivity.
		Score 5 Company has a real productivity greater than planned productivity.
SHF-10	Non-planned breakdown indices	Score 1 Company eventually has production downtime because of equipment breakdown.
		Score 3 Company rarely has production downtime because of equipment breakdown, but still has emergency maintenance before imminent breakdowns.
		Score 5 Company never has production downtime because of equipment breakdown.
SHF-11	Polyvalence indices	Score 1 Company has less than 20% of polyvalent employees.
		Score 3 Company has between 40% and 60% of polyvalent employees.
		Score 5 Company has more than 80% of polyvalent employees.

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