How context factors influence lean production practices in manufacturing cells

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Abstract: Factors influencing the implementation of Lean Production (LP) in the company as a whole have been widely studied; however, there is a gap in the literature about the factors that affect LP in smaller units of the manufacturing system, such as Manufacturing Cells (MC). Hence, the objective of this study is to identify the factors that affect the implementation of lean practices in MC. We conducted four in-depth case studies, and the MCs were fully using 39% (case 1), 6% (case 2), 39% (case 3) and 56% (case 4) of the lean practices. Results suggest that there are seven factors that affect the use of LP practices in MC: (*i*) the reason for adopting LP, (*ii*) the experience of the company with LP, (*iii*) the need for involvement of the supporting areas in some LP practices, (*iv*) the interdependence of some practices, (*v*) the variety of product models produced bin the MC, (*vi*) the synergy between LP and MC attributes, and (*vii*) the size of the equipment used in the MC. We recommend testing the association of those proposed contextual factors with LP practices and performance metrics empirically with large samples of MCs or with mathematical modelling as future research.

Keywords: Lean production, Toyota Production System, Lean system, Manufacturing cells

1. Introduction

Cellular manufacturing is widely known as a means to reduce lead times, improve quality and provide flexibility for changes in the products mix and volume. Since these features are prioritized in lean production (LP) environments, manufacturing cells (MC) are often used in this context [1]. Moreover, the fact that a MC is a small unit of the manufacturing system tends to reduce the complexity of implementation of LP principles and practices. In particular, many companies adopting LP have adopted MC to replace functional job shop layouts [2, 3], whose characteristics, such as large batches and confusing flows, conflict with LP goals.

Conflicts at LP goals are part of manufacturing strategies [4]. Manufacturing strategy constitutes the set of goals, plans, programs and actions related to competitive priorities, being influenced by cost, differentiation and focus [5]. This concept allows classifying the strategies in: (i) mass production, (ii) lean manufacturing, (iii) mass customization, and (iv) expert manufacturing. The strategy defines how much cells are affected in terms of resources.

Therefore many factors are known to influence the LP implementation in the company as a whole, such as organizational culture [6], infrastructure to support manufacturing, ie, a complete set of machines and people [7], the process type and size of the company [8]. However, the literature has not emphasized the most relevant factors from the perspective of smaller units of the manufacturing system, such as MC or assembly lines. Several studies that evaluate and discuss factors that affect LP implementation [9, 10] do not stress the understanding of LP implementation at a MC level. Companies often have different processes and productive sectors which may be experiencing various difficulties in LP implementation due to their specific characteristics. For example, factors affecting the implementation of lean practices in an assembly cell may differ from those that affect a machining cell, even if they are part of the same company. This may be due to the characteristics of their environment, such as the differences between operators, machines, materials, equipment, procedures, requirements and product quality.

In this context, the main objective of this paper is to identify and describe factors that affect the implementation of lean practices in MC. The existence of different perspectives around the fundamental characteristics of a lean enterprise [11] requires an assessment of the lean implementation at the studied companies. An example is given by Seppälä [12] where it was developed a new cell and team-based work according to a participative approach with cell members, manufacturing managers and other support function involved.

Thus, it was applied the LP assessment method from Marodin and Saurin [13], because this was the only one found in the literature that evaluates the implementation of lean practices in MC. It is important to notice that the implementation of lean practices does not assure that the underlying principles are in place [14]. In relation to that, Mann [6] recommends that companies begin LP implementation with the adoption of practices, because the absorption of the principles by organizational culture is a slow process. Thus, the assessment of lean practices makes more sense in businesses that are starting their lean journey. The method of Saurin and Marodin [13] also emphasizes the integrated application of lean practices from a systemic perspective, which is essential to understanding general socio-technical environments systems [15].

2. LP and Lean Assessments

LP originated from the Toyota Production System and, along its evolution, terms such as Just-in-time and Total Quality Management, and more recently lean systems, were used as both elements and synonymous of LP [35]. The core concepts and principles that characterize LP have been defined similarly. For Womack et al. [16], LP is a superior way to manufacture products using fewer resources to generate greater value to customers. Most recent definitions recognize that LP is a management system formed by two levels of abstraction: principles and practices [17, 18, 35].

The principles represent the ideals and laws of the system, such as to encourage employees' participation in continuous improvement activities [19, 20]. The practices operationalize the principles and they encompass a wide variety of integrated management methods, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management [21].

Prior literature is extensive in methods to assess LP, although, to our knowledge, there is only one study that proposes a method to assess LP in a MC. In a literature review of 109 papers about LP implementation, Marodin and Saurin [13] showed 24 studies that proposed LP assessment methods. Five of them focused at to assessing LP at the plant level and 18 at the plant level. The number of practices and performance metrics that each method captures varies substantially, from 8 to 65 practices and from 3 to 90 performance metrics.

3. Assessment of LP practices in MC

The method for assessing LP practices in MC [22, 23] has four phases: (*i*) phase 0, preparatory phase, (*ii*) phase 1, collection of preliminary information, (*iii*) phase 2, collection of evidence and evaluation of the use of lean practices and (*iv*) phase 3, feedback meeting and validation of results.

The preparatory phase starts by identifying a qualified auditor, who should have both a strong theoretical background and practical experience with LP. Then, this phase includes: (*i*) to present the assessment tools to company representatives, (*ii*) to select the MC to be evaluated, and (*iii*) to set a timeline for data collection.

Phase 1 aims to understand the MC functioning and identifying its characteristics. A questionnaire guides data collection in this phase. It has four sections designed to characterize the company and the cell: (*i*) X questions about the company, such as market segment, business, products, customers and LP implementation process, (*ii*) Y questions about the number of employees, equipment, products, organization of the cell, (*iii*) development of a products and processes matrix for the cell in order to assess the presence of the group technology attribute and (*iv*) cell evaluation according to the attributes of time, space and information.

Phase 2 consists of collecting and analyzing evidences of the use of LP practices in the cell. Analogously to phase 1, there are specific questionnaires structured as checklists for each source of evidence. There are three sources of evidence at this phase that allow the data analysis: (*i*) observation of the MC, (*ii*) interviews with operators and (*iii*) interviews with leaders or supervisors. Table 1 shows the pre-selected qualifying attributes for each of the 18 LP practices assessed in MC. They are divided into three subsystems: (*i*) human resources, (*ii*) planning and production control and (*iii*) process technology.

Phase 3 of the method is the feedback meeting. This meeting includes a discussion of the results and identification of improvement opportunities, which are resultant from the gap between cell current state and what would be missing for the attribute be fully achieved.

Insert Table 1

4. Research method

4.1 Overview

The research method was divided into three steps: i) selection of participating companies, (ii) case studies in MC and (iii) integrated analysis of case studies. The case study is used for an in-depth understanding of the characteristics of a specific object, which can be a single event or phenomenon or one of its aspects [24]. According to Yin [25], the case study is an empirical investigation in which combines different methods of data collection to examine real-life phenomena. By studying a company in its natural environment, the theory generated by the case study can provide an explanation why the phenomenon occurred [26].

Among the reasons for choosing case study, it highlights the fact that the identification of factors affecting LP implementation does not require direct action of company members or any kind of intervention with them. Furthermore, multiple case studies were carried out with the intention of investigating different organizational contexts to achieve greater generalization validity [24].

4.2 Selecting the case studies

Three companies were selected for case studies called Alpha, Beta and Gama. In Gama, two cells were evaluated while only one cell was evaluated in Alpha and Beta. The Alpha and Gamma companies belong to the automotive industry, which is one of the reasons for choosing them, since this kind of industry is recognized as one of the most experienced in terms of LP practices. Alpha is a tier two supplier in the automotive sector and Gama is a tier one. Moreover, Alpha and Gama are implementing LP as corporate policy. On the other hand, Beta provides electronic components and is its starting lean implementation.

4.3 Data collection

Throughout the four case studies (case 1 in Alpha, case 2 in Beta and cases 3 and 4 in Gama) there were some differences in the way evaluations were conducted. The choice for investigated MC in each company was based on different criteria. In Alpha, the cell was chosen due to its simplicity, since there were only two operators and three operations. However, in Beta the criterion of choice was the opposite, since the selected cell presents the largest products and machines in the plant. Cases 3 and 4 represent all MC in Gama´s plant and present a customer-supplier relationship between them. Table 2 presents the procedures that were undertaken at the collecting data step, the case study that they were for, the phase, the people that was involved, the source of evidence and the duration.

Insert Table 2

4.4 Data analysis

The results of the four individual analysis were used as input for the integrated analysis, organized into two activities: (*i*) a comparison of the number of LP practices distributed in each of the three categories in order to analyze the characteristics related to such impacts, (*ii*) an analysis of the classification of each practice in each case, with the goal of raising the presence of factors that affect the LP implementation in MC.

5. Results

5.1 Case Study 1

Alpha has 150 employees and produces components for automotive companies. Regarding LP, its implementation began in 2002, with some training initiatives conducted by a consultancy. After 10 months of training, the implementation became responsibility of the company´s employees under the guidance of the production supervisor. Moreover, LP implementation was reinforced when the company participated, in 2005, of a supplier development program performed by one of its largest customers.

The plant presents a typical job-shop layout combined with a few downstream cellular processes. The creation of MC occurred within the first LP deployment efforts in 2003, aiming at reducing process lead time. Previously, the entire plant had functional physical arrangements. Although the sequence of operations may change, all cells are similar to MC 1, which operates in two shifts with three operators each, performing identical cycles, characterizing the existence of multifunctional type operation of multiple processes [27]. Figure 1 presents a picture of the cell, the layout and one of the products that was produced at this cell.

In MC 1, among the eighteen practices, seven were fully used (3, 6, 12, 15, 16, 17 and 18) three were partly used (4, 5, and 11) and eight were not used (1, 2, 7 8, 9, 10, 13 and 14). Figure 1 illustrates how the results were compiled and presented to company management.

Insert Figure 1

5.2 Case study 2

The company Beta presents two plants and about 1,600 direct employees. The main customers are the automotive and electrical sectors. From a strategic standpoint, the company had never done a project or formal effort to implement LP. However, some isolated improvement actions were driven over the past 10 years, such as 5S projects, search for root causes and incentives to suggestions for improvements.

The physical arrangement of the visited plant is composed almost exclusively of highly automated MC. Products do not undergo more than one cell to become finished products. Most of the cells comprise one or two operators that perform only the activities of feed, product removal and maintenance of the equipment s.

Case 2 cell operates with 9 operators and three shifts. The summary of LP practices in MC 2 is shown in Figure 2. In total, it was identified full presence of only one practice (18), nine others were classified as partially used (1, 2, 3, 4, 10, 11, 13, 14 and 16) and the remaining eight (5, 6, 7, 8, 9, 12, 15 and 17) were absent.

Insert Figure 2

5.3 Case study 3 and 4

Gama is a subsidiary company of a multinational company that is located in an industrial condominium and exclusively supplies to one automaker. This plant presents 39 employees and two MC. Production volumes are about 800 units per day, and the first cell operates in two shifts and the second in three. According to the interviews, both cells were developed with the participation and suggestions from operators.

The company has a program that evaluates and scores industrial units according to various performance indicators. Although this is not a specific lean approach, 8 of the 20 indicators are related to lean practices. There is no responsible for implementing LP concepts.

MC 3 operates with one operator and produces three different products that are used in the MC 4, which has six operators per shift. The characteristics of each of the LP practices for MC 3 and 4 are shown in Figures 3.

Insert Figure 3

5.4. General analysis on LP practices implementation

Regarding the practices implementation, practice called “lean indicators for measuring performance” (number 11) had a partial application in all cases, which may be explained due the following reasons: (a) in Gama, where LP implementation is more mature, both cases use three out of four pre-determined indicators; (b) OEE indicator was used in all cases, even in companies that are not undergoing a lean implementation, which reinforcing the ambiguous nature of this indicator, which reflects both the mass production and LP principles. Figure 6 shows the consolidated results for all MC.

Insert Figure 4

The practice “pull production” was categorized as not applied in all cases. The assessment of this practice is quite difficult, since it is necessary to consider interactions with elements outside the cell (purchasing, warehouse and sectors that supply or are customers of the cell). This fact may be explained due to the need of support and participation of other sectors for its implementation [28]. Case studies were differentiated in relation to number and application of LP practices, as shown in Figure 7.

Insert Figure 5

MC 3 and 4 presented the highest levels of LP practices implementation. This result may be due to some existent characteristics of the company, such as: (a) existence of formal initiatives to implement the LP; (b) company supplies to automakers within an industrial condominium, which reinforces LP implementation in the company; and (c) there is only one customer for these cells, which facilitates information flow and reduces variation in customer requirements.

Indeed, the impact of the diversity of product mix is evident when comparing MC 4 (manufactures two models of products throughout the plant) and MC 2, which manufactures 83 different models in the cell. Experience with LP implementation among employees may also have influenced the results of practices implementation. On the other hand, results for MC 2 (Beta) demonstrate that some LP practices can be applied in MC even if companies do not have a previous knowledge or effort in this direction. However, many practices have not been fully adopted. In a first analysis, comparing MC 1 and 2, it is identified that both have the same results. However, the adoption level may change according to the practices.

6. Discussions

6.1 Reason for adopting the LP

The motivation for the implementation of lean at Case 1 was a corporate policy, without any technical or financial support coming from the firm's headquarters. As a result, there was an inefficient structure for the coordination and implementation practices and a lack of commitment from the support areas and top management. Case 3 and 4 had the company located in an industrial condominium of a car assembly company that is strongly imbibed in LP principles. In fact, the car assembler creates a strong interdependence between firms that are located in the facility, suggesting that they should adopt LP. The lower level of adoption of LP practices on Case 2 was influenced by the firm's lack of any policy or plan to implement LP, where they had only a few and isolated lean practices implementing initiatives.

Although the reason for adopting lean is not frequently presented as strong factor for hindering the LP implementation at the literature, this factor may impact on the support of top and senior management and the belief of the importance of lean to the company [29]. Nevertheless, top management support is generally considered as a crucial to LP implementation [30, 31], although there is still a lack of knowledge in what makes a top management supportive or not to the LP implementation [32].

6.2 Experience of the company with LP

How long the company was implementing lean and the age of the MC was appeared to positively influence the presence of the LP practice of PE at the cells. While the company Alpha (case 1) started their training on lean in 2002, the company Gama (Cases 3 and 4) started the LP implementation with training and kaizen events four years earlier 1998. The people that worked on production, support areas and the managerial team of this company had a higher knowledge of the use and implementation of lean practices because of the longer experience with the subject. At the same firm, Case 3 showed a lower level of implementation of the lean practices than Case 4 due to the fact that it was 2 years younger than the other that has running for 4 years. The factor of the age of the cell had a more impact on the LP practices that had a needed a higher involvement of the operators, such as Continuous improvement (2), Multifunctionality and cross-training (3), Workers' autonomy (4) and Quick setups (9). In fact, a certain amount of time is needed for the workers to feel comfortable to accept the use of lean practices [10].

6.3 Involvement of the supporting areas in some LP practices

Some of the lean practices appeared to be more difficult to implement because they required a higher involvement of areas that support the production at the shop floor, such as Production planning and control, maintenance, sales and purchase. Teamwork (that was fully used at three cases) and Multifunctionality (fully used in two cases and partially used on the other two) are examples of practices that could be implemented only by the involvement of the people from the shop floor, such as workers, leaders and production supervisors. On the other hand, in Case 1, the lack of human resources in some areas such as quality and maintenance made it very hard to implement practices such as Total productive maintenance (10) and Visual management of quality control (13).

The Pull production, for example, was not used in all cases. The implementation of a full pulled production system requires a broad and high involvement and effort of areas such sales (e.g. leveling sales), purchasing (e.g. long term negotiation and supplier development), logistics (just-in-time deliveries) and production planning and control (e.g. planning and controlling the kanban cards) [28]. In fact, the implementation of lean is often lower in other areas rather than production because those areas typically have managerial practices and metrics that are that are guided by mass production principles [33].

6.4 Interdependence of some practices

Saurin et al. [23] identified 46 direct relationships between the 18 LM practices at a MC. These relationships were used to classify the practices into three groups, the Basic practices (depends on fewer practices), Intermediate practices (depends on an average number of practices) and End practices (depends on a higher number of practices). The case studies suggested that a higher number of relationships between the lean practices increase the difficulty of implementing the some of those practices. For example, in Case 1, the MC was not able to implement pull production because of a lack of production stability. This stability could be achieved if the company had implemented the Quick setup and Total productive maintenance before trying to apply a pull system. Other relationships were found within practice 1 (Teamwork and leadership) and practice 2 (Continuous improvement) in Case 1.

It is worth pointing out that this assumption could also be supported by the fact that a Basic practice can be implemented without any other practices. That was presented on Case 2, in which the Organization by the dominant flow (18) was the only practice fully implemented.

The relationships between LP practices at the company level were largely tested in empirical studies with large samples [34, 35]. However, the fully systemic nature of the LP does not seem to be yet fully understood [36].

6.5 High variety of models produced by cell

The higher number of product models that are made at the cell tends to negatively influence the use of the lean practices. It happens because this higher number usually different requirements for each product, for example, frequency of deliveries, production volumes, cycle times, setup times and other technical differences. This factor was highlighted comparing Cases 1 (23 different products) and 2 (83 different models). The differences at the products made the setup time to vary from 20 minutes to two and a half hours at Case 2 and, because of that, the batches were made to last for at least one month which made all the waste reductions and implementing other practices more difficult.

Meanwhile, the lower number of product models (only two) and the frequent deliveries (16 times a day) at Case 4 made it easier to: (a) Organize in a dominant flow because the was only one flow between the two models; (b) the Quick setup tool, because there was only one setup needed; (c) the Smoothed production with only two products. Meade et al. [37] found that a high number of models manufactured by the company increases the variety of different sequences flows at the factory and generates higher inventories and hindering the use of LP practices.

6.6 Synergy between the LP and MC

The LP practices and the MC attributes presented a series of synergies that complements each other. For example, a group technology of 100%, a MC attribute that was assessed at the Phase 1 of the Saurin et al. [23] framework, was presented at Cases 1 and 4. This high group technology has positively influenced in practices 16 (visibility and information exchange) and 18 (organization by the dominant flow), because it does not made it necessary to have alternative flows which would need additional equipment's at the MC.

The lack of the Organizational attribute of the MC was also cause a negative influence at the implementation of some practices, such as Teamwork and leadership and Continuous improvement at Case 1. The fact that the workers at the cells were not managed as a team and had metrics that assessed the individual performance rather than team performance had a negative impact on the use of those two practices.

Regarding the attributes of time, space and information between workstations, a few lean practices also demonstrated that they had a positive impact on those connections. For example, the use of visual devices to request assistance, the organization of the workplace and visibility in case 4 clearly contributed to the connections of information. Similarly, the single piece flow, multifunctionality and the size and shape of the layout contributed to the connections of time and space in case 1.

In fact, many authors suggested that the use of MC is a crucial for implementing a lean system. Marodin and Saurin [13], in a systematic review with 102 papers on LP implementation, found out that the MC is one of the most common practice used in lean assessment methods, which corroborates with the results of the case studies.

6.7 Size of the equipment

Larger equipment's seems to have a negative influence on some of the LP practices of and MC attributes. For example, there were two machines occupy about 25 to 10 square meters each at Case 2 and there were two machines occupying about 4 square meters each in Case 4. In such cases, large equipment hindered the practice 15 (One-piece-flow), 16 (Visibility and information exchange) and 17 (Layout size and shape) because it represents a longer distance for the worker and the parts to move and visual barriers for the information and product flow within the cell. Moreover, large equipment, such as presses or forges, require also great tools that hinder other practices of LP, such as Quick setup (practice 9) and, by direct causal relationships a negative impact on Smoothed production (practice 8) and Pull production (practice 7).

7. Conclusions

This study suggests that seven factors influence LP practices implementation in MC: (*i*) the reason for adopting the LP, (*ii*) the experience of the company with LP, (*iii*) the need for involvement of the supporting areas in some LP practices, (*iv*) the interdependence of some practices, (*v*) the variety of models produced by cell, (*vi*) the synergy between the LP and MC, and (*vii*) the size of the equipment.

Finally, conducting multiple case studies provides a greater degree of external validity for the results [26]. Nonetheless, it is suggested that the results may be tested with a larger samples of MC, which enables a statistical analysis regarding the presence and impact of factors on LP practices implementation. Therefore, future research could be driven to develop mathematical models that explain the relationships among those factors based on statistical procedures, such as structural equation modeling. Moreover, future studies could verify the impact effectiveness of management actions that abrogate the presence of one factor in a long term.

Ethical Statement

The authors acknowledge that the manuscript is in compliance with the ethical rules of the International Journal of Advanced Manufacturing Technology.

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Table 1. Qualifying attributes for LP practices in MC Saurin et al. [23].

Practices	Attributes
1. Teamwork and leadership (TWL)	Team leader supports workers in continuous improvement activities, such as problem solving and implementation of improvements. Team leader substitutes missing workers. Performance assessment of workers is made on a team basis, rather than on an individual basis.
2. Continuous improvement (CI)	Workers are trained in problem solving methods, including root cause analysis. Workers are involved in continuous improvement initiatives, whether formal or informal ones. Continuous improvement groups are coordinated either by workers or team leaders.
3. Multifunctionality and cross-training (MCT)	All workers are able to carry out all cell operations (i.e. cross-training is fully implemented). There is a skills matrix that documents every worker's skills. Job rotation among cell workstations is undertaken on a daily basis.
4. Workers' autonomy (WAU)	Workers have autonomy both to identify and to control process and product variability. Workers have autonomy to stop production if abnormalities occur. There are visual devices for calling the team leader or support areas, such as maintenance.
5. Standardized work (STW)	There are documented work standards. Work standards are visible to the team leader. Standards include information on takt time, cycle times, manual and automatic time, production sequence, standard inventories, and cell layout. Standards are updated on a regular basis. There are audits to check compliance with work standards on a regular basis.
6. Workplace housekeeping (WHK)	The cell is clean and equipped with only the necessary objects. Every object has a standard place, which is easily identified by visual devices. There is a 5S program, which is audited on a regular basis. Results of 5S audits are posted in the cell.
7. Pull production (PULL)	All inventories (raw materials, work-in-process, and end products) have visually defined maximum caps. There are visual devices informing both production sequencing and materials loading sequences. There are standard routes for loading raw materials and removing end products, including standard picking times. The above attributes exist for all components, whether manufactured in the plant or purchased from external suppliers.
8. Smoothed production (SPR)	All product models are produced every day. Consumption of raw materials from the preceding processes occurs at constant intervals and volumes.
9. Quick setups (QST)	There are no setups among different models. If there is setup, its tasks are standardized and separated into internal and external tasks
10. Total Productive Maintenance (TPM)	Workers carry out routine maintenance on all equipment (e.g. cleanliness, lubrication and small repairs) following standardized procedures. There is either preventive or predictive maintenance of all equipment.
11. Lean performance metrics (LME)	Cell performance is assessed based on metrics linked to lean production principles, such as lead time, rework and scrap rates, standard inventory versus actual inventory, overall equipment effectiveness (OEE).
12. Visual management of production control (VPC)	There is a production control board visible to all cell workers, showing production schedule either on an hourly or shift basis. The following information is presented on the board: planned; undertaken; difference pending; reasons for failing to comply with schedule; corrective actions.
13. Visual management of quality control (VQC)	There are quality control boards, which are visible to all cell workers. The boards display quality related metrics, root causes of defects, and respective action plans.
14. Equipment autonomation (EQA)	Machinery carries out value adding operations without either workers monitoring them or manual intervention. All pieces of equipment have devices either for preventing or detecting

	abnormalities. These devices stop production or provide warning of abnormalities.
15. One-piece-flow (ONE)	Single pieces of material are produced and moved between operations. There is no piece of material waiting between adjacent workstations.
16. Visibility and information exchange (VIS)	All workers can easily see their cell counterparts, equipment and materials. All workers can talk with each other in a normal tone of voice.
17. Layout size and shape (LSS)	All workers can exchange materials without walking more than 1 m (this distance was arbitrarily established). Cell design allows changing the amount of workers and production capacity.
18. Organization by the dominant flow (ODF)	All products pass through the same processes in the same sequence.

Table 2. Data collection procedures

Month	Case	Objectives	Participants	Activity	Duration
1	Alpha / 1	Preparatory Phase	CEO, intern, production supervisor, head of production and *lean* coordinator.	Meeting	90 min
1	Alpha / 1	Phase 1	CEO and *lean* coordinator.	Interviews	120 min
1	Alpha / 1	Phase 1	Production supervisor, intern and head of production.	Interviews	180 min
1	Alpha / 1	Phase 2	Head of production.	Interview	30 min
1	Alpha / 1	Phase 2	Head of production.	Observation	60 min
2	Alpha / 1	Phase 3	Production supervisor, intern and head of production.	Meeting	90 min
2	Beta / 2	Preparatory Phase	Process engineer.	Meeting	45 min
4	Beta / 2	Phase 1	Process engineer.	Interview	60 min
4	Beta / 2	Phase 2	Process engineer, head of production and operator.	Observation and interview	80 min
4	Beta / 2	Phase 3	Process engineer.	Meeting	60 min
6	Beta / 2	Phase 3	Five process engineers, two head of production, two production supervisors and the plan manager.	Meeting	80 min
7	Gama / 3 e 4	Preparatory Phase	Production supervisor.	Meeting	45 min
7	Gama / 3 e 4	Preparatory Phase and Phase 1	Production supervisor, human resource responsible, buyer, planner, two team leaders, quality engineer.	Meeting and interview	60 min
7	Gama / 3 e 4	Phase 2	Two team leaders from morning and night shifts.	Observation	90 min
7	Gama / 3 e 4	Phase 2	Two team leaders from morning and night shifts and two operators.	Interviews	90 min
8	Gama / 3 e 4	Phase 3	Production supervisor, buyer, PPC planner, two team leaders, quality engineer.	Meeting	60 min

Practice	Description of the LP practices at Case 1
1. TWL	Head of production coordinated 40 employees, without time to substitute employees in MC1. Performance evaluation was carried out based solely on individual performance
2. CI	Head of production, immediate superior of operators, reported that he would has no time to replace some operator in the cell, there would not be teams dedicated to specific cells and improvements are made by lean coordinator.
3. MCT	Operators perform all three operations on each product and caster occurs between cells daily.
4. WAU	Operators are responsible for controlling quantity and quality of products, being instructed to stop production when an abnormality was detected, but the requests for assistance to the head of production or service areas are made verbally.
5. STW	Standards did not have the standard stock and the layout design, neither periodic audits were performed. The other attributes existed.
6. WHK	The workplace was visibly clean and there was demarcation of the location of benches, tools and tables with results of audits of the past six months.
7. PULL	The production scheduling is characterized by shipping production orders for a whole month at a single time for the cell, to its client process (packaging sector) and to processes suppliers.
8. SPR	The cell production orders are grouped only in terms of models and each product model is manufactured in one or two batches per month.
9. QST	The setup of the cell takes around 10-20 minutes and is performed by operators, with no mapping or standardization of the activities involved.
10. TPM	The maintenance of cell's equipments is made mostly in a corrective and emergency manner, without the involvement of operators.
11. LME	The only performance indicator used aligned with the lean philosophy is the OEE
12. VPC	A board for manual filling indicating cell production per periods of one hour, with information of quantities planned, performed, balance of non-performed and the reasons for non-attendance.
13. VQC	Although there is a quality control sector, there is no board in the factory to report work results.
14. EQA	There is no time separation between man and machine time and there is no device embedded in solder point to detect abnormalities.
15. ONE	Each operator performed all operations in one piece at a time, featuring the unitary flow without intermediate inventory. The multifunctionality form adopted contributed to attend the attributes.
16. VIS	There are no physical barriers and operators have full visibility of all operations, materials and finished products in the cell.
17. LSS	The physical arrangement presents operations close from each other, which reduces movement waste and facilitates verbal communication between the operators.
18. ODF	All product models go through the same activities in the cell.

Fully utilized	Partially utilized	Unused

Figure 1. Assessment results for MC 1

Practice	Description of the LP practices at Case 2
1. TWL	The production supervisor assists in the production and problem-solving activities, but does not replace operators in their absence. The work is evaluated according to team of the cell in a uniform manner.
2. CI	Only two of the ten operators are trained in problem solving and continuous improvement (5 whys and Pareto) tools. The improvements actions are performed by the areas of process and quality engineering, but without an established periodicity, which mean that they are sporadic.
3. MCT	Only three of the nine operators are multifunctional in three different positions of the same equipment. These posts practice caster on a daily basis.
4. WAU	The operators are empowered to identify and control variations and are allowed to stop production. There are devices that indicate the occurrence of problems. There are no visual devices to request assistance from supervisor or other sectors.
5. STW	Does not present a form of standard operation. In the cell there is a "standard for operations" (with, for example, instructions for connecting, disconnecting and load each equipment), but does not have the necessary information from the form of standard operation. This "rule" is stored in a closet next to the cell.
6. WHK	The place is clean, but without a formalized program of 5S. There are some demarcations, such as location of components (reels and tapes) and some benches.
7. PULL	The production scheduling is sent every 15 days to the cell (containing a one month period. Purchases are made based on the monthly schedule. The stock of components has no reorder point or safety stock.
8. SPR	The production orders related to the demand for a fifteen-day period are grouped together to be performed once, in order to reduce the number of setup in the month
9. QST	Does not present the mapping of setup activities. The setup time of the cell can take 45 minutes to an hour, depending on the models.
10. TPM	The corrective and preventive maintenance is performed on all equipment of the cell. There wa not basic maintenance activity performed by operators.
11. LME	FTT and OEE are used in the cell, but the formulas were not disclosed. The lead-time and WIP-TO-SWIP are not calculated.
12. VPC	Does not present a board for production control. The production control is performed at the end of the day by the production supervisor.
13. VQC	The board shows the statistical sample control and a Pareto chart for analysis of problems, but no action plans for solving the problems.
14. EQA	There is a separation between man and machine time in most equipment, except in packaging operations. One equipment has poka-yokes devices embedded in the processing that stop the production and signalize. There are not meetings to suggest new devices. The equipment came from the manufacturer with the devices and the company implemented none.
15. ONE	Five of the six operations are performed in unitary flow. None Transport of product in process within the cell is done through the unitary flow, only on lots, with inventory accumulation among all operations.
16. VIS	The six operators that work inside of the cell have visibility and the possibility of exchange audio information between operations and inventories. The others do not have these characteristics.
17. LSS	The non-compact form of the physical arrangement with posts located in a distant manner in the physical arrangement. Dimension does not allow exchange of materials among most operators.
18. ODF	All products are manufactured by the same process and follow the same production flow.

Fully utilized (green)	Partially utilized (yellow)	Unused (red)

Figure 2. Assessment results for MC 2

LP practices	Case 3 characteristics	Case 4 characteristics
1. TWL	The production leader assists in problem solving and replaces operators when necessary. The evaluation of operators job is made for the team as a whole, based on the performance of the cell. The cell has only one operator per turn.	Same as case 3, but the cell has a team of six operators.
2. CI	There are 1h weekly meetings with an operator coordinating each week. At the meetings are discussed problems of quality and continuous improvement, with the presence of operators from the two shifts and the leader..	Same as case 3, but the discussions are made with the staff of each shift separately. The operators of the two shifts have knowledge of quality tools.
3. MCT	One operator in cell performs all operations. There is multifunctionality, however, damaged by being tied to a single operator. The operator does not perform caster with another cell.	More than 80% of the operators are trained to occupy all the work posts, while the other 20% were in training.
4. WAU	The operator has the autonomy to identify and control variations and is authorized to stop the production. The last operation of the cell is a device for manual quality control in relation to dimensions, conducted in all products of the cell.	Same as case 3 in relation to autonomy of the operators in identifying and controlling variations and stop the production
5. STW	The form of standard operation is visible to the operator on an information board next to the cell. There is one form for each of the three models produced.	Same as case 3, but there is just a generic form for the two models, since the movement of operators, time and sequence of activities do not change according to the models.
6. WHK	The cell has the 5S program with all the premises. The demarcation of the proper place for the equipment, boxes of components, finished products, tools and visual boards, in addition, a clean place.	Same as case 3, but the result is close to the cell, about 2 meters.
7. PULL	The inventory of all purchased components has a card to determine the level of safety stock. However, these information are not utilized for components purchase, ie, does not determine which, when and how much to buy. The purchasing and production scheduling are made according to the monthly schedule.	
8. SPR	Every day the three different models are manufactured in the cell.	Every day the two different models are manufactured in the cell
9. QST	The two equipment need setup to exchange models. The setup time is about 20 minutes for the entire cell.	Same as case 3 in relation to the checklist, however, only one equipment needs setup to exchange products. T
10. TPM	The operator performs minor maintenance tasks planned in a checklist. There is a maintenance team that conducts preventive maintenance on all equipment.	Same as case 3, but for all operators.
11. LME	The indicators of lead-time, quality at source and OEE are used. Control of planned versus actual inventory is not done for each cell, but for the whole factory. The quality indicator is done per kg in the case of refuse and working hours in the case of re-work, not jointly.	
12. VPC	There is not a board for production control. The control of production planning versus production performed is done at the end each time by the operator.	Same as case 3, but who makes the record is the last operation of the cell.
13. VQC	The visual board of quality management presents the results of quality control inspection tools in 100% of the products, root cause, and a Pareto chart for defects found.	Same as case, but the board is located about 3 meters from the cell.
14. EQA	In terms of equipment, there is separation between man and machine time on the equipments, but without embedded devices in the processing to detect or prevent defects.	There is man-machine separation in the automatic welding equipment, but not in manual welding.
15. ONE	All operations and transports within the cell are performed through unitary flow, without the possibility of parts accumulation between stages.	Same as case 4, however, there is a point that allows the accumulation of more than one piece between operations. The transportation is done in unitary manner.
16. VIS	The operator has visibility of the entire cell, operations, equipment and components used.	All operators have visibility of the entire cell, operations and components.
17. LSS	The cell operates with only one operator, making impossible the exchange of information and materials. However, the physical arrangement allows a second operator, if necessary.	The dimension and physical arrangement result in the possibility of materials exchange between operators
18. ODF	The three products which are produced in the cell pass through different operations. 1 = Fold; 2 = Cut; 3 = Expansion; 4 = Inspection.	The two products that are manufactured in the cell pass through all operations following the same flow.

Figure 3. Assessment results for MC 3 and 4.

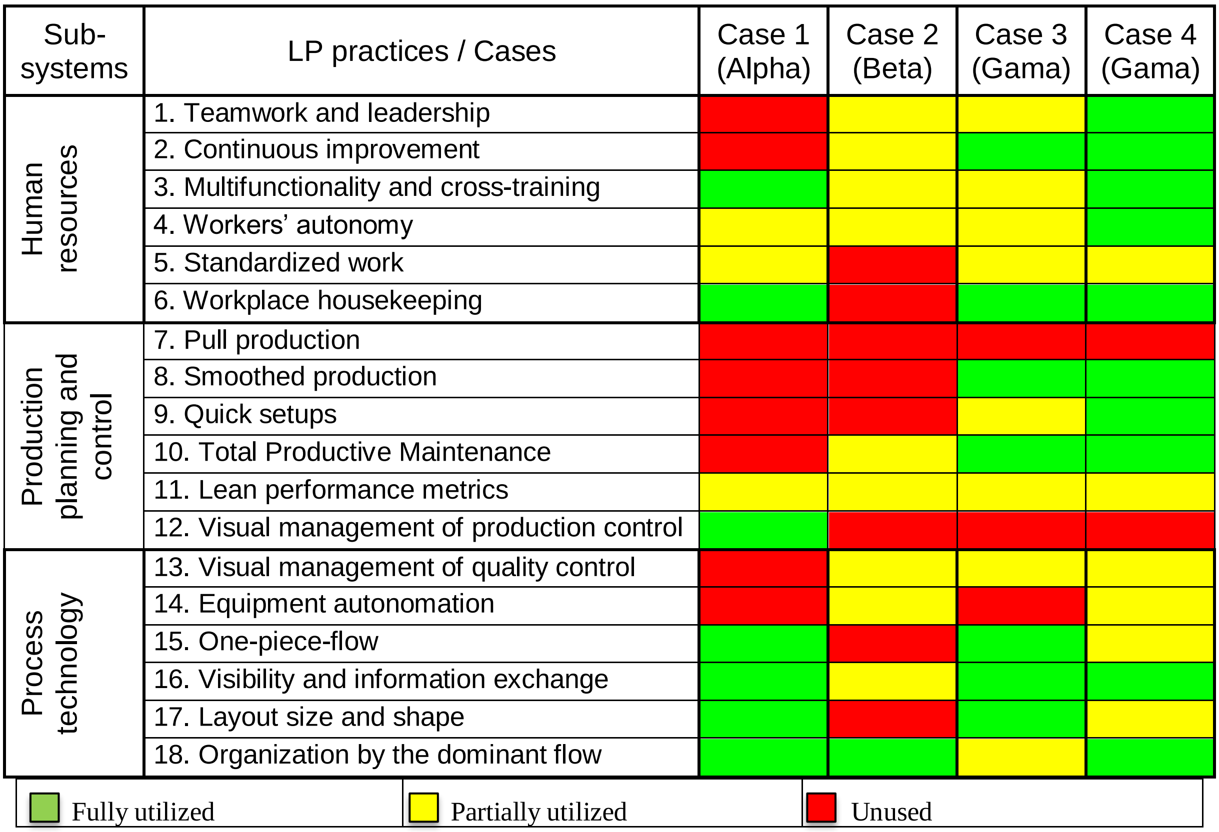

Figure 4. Results comparison for each LP practice in the case studies.

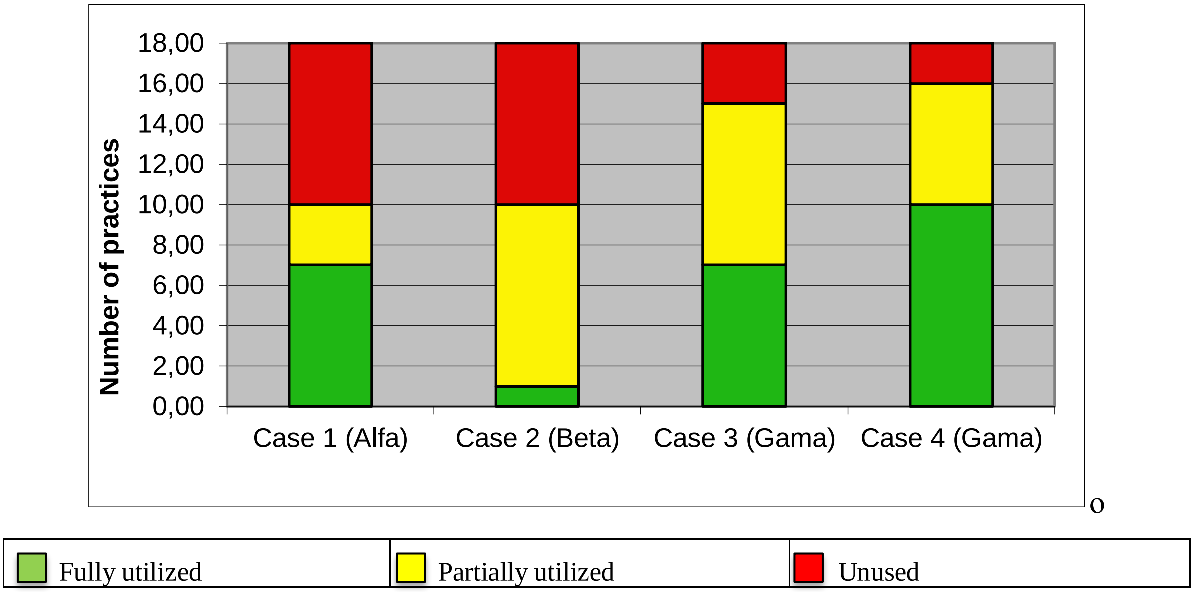

Figure 5. Consolidation of results