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Using Process Modelling Tools to Support Lean Management Implementation

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Abstract
This paper aims to demonstrate that the implementation of Lean Management (LM) can benefit from prior process modelling and redesign using Business Process Model and Notation (BPMN). Single case study research was conducted, which allowed the detailed documentation of the operations of a wind blade manufacturer and the evaluation of the applicability of combining Business Process Management (BPM) and LM, which are two different process management approaches. BPMN allowed the identification of handoffs in the production process and the reassignment of tasks to eliminate waste. It provides a visual representation of process flows, facilitating a common understanding of the processes and providing a solid basis for discussing process improvements. As a result of the interventions, the cycle time of the target processes was reduced by up to around 30%. This work enriches the still scarce literature that crosses both fields. It also responds to the claims for more case study research on LM and studies with business collaboration.

Keywords
Lean manufacturing, business process management, process improvement, process modelling, business process model and notation.

Introduction

Companies continually seek to stay competitive by improving efficiency and quality while reducing costs. Several process improvement methodologies present different concepts, tools and techniques to improve organizational performance. LM is one of the continuous improvement approaches that has gained ground in recent decades (Maldonado et al., 2020). It is a management philosophy focused on reducing waste, eliminating non-value-added activities and generating value by standardizing processes (Womack and Jones, 2003). Most studies on the implementation of LM practices report a positive impact of these practices on performance (Negrão et al., 2017).

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However, Maware et al. (2022) suggest that manufacturing firms randomly adopt LM tools, contingent upon the organization's specific conditions and challenges. This randomness can often lead to implementation failure in many organizations. According to Badhotiya et al. (2024), most published case studies on LM use basic lean tools such as Value Stream Mapping (VSM), and therefore, they are considered less mature. Manufacturing companies overlook the potential benefits of incorporating other process improvement approaches to enhance the LM implementation process (Mamoojee-Khatib et al., 2023). To ensure successful implementation, organizations must first redesign their processes, provide training, assign roles to employees, and reach a consensus on the tools to be utilized (Negrão et al., 2017).

As processes become more complex, the need for cooperation and coordination to manage the activities of various functions also increases. The transition points where information or work is transferred represent points of vulnerability (Ferreira et al., 2018). Business process modelling, one of the main tools used within the BPM approach to process improvement, can help organizations document their business operations, implement repeatable processes and continually improve them. It represents the functional behaviour of real-world processes, including all involved elements, such as different departments and resources (Dani et al., 2019).

The work presented in this paper aims to demonstrate that implementing LM principles and tools can benefit from prior process modelling and redesign using BPMN. The case study reports the work that was carried out at a wind blade manufacturer, whose process is characterized by high complexity, and in which the two process improvement approaches were combined to solve a real problem. Due to its recent integration into a new group, the plant has undergone several changes in its organizational structure, presenting several opportunities for improvement related to some instability in processes and information flows. Process improvements were identified and implemented to reduce waste and cycle time. Process modelling was the starting point and supported the discussion of the role of the various participants in the process and the redistribution of tasks. Then, some LM practices and tools were implemented to reduce waste.

This research suggests that other approaches can be used to support and complement the implementation of LM practices, further enhancing the benefits of LM adoption. It responds to calls for identifying the contribution of BPM techniques and their positioning in relation to other fields (Klun and Trkman, 2018) and for more case research on LM and studies with business collaboration based on the company environment and with professionals as active participating members (Psomas 2021).

The paper is structured as follows. Next, in the background section, LM is briefly introduced, and the contributions of process modelling for process improvement are discussed, considering the prevalent literature. Then, the methodology is outlined, and the case study is presented in detail. The paper ends with a conclusion that summarizes the main contributions and limitations of the work while also offering suggestions for future research.

Background

Lean management

LM had its roots in the automotive industry in Japan and has evolved into a global reference for manufacturing companies (Maware et al., 2022; Badhotiya et al., 2024). It is a philosophy focused on reducing waste, eliminating activities that do not add value and generating value by standardizing processes (Womack and Jones, 2003). According to a systematic literature review conducted by Maware et al., (2022) on the implementation of LM in manufacturing-based sectors, LM contributes to eliminating waste and inefficiency, reducing cycle time, improving labour productivity, product quality, delivery time and lead time. Nevertheless, applications of LM have been reported in different geographies (Lukrafka et al., 2020), small, medium or large companies (Ramadas and Satish 2021), service companies (Bortolotti and Romano, 2012), and in private, public and third-sector organizations (Klein et al., 2021; Mogotsi and Saruchera, 2023).

There are more than a thousand tools and techniques that can support LM implementation (Tortorella et al., 2015) and that were designed to reduce different types of waste (e.g., movement, waiting times or defects) and achieve different goals (Naeemah and Wong, 2023; Badhotiya et al., 2024). Maware et al. (2022) affirm that manufacturing firms often randomly adopt LM tools, contingent upon the organization's specific conditions and challenges. Badhotiya et al. (2024) found that most published case studies on LM have a low degree of maturity as they report the deployment of fundamental LM tools such as VSM, Kaizen or 5S.

However, Negrão et al. (2017) defend that organizations can successfully implement LM by quickly implementing simple practices that can produce tangible results in the short term. According to the authors, this approach will motivate the adoption of more complex practices later, helping to sustain the LM initiative in the company. They also suggest that processes should be redesigned, employees should agree on the tools to be used, they should be trained, and responsibilities assigned before implementation. Mamoojee-Khatib et al. (2023) point out that companies may be ignoring the advantages of integrating other process improvement methodologies to strengthen the implementation process, following the most common approach to LM implementation by implementing traditional LM practices and tools.

Contributions of process modelling to process improvement

Process modelling can be used to either develop software that supports processes or analyse them themselves (Aguilar-Savén, 2004). BPM, particularly business process modelling, enables organizations to document their business operations, implement repeatable processes and improve them (Dani et al., 2019). Klun and Trkman (2018) argue that organizational procedures can be identified and visualized as business process models, and BPM can support implementing any organizational change when needed. Thus, modelling makes it possible to specify how organizational procedures, which directly affect quality and, consequently, customer satisfaction, are carried out to identify and solve problems (Zarour et al., 2020).

The points in the processes where work or information is transferred from one function to another, called handoffs, are points of vulnerability in the processes, which can result in disconnections and cause inefficiencies. Therefore, the analysis of handoffs is a great opportunity for process improvement. Identifying the points that are bottlenecks and more likely to delay the process and taking measures to resolve them can help to reduce the process's vulnerability (Ferreira et al., 2018).

BPMN is an increasingly important standard for process modelling. The BPMN language is widely used for its expressiveness, simplicity and semantic richness. It establishes a clear and common language that everyone can quickly and fully comprehend, even those not involved in the mapping (Zarour et al., 2020). Intuitive graphical models depict processes that aim to deconstruct organizational complexity (Recker, 2010). BPMN can be used to document organizational processes. However, it also provides advanced concepts that can be used to refine basic models and represent process choreography or inter-organizational collaboration. Pools and lanes can be used to group activities into separate categories. Pools group the various elements of an organization, while lanes divide a pool into different organizations' resources, such as departments and participants (Dani et al., 2019; Recker, 2010). Pools and lanes demonstrate handoffs in the process by identifying the responsibilities of each actor involved.

Lean Management and Business Process Management

Significant improvements in operational performance can be achieved by incorporating two or more process improvement approaches, such as LM and BPM, as adopting a single methodology is often cited as the main reason for the high failure rate of improvement programmes (Nwabueze, 2012).

According to the existing literature, case studies reporting LM implementation were primarily found in manufacturing companies, while cases on BPM implementation were mainly found in service companies (Maldonado et al., 2020; Erasmus et al., 2020). Few authors have reported on case studies of the joint implementation of LM and BPM in manufacturing firms. Calçado et al. (2024) presented a case study in which LM tools and practices were used to complement the BPM methodology and support improvements in information and documentation flows associated with quality management in a large manufacturing company. Bernardino and Ávila (2025) presented BPMN as an alternative to the Visual Stream Mapping (VSM), which is widely used in LM implementation. BPMN was used as it is better suited to analysing information flows and tasks involving several stakeholders.

However, Basulo-Ribeiro et al. (2023) and (Erasmus et al. (2020) highlighted the potential of using business process models to specify physical operational processes, thereby contributing to the implementation of the smart manufacturing concept within the Industry 4.0 context. Nevertheless, no empirical studies were found that use BPMN to model physical operational processes within manufacturing firms.

This paper responds to the concerns found in the literature, suggesting that LM implementation can benefit from prior process modelling and redesign, thus combining two process improvement methodologies (LM and BPM). Furthermore, while previous work focuses on information flows, in this paper, BPMN is used to model physical operations processes.

Methods

A case study approach was adopted in this research. Case studies are appropriate when the focus is on a contemporary phenomenon in a real-life context, and researchers have little control over the event (Yin, 1994). According to Voss et al. (2002), case research is one of operations management's most powerful research methods. It can lead to new and creative insights and the development of new theories, and it has high validity among practitioners, who are the end users of research. Case studies are widely used in the field as a practical technique for evaluating the applicability of tools and methods that aim to improve a company's performance (Kitchenham et al., 1995).

A suitable organization was identified to study the combination of BPM and LM, two process improvement approaches. A single case study allows for detailed documentation of the operations of a single plant. A wind blade manufacturer was selected due to the complexity of the production process and the challenges the plant faced in managing the production and information flows of a new blade model. The organization's activities were monitored closely for around eight months, from October 2021 to May 2022. Relevant data was collected from documentation provided by the company, as well as direct observation and informal interviews with those involved in the process.

The first three months were dedicated to understanding the process and identifying all the steps involved.

Improvement opportunities were identified and prioritized. VSM was used to identify critical points in the production process. According to Sangwa and Sangwan (2023), LM implementation should start with mapping organizations' value streams after finding the takt time to fulfil the customer demand. Then, as a second step, BPMN was applied to map the processes to be intervened in to study the responsibilities of each participant and process handoffs. Ishikawa and spaghetti diagrams were also used to support the identification of causes that are contributing to process inefficiency at specific points. Strategies to improve processes were then defined and implemented, mainly through redistributing tasks between the departments involved, to which process modelling using BPMN contributed significantly. About three months after the improvement actions were implemented, the results before and after the implementation of measures were analysed and compared to verify the gains achieved. Finally, actions were taken to maintain the achievements, such as defining new work standards.

Case study

The work described in this paper was developed in an onshore wind blade plant owned by one of the main world leaders in the wind energy sector. It has been operating since 2009 and employs more than 1300 workers. Due to its recent integration into a new group, it has undergone several changes in its organizational structure, presenting several opportunities for improvement related to some instability in processes and information flows.

Several models of wind blades are produced in the factory. The work focused on the most recent blade model, which at the time represented the company's most significant investment since acquiring the factory. The model was in the initial stage of industrialization, and it is expected to have the most significant economic impact on the company's results by creating a new production line dedicated to it. In addition, it is the largest model produced by the group.

Due to the recent industrialization of the model and the production process being primarily manual, the factory had several quality problems that led to a greater number of repairs and, consequently, to an abrupt increase in lead time in a process already characterized by a long cycle time. Considering all this, there was a need to reduce waste and improve processes and resource allocation to reduce quality issues, cycle time and lead time and provide a better working environment for the workforce. This was done by identifying and analysing the tasks that could compromise the level of productivity and demand response and implementing solutions to the challenges faced. All the steps followed are described in the next sections.

Identification of critical points through VSM

An initial diagnosis of the production process was carried out through a VSM to identify the critical points and, from there, develop an action plan. VSM is one of the tools that can be used as the starting point in designing improvement actions, as it helps to identify critical areas of performance where the organization should focus its efforts (Maldonado et al., 2020). It allows the visualization of waiting times, imbalances between stages, accumulations and reworks.

First, all the necessary data was collected to build the current state VSM. The production process was monitored on the shop floor to identify the sequence of the activities from the moment the raw materials were received in the warehouse to when the product was shipped. Several metrics were then calculated, starting with the takt time of each stage of the production process, representing the time available per blade to meet customer demand. It was calculated according to expression (1):

$$\mathrm{TT} = \frac{(\mathrm{WHD} - \mathrm{B}) \times \mathrm{WDM}}{\mathrm{O}} \times \mathrm{A} \tag{1}$$

where: TT = takt time (hours/unit), WHD = Working hours per day (hours), B = Breaks (hours), WDM = Working days per month (days), O = Number of blades ordered (units/month), A = Availability (%).

Although the VSM was built in January, the number of blades ordered for May was considered in the calculations. According to the annual production plan, known at the beginning of the year, May would be the month of greatest demand. Due to the quality problems that the factory faced, the number of blades produced in January was four (one per week), and in May, the production of ten blades was expected in 22 working days. Therefore, the study considered this value to assess the plant's ability to meet the highest demand. In addition, an "availability" factor was considered when calculating takt times, as teams divided their working time between different blade models. It corresponds to the percentage of working time the team dedicates to producing the blade model under study.

In addition to calculating takt times, the actual performance of the various stages of the production process was analysed by calculating cycle times. Data was collected from shop floor monitoring boards filled in by operators and supervisors, the computer system linked to the company's management information system, and some Excel files. Due to the quality problems that the plant was facing, some informal conversations were held with operators and supervisors to understand how these problems were affecting cycle times and how they would be under ideal conditions. Cycle times were calculated considering the mean values for a sample of five blades. Figure 1 presents the takt times and cycle times per stage of the production process. The comparison of the values allowed to conclude that in the last stages of the process (Main Shell SS, Main Shell PS, P0, P1, UT Scan, P2, P3 and P4), the cycle time was greater than the takt time, which means that, at this rate, it would not be possible to respond to demand in May.

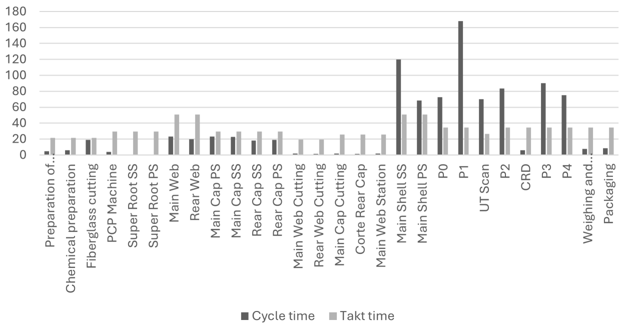

Fig. 1. Takt time and cycle time for each stage of the production process

The production process is carried out in two main buildings: the mold building, where all the prefabricated parts are prepared and the blade takes shape, and the finishing building, where the blade is repaired, painted, calibrated and weighed. Except for "Main Shell SS" and "Main Shell PS", all the other stages in which the cycle time exceeds the takt time are carried out in the finishing building. Therefore, the analysis focused on identifying and implementing improvement actions in the activities carried out in that building.

Data on inventories, the number of operators per stage and shift, and transport times between stages were also collected to construct the current state VSM. Figure 2 shows the current state VSM for the finishing building.

Once the process is completed in the mold building, the blade is demoulded and transported to a stock area, waiting for position P0 to be available. When position P0 is unoccupied, the blade goes to the finishing building, going through several positions (P0, P1, P2, P3 and P4) and finishing processes until completed and shipped. Some materials, such as putties, fibers for repairs and paints, are required in positions P0, P1, P2, P3 and P4. Two supermarkets supply these materials, one dedicated to finishing materials and the other to paints. Materials are ordered through a Kanban control system. Every hour, an operator visits all five positions to collect Kanban cards. Then, the operator goes to the supermarkets, picks up the material ordered and supplies each position.

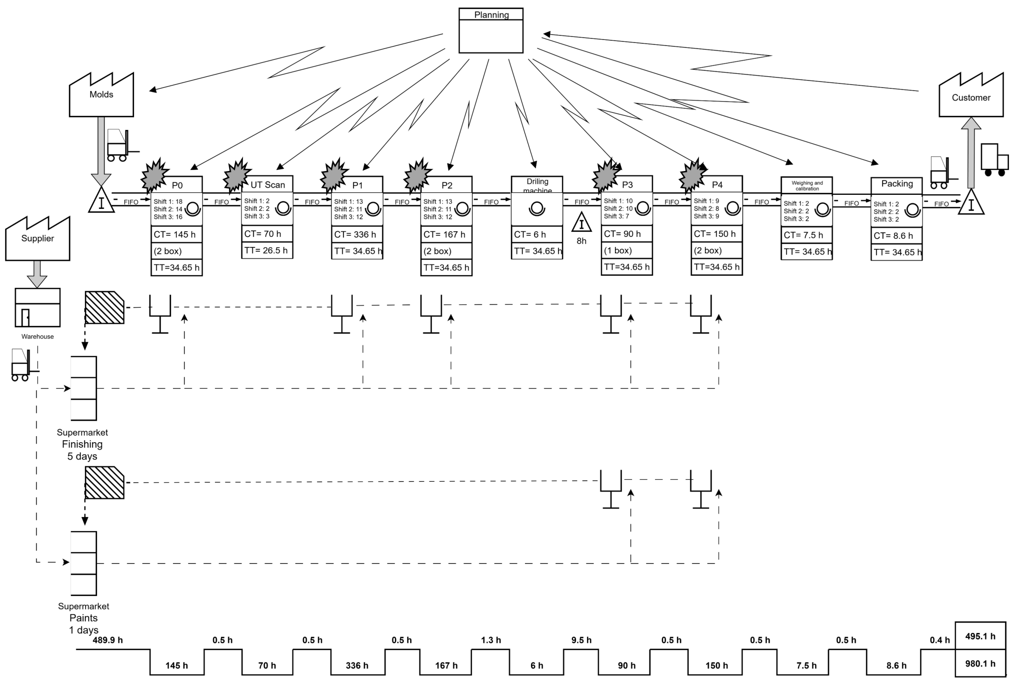

Fig. 2. Current state VSM for the finishing building

After drawing the VSM for the current state, some critical points were identified by considering cycle time values and their potential impact on process performance. In the finishing building, positions P1, P2 and P4 were identified as the critical points to be intervened first. Based on the analysis, the future state VSM was elaborated (Figure 3).

As a result of the VSM analysis, an action plan was designed, considering the inputs from different departments (continuous improvement, logistics, production, quality, and human resources). Some brainstorming sessions were held to identify problems and define actions to be taken, as well as the departments involved and the collaborators responsible for their implementation. The Continuous Improvement Department was responsible for implementing actions in the finishing building to reduce lean waste and cycle time in positions P1, P2, and P4, which were related to the preparation of the Lightning Protection System (LPS) cable and the preparation and distribution of fibers for the cable. The procedures adopted and improvements implemented are described in the following section.

Using process modelling to support the implementation of LM practices

- *Preparation of the LPS cable*

After some brainstorming sessions and a detailed analysis of the activities performed in position P1 in the finishing building, preparing the LPS cable was identified as one of the tasks that most contributed to the high cycle time. Although this activity is directly related to position P1, it is shared with one of the prefabricated elements, the web, and therefore the improvements would benefit both workstations.

The LPS cable protects wind turbines from lightning strikes. It must protect mechanical components from damage and ensure that electrical and electronic components are not destroyed or subjected to excessive stress. It allows the electricity to be distributed through the electrical system directly to specific equipment within the turbine constituents once it arrives at the wind turbine. This cable is made from a costly material, copper, which represents a high percentage of the cost.

The cable is placed in the mold building (at the web workstation) and the finishing building (position P1). Preparing the LPS cable involves several operations, such as cutting the structure and making electrical connections, interrupting other value-added activities, and increasing the cycle time to produce wind blades. Its preparation requires four operators, two at the web workstation and two at position P1. On the last workstation, the task has a cycle time of approximately two hours.

The studied improvement solution involved transferring responsibilities for preparing the LPS cable from the production line to the subcomponent room. In the first instance, BPMN was important in modelling the as-is process and information flows, identifying process handoffs, and improving them. The subcomponent room is used to prepare the components necessary for

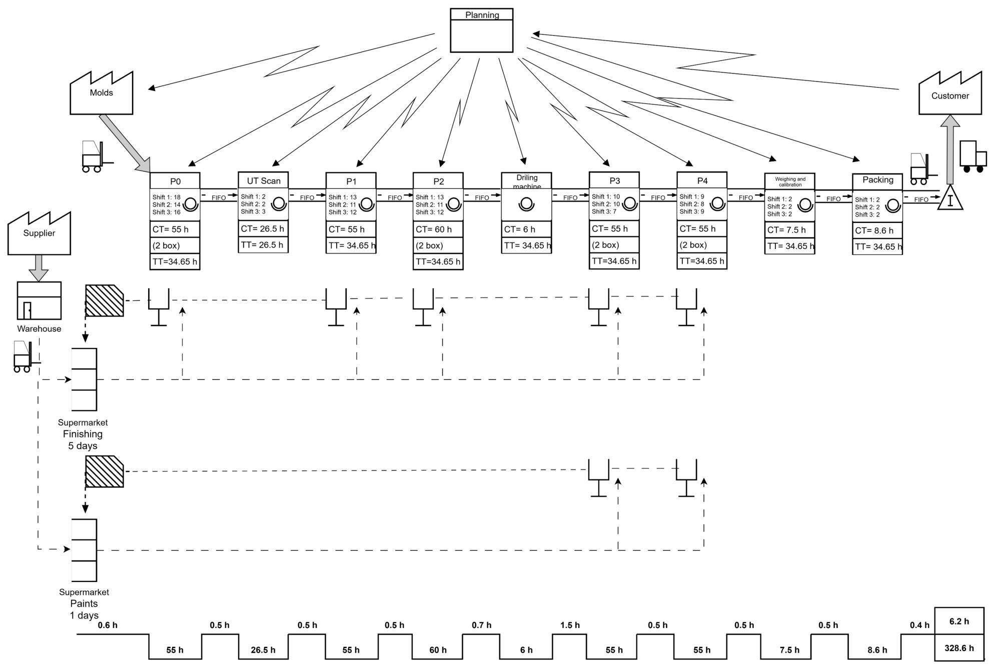

Fig. 3. Future state VSM for the finishing building

the final product, functioning as a production support room. To this end, it was essential to analyse the real needs of LPS cable, create an adequate information flow between the participants to satisfy the production needs, eliminate non-value-added activities, and improve the cable preparation in the subcomponent room. BPMN was combined with other tools to identify the challenges and implement improvements.

BPMN was used to identify failures in the productive flow, as presented in Figure 4. According to the process mapping, the process begins with the creation of the master production plan by the Production Planning team. This plan is shared in the ERP (Enterprise Resource Planning) system. The Production team received the information to start production of wind turbine webs and the LPS cable kit, which was later assembled into the web. Also, the operators assigned to position P1 received the information that the wind blade was ready to be processed and started preparing the LPS cable. To do so, they went to the mold building to cut the LPS cables and then returned to the finishing building to prepare the LPS kits. Then, an operator prepared the electrical connections of the four cables, fixing the LPS cable to the wind blade.

The analysis of the as-is process, modelled with BPMN, allowed to identify some challenges. Operators working in position P1 had to wait to receive the information that LPS cable was needed, and their tasks were interrupted, so they went to the mold building to collect the cable. The movements made by the operator from the finishing building to the mold building to collect the LPS cable were analysed using a Spaghetti Diagram (Figure 5). It was found that the operator covered 662 meters between going to the mold building to collect the LPS cable and returning to the workstation in the finishing building.

In addition to movement, there were other issues and waste associated with the preparation of this component, namely the time required to complete the task. To better understand the causes of the high cycle time for preparing the LPS cable, an Ishikawa Diagram was created (Figure 6) based on observation and detailed analysis of the production process, as well as inputs from the Engineering and Production teams and supervisors from position P1 during some meetings held for this purpose.

After analysis, several causes were identified that were contributing to the problem. Regarding the workforce category, one of the leading causes was the need

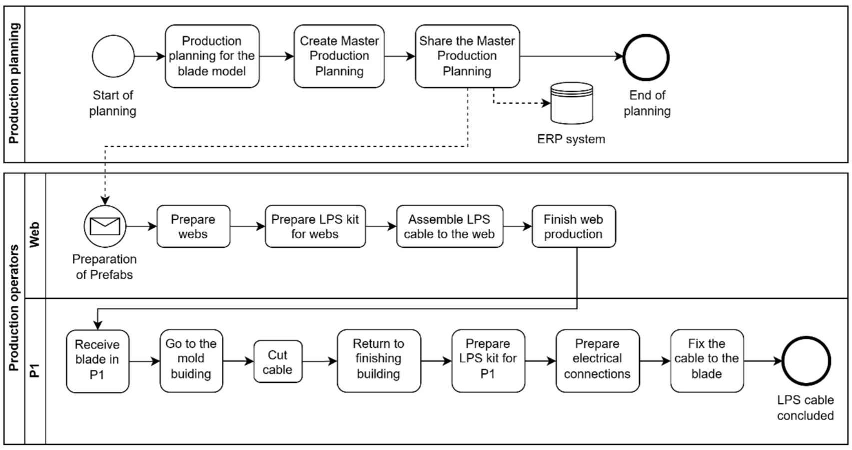

Fig. 4. Preparation of the LPS cable "As-is" process

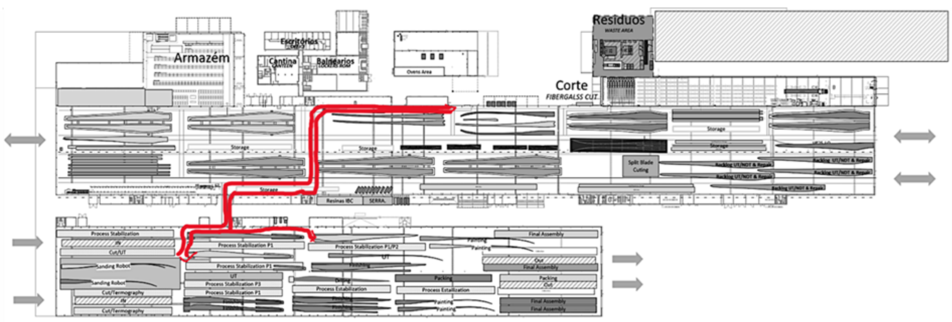

Fig. 5. Spaghetti diagram for the collection of the LPS cable

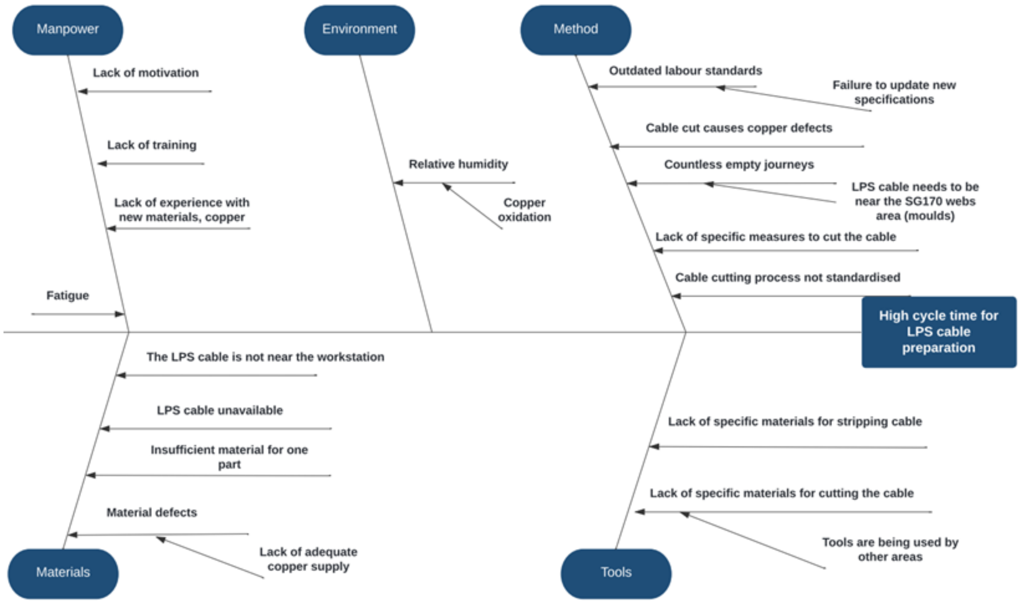

Fig. 6. Ishikawa Diagram with the causes of high cycle time for LPS cable preparation

for more training in the tasks to be performed and experience handling copper. As pointed out by the teams, the leading cause concerning the method used is the need to update the standard work, allowing operators to carry out their jobs correctly and efficiently. This led to technical failures and rework due to the need for work standards. In addition, other causes for the high cycle time were related to the fact that the LPS cable was not placed in a specific location on the factory floor and was not close to the finishing building. This resulted in time spent handling the cable and defects in the material caused by the lack of copper supply, which oxidizes at room temperature. Regarding the machines used in the task, the leading cause was the lack of tools or machines suitable for its preparation.

Finally, after identifying the main problems associated with preparing the LPS cable, some solutions were identified and implemented to solve them. The leading solution was the creation of a new information flow through the addition of a new subprocess. Once again, BPMN was used to map the new process, represented in Figure 7. The new subprocess begins with creating the master production plan, which is shared in the ERP system and then sent to the logistics manager for the mold building. The Logistics team checks the Bill of Materials (BOM) required for the logistics cart for position P1 and the availability of materials in the warehouse. If the materials are available, the operator collects them from the warehouse according to the BOM, preparing the logistics cart for position

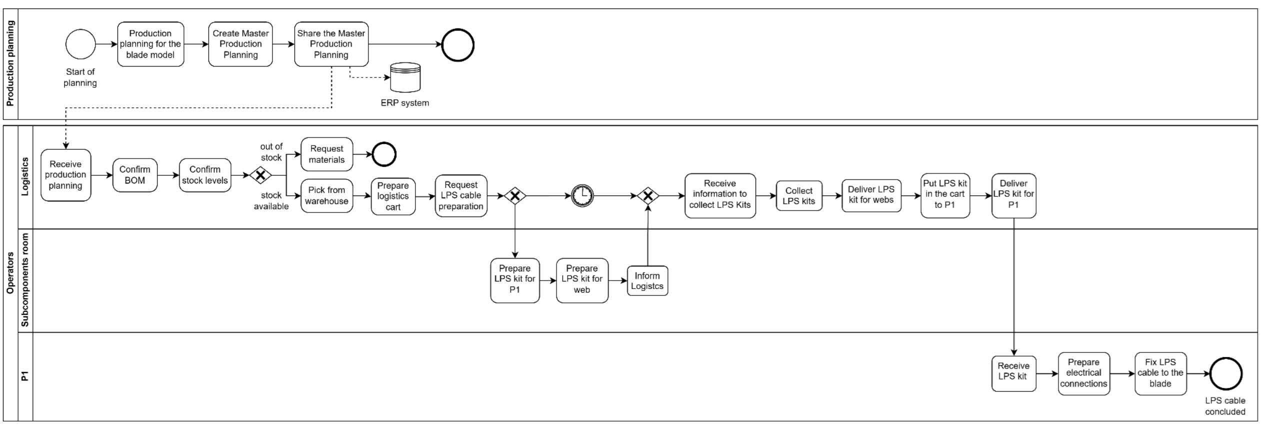

Fig. 7. Preparation of the LPS cable "To-be" process

P1. Then, operators in the subcomponents room begin preparing the LPS kit, which involves measuring the four cables using a more precise method. When the kit is ready, the Logistics team receives information from the subcomponents room, collects the LPS cable, includes it in the cart, and delivers it to the finishing room. According to the new subprocess, operators in position P1 must only receive the cart, prepare the electrical connections between the cables and place them on the finished blade.

In addition to the new information flow, other measures were implemented to improve the preparation of the LPS cable in the subcomponent room, aiming to reduce the high cycle time. One of them was the development of a new standard of work in collaboration with the Engineering team, which allowed operators to reduce the time spent fixing the cable to the blade structure. This resulted in fewer errors and rework. Moreover, some training was also provided to operators in the subcomponent room, and the measurements for cutting the LPS cable were marked on the worktable to improve the task's efficiency and avoid wasting material. A request was made for more suitable tools for cutting and connecting copper cables.

The creation of the new information flow between the Logistics team, subcomponent room operators and operators from position P1 allowed the reassignment of a large part of the task to the Logistics team and subcomponent room, significantly reducing the distances travelled (about 97%) and the two hours spent by position P1 operators in preparing the LPS cable.

- *Preparation and distribution of fibers for LPS cable*

Other activities that contributed to the high cycle time in the various positions of the finishing building were identified. When studying the LPS cable process, several issues arose and were discussed with the supervisors and team leaders at positions P1, P2 and P4.

After the LPS cable is prepared and cut at position P1, it is protected with several layers of fibers applied to the structure of the wind blade in positions P1, P2 and P4. The operator went from where the fiber was needed to the repair room, where he/she cut and prepared the fiber appropriately. Operators in positions P1, P2 and P4 took 36, 34 and 45 minutes, respectively, on this task. The proposed improvement consisted of moving the preparation of these fibers to the cutting area. The preparation and distribution of fibers for position P1 were treated separately from positions P2 and P4, as the supply process differs.

Several brainstorming sessions were held with the Cutting, Logistics, Finishing and Continuous Improvement teams to discuss opportunities for improving the process and reassigning responsibilities. The Continuous Improvement team proposed a new process flow between the Logistics, Cutting and Finishing teams and modelled using BPMN (Figure 8). Additionally, the creation of a structure for placing the fibers and the location of this structure in positions P2 and P4 were discussed with the Logistics team; the number of units per box and the number of boxes per structure were discussed with Logistics and Continuous Improvement teams; and a standard for the supply and identification

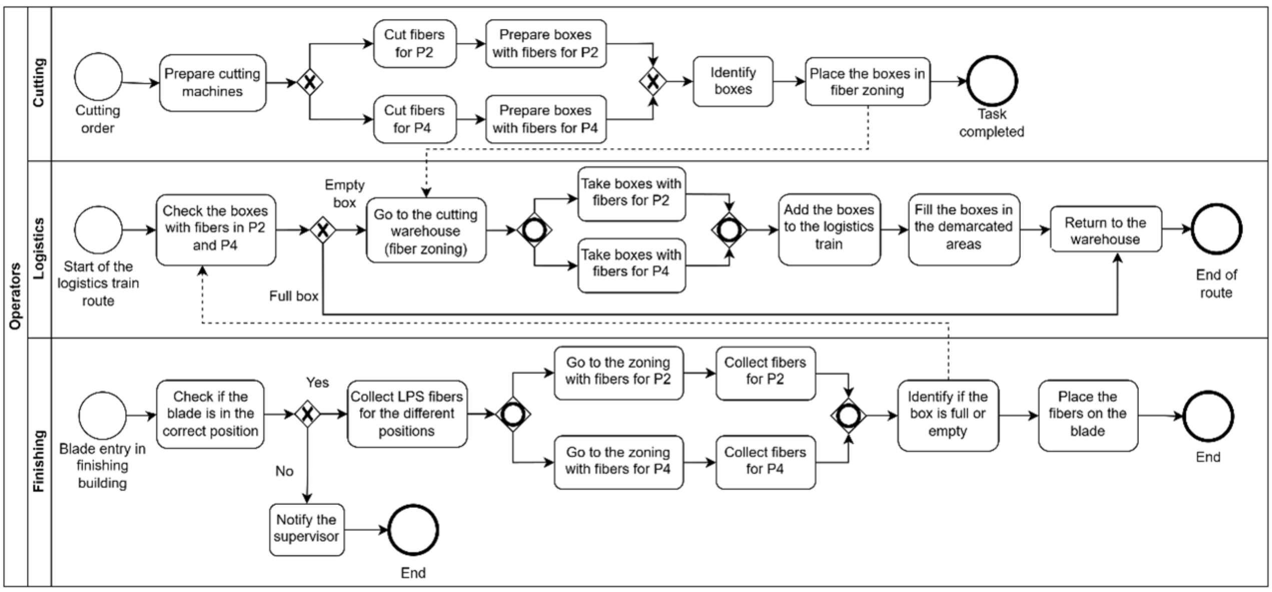

Fig. 8. New process flow for the cutting and preparation of fibers for the LPS cable in workstation P2 and P4

of boxes was defined with the Continuous Improvement team. Responsibility for cutting and identifying fibers was assigned to the Cutting team.

A tugger train carries out a scheduled route daily, covering the different finishing positions (starting from position P2). With the new process flow, a Logistics operator now checks the status of the boxes. If the box is full, the route is completed without replacing it. Otherwise, if the box is empty, the Logistics operator goes to the cutting warehouse and collects the box, depending on the need for fibers. During the tugger train route, the boxes are filled. There are marked areas for placing the boxes, created close to positions P2 and P4, as shown in Figure 9. When the route is completed, it returns to the warehouse.

Fig. 9. Zoning for placing boxes with fibers

According to the new process flow, production operators only need to check whether the LPS cable is in the correct position on the blade and, if so, go to the area where the boxes with the fibers are, collect them, communicate to Logistics team if the box is full or empty and apply the fibers to the LPS cable. Cutting operators work independently, preparing fibers for cables according to a fiber-cutting order created by the Engineering department after weekly production planning. They only need to ensure the process is completed, filling in the boxes Logistics operators will transport.

In relation to position P1, the fibers necessary for the LPS cable were included in a cart, which Logistics team already uses to transport the fibers needed for other tasks carried out in this position.

With these improvements in the process flow, the time spent by Production operators on this task was eliminated since all fiber preparation and distribution were assigned to Cutting and Logistics operators. The distances travelled by Production operators were significantly reduced (99% for P1, 62% for P2 and 87% for P4), as was the cycle time in positions P1, P2 and P4 (around 95% in each position). Figure 10 presents a Spaghetti Diagram representing the distance travelled to prepare LPS cable fibers in positions P2 and P4 before (in blue) and after (in red) implementing the new process flow.

This enables operators to be more efficient by reducing non-value-added activities and waste, such as transport.

Impact of implemented actions on cycle time

Once the implementation of the improvement actions was completed, the impact of the actions carried out on the cycle time was evaluated. The cycle time of the six blades produced in May was measured. Although the objective of producing ten wind blades was not achieved, the reduction in cycle time of the operations studied was considerable.

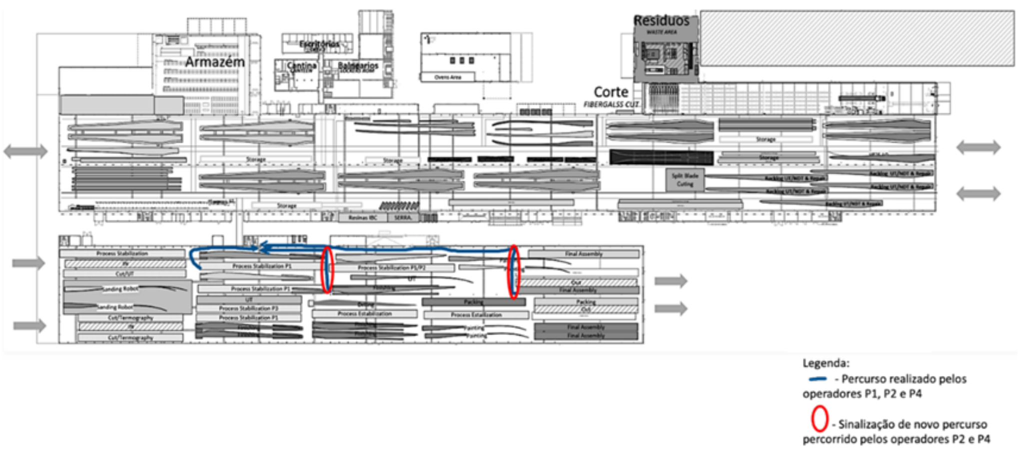

Fig. 10. Distance travelled to prepare LPS cable fibers in positions P2 and P4 before (in blue) and after implementation of the new process flow (in red)

Analysing the values presented in Table 1, the cycle time in positions P1, P2, and P4 of the finishing building decreased by around 27%, 7% and 20%, respectively, compared to the cycle time values determined in the initial diagnosis, when designing the current state VSM. The standard deviation of cycle time values decreased following the implementation of corrective measures, indicating enhanced process consistency and predictability. This trend reflects greater operational stability and improved responsiveness to customer demands. The cycle time remains above the takt time. Improvements must continue to be identified and implemented, mainly regarding quality.

Regarding the results obtained, it is important to reflect not only on the performance indicators but also on the successful implementation of a culture of continuous improvement in all teams, which has proven to be a fundamental part of improving processes.

Table 1
Takt time and average cycle times before and after implementation

Position	Takt time (hours)	Initial cycle time (hours)	Final cycle time (hours)
P1	34.65	168	122.08
P2	34.65	83.5	77.75
P4	34.65	75	60

Conclusion

Based on empirical evidence, the work aimed to demonstrate how process modelling with BPMN can support LM implementation and help enhance the benefits associated with this process improvement approach. It contributes to enrich the existing literature, bridging the BPM and LM fields, which have been seen as two different management paradigms, incompatible in their goals and vision (Maldonado et al., 2020). It supports the findings of Calçado et al. (2024) and Bernardino and Ávila (2025) that they can complement each other, providing more evidence of their applicability to improve processes in manufacturing firms. To the best of the authors' knowledge, this is one of the first case studies addressing the use of BPMN for modelling physical operations processes aiming to support LM implementation. BPMN's most significant contribution to the implementation of LM is in identifying the responsibilities of the different participants and process handoffs, which are critical points for process efficiency. Models created using BPMN language visually represent process flows that are easily readable by anyone. This facilitates a common understanding of the processes and offers a solid basis for discussing process improvements, namely the reassignment of tasks. In the case described, the reassignment of tasks reduced waste, such as waiting, movement, and knowledge waste, considered the eighth lean waste.

Some managerial implications can also be drawn from this work. The case described can guide other companies with complex production processes, with many handoffs, on LM implementation. It provides insights into how process modelling, and BPMN in particular, can support the implementation of LM, as well as some practices and tools that can be used to eliminate waste and reduce cycle time. Companies can use BPMN and VSM together to create powerful synergy for LM implementation. These tools provide complementary information that is useful for identifying process inefficiencies. Furthermore, they both enable future state models to be designed and changes to be simulated and discussed before implementation. The example described can help managers become aware of the importance of carefully identifying the causes of inefficiency and redesigning processes, not neglecting the planning phase in the desire to move quickly to action. LM principles are widely adopted by manufacturing firms, but BPM is not. Training employees in BPM to better understand its potential application in organizational processes and encouraging them to map processes to identify handoffs and opportunities to improve process flows could contribute to more successful process improvement initiatives. The case study presented also highlights, as a good practice, the involvement of the people who participate in the process, directly or indirectly, not only during the implementation but also a priori, in the discussion and identification of problems and ways to resolve them. The practices implemented will only last when accompanied by changes in the treatment and behaviour of those involved before, during and after their adoption (Negrão et al., 2017).

In terms of the study's limitations, the company under analysis operates within a highly specific sector. The case study approach limits the scope for applying the findings because only one case was analysed. Relying on a single case study means it is impossible to confirm whether the approach would have a similar impact on other companies, whether in the same sector or a different one. Furthermore, the organization's ongoing involvement in various operational initiatives makes it difficult to determine the effect of individual measures. Overlapping interventions may influence the observed results, limiting the internal validity of the study. Time constraints also limited the assessment of the medium-and long-term impact of the implemented measures.

As future research directions, the same approach can be tested in other companies operating in different contexts to validate and generalize the findings. This would consolidate the contributions of this study to the literature and enable practitioners to realize the benefits of complementing LM practices and tools with approaches and tools from other fields, thereby maximizing the gains from efforts to improve processes. Further studies could be conducted to build on the lessons learned and their implications, particularly regarding the contributions of the two methodologies to companies preparing for and transitioning to digitalization.

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