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INTEGRATION OF SIMULATION AND HIERARCHICAL APPROACH TO SUPPORT LEAN IMPLEMENTATION

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Abstract
This study develops and implements a tool to support Lean practices through simulation integrated with a hierarchical approach using Moore-Hodgson algorithm and Genetic Algorithm (GA). The approach assesses the performance impact of Lean practices in a textile manufacturing system, focusing on material handling and setup time. Discrete Event Simulation (DES) is used to test scenarios, optimize decisions, and evaluate improvements. Integrated with hierarchical methods and GA, DES helps guide production scheduling, aiming to reduce waiting and setup times. Applied in a case study of a raffia packaging plant, the tool optimizes operational management decisions by introducing new equipment and scheduling strategies to improve material handling and setup processes. Several scenarios were tested, resulting in improved operational efficiency and higher output without affecting delivery timelines.
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Key Words: Lean Manufacturing, Simulation, Hierarchical Approach, Moore-Hodgson, Genetic Algorithm

1. INTRODUCTION

The implementation of Lean Philosophy in production processes (goods and services) appears as a key activity towards more efficient processes. This philosophy is based on eliminating waste and improving flows, aiming, among other objectives, to improve the efficiency of processes and systems [1]. In Lean implementation, the central focus of actions for each objective must be customer requirements [2]. To this end, the activities of a system can be viewed from distinct perspectives: Activities that add value to customers and activities that do not add value, representing wastes [3, 4]. In this context, decision-makers must seek to reduce and eliminate activities that do not add value by eliminating waste such as overproduction, unnecessary stocks, unnecessary movement of materials and people, waiting times, unnecessary activities, and defective products [3].

However, it is noted that the increasing complexity of production systems over the years might make the implementation of Lean difficult [2]. In this sense, there is a growing search for tools and techniques to support decision-making. Lean will continue to be a key factor in achieving greater efficiencies on the part of organizations, while tools and solutions brought by the evolution of the industry will assist in the implementation and resolve difficulties currently encountered in implementing the philosophy [5]. In this context, simulation can contribute to faster achievement of objectives involving the implementation of Lean, allowing the testing of effects of Lean solutions before, during, and after their implementation [6]. Furthermore, the implementation of Lean involves solutions that may be conflicting and/or have multiple objectives, a fact that makes a preliminary analysis of its effects on the system difficult, with

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simulation being an important tool to minimize such difficulties and provide good predictions to decision makers [7].

Simulation has consolidated itself over the last few decades as a valuable decision support tool, with applications in hospitals, military activities, services, logistics, and mainly in manufacturing processes [8, 9]. In this case, it is possible to investigate the behaviour of complex systems, carry out "what happens if" experiments, and evaluate changes without the need for interventions in real systems [10]. Moreover, although several works have been exploring the use of simulation in Lean implementation [7, 11-15], we also note that there is a tendency of integrating simulation with other analysis tools to amplify its benefits and analysis power. In this way, Santos et al. [16] highlight the use of simulation integrated to optimization techniques, Artificial Intelligence (AI) models, virtual and augmented reality devices, among other analysis and decision techniques. The same authors state that such an approach is in line with the Industry 4.0 requirements.

Therefore, the purpose of this study is to develop and implement a tool to support Lean practices implementation through simulation integrated to a hierarchical approach based on Moore-Hodgson and Genetic Algorithm (GA). The proposed approach must support the assessment of the impact on performance resulting from the Lean practices implementation in a real textile manufacturing system, focusing on both material handling and preparation process (setup time) of the printing process. In this case, we adopted the DES to test scenarios, evaluate the improvements, and optimize decisions. Furthermore, DES will be integrated with a hierarchical approach based on Moore-Hodgson algorithm and GA to guide decisions regarding production scheduling and planning, aiming to minimize waiting and setup times. All actions and improvements are related to Lean principles since they seek waste elimination and efficiency improvement.

The case study refers to a raffia packaging manufacturing line. The packages are made of woven polypropylene (PP), a type of plastic resin packaging with many advantages. It can be transparent, allowing the product's colour and type to be seen, and it provides greater protection against moisture, rodents, and environmental dirt. In this way, considering the current dynamic demand (high variability and customization), and the consequently need for more efficient decisions during the manufacturing process, Lean practices stand out as an important approach in the textile segment.

2. MATERIAL AND METHOD

The proposed approach was divided into three stages: (i) Scope and Objectives definition; (ii) Actions implementation; and (iii) Results assessment. Fig. 1 illustrates the three stages framework followed by the characteristics of each of them.

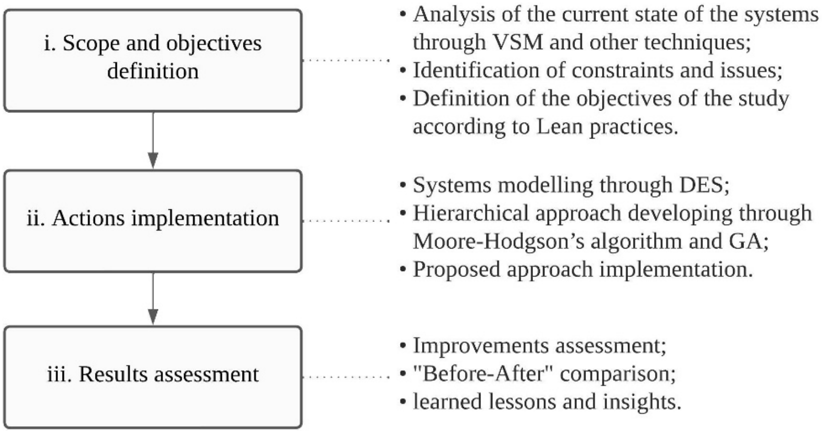


Figure 1: Three stages framework to guide the proposed approach implementation.

Among several stages during a manufacturing process, it is necessary to define the scope of the work, since the improvements implementation in all stages would not be feasible. In this case, we used the Value Stream Mapping (VSM) to identify the most critical activities. According to [3], the VSM is an important and widely applied Lean tool to represent the processes and their flows (material and information), allowing the identification of the most critical activities and their inefficiencies. Moreover, once the most critical activities have been defined, the objectives should be defined considering Lean principles.

Regarding the actions implementation stage, the first focus is to model the processes defined in the previous stage through DES. In this case, the objective is to virtually represent the processes with high accuracy in order to support decisions. For this, it is necessary to perform several activities from data collection to conceptual and computational modelling, including verification and validation steps. More details about the activities related to DES modelling can be consulted in [17]. Moreover, the proposed approach is focused on production planning and, in this way, we opted to integrate the DES model with widely adopted methods for production planning decisions, a hierarchical approach based on Moore-Hodgson's algorithm and GA. Therefore, we can simulate scenarios, test solutions and optimize decisions through an advanced tool.

In this work, a hierarchical approach based on algorithms for production planning scheduling to minimize late and setup times is executed in two stages: the production schedule upon receipt of production orders and the production schedule during the printing process [18]. In production scheduling upon receipt of production orders, a single machine scheduling problem (SMSP) is addressed using Moore-Hodgson's algorithm. The algorithm prioritizes production orders that are due to be completed soonest, selecting the job with the earliest due date. In production scheduling during the printing, another single machine scheduling problem (SMSP) is tackled using the GA to solve the problem of sequence-dependent setup times.

The production scheduling in this study addresses the single machine problem in two stages. Firstly, during the printing process, it assumes that the machine requires a setup between jobs and that the setup times depend on the production sequence. Secondly, upon receipt of production orders, it assumes that the jobs with the earliest due date should be executed promptly, for both laminated and non-laminated packaging.

Finally, considering the results assessment stage, the main objective is to carry out "before-after" decisions to evaluate the proposed approach results. In this case, the learned lessons and insights will be highlighted. The three-stage framework will be presented in the next section.

3. RESULTS AND DISCUSSIONS

3.1 Scope and objectives definition

Among the various industrial segments, the textile industry stands out. Despite being considered traditional, it is very competitive globally. Besides its complexity, due to the branches that include the sectors of spinning, flat weaving, knitting, dyeing, printing, and clothing [19, 20], the textile industry also persists in attempting mass customization to meet the current dynamic demand [20].

However, it is necessary to study and understand future alternative possibilities for a flexible and intelligent production chain [20, 21], enabling the growth of the textile sector alongside the development of the global industrial market, making it increasingly competitive and valued [20]. In this context, the proposed research was developed in a textile manufacturing plant located in Brazil. It is a medium-sized plant (with an annual revenue of R$2 million to R$4.8 million) and the objective was to evaluate the application of Lean concepts in the raffia packaging manufacturing line through DES integrated to hierarchical approach.

We should highlight that the sealing of the raffia packages allows the weaving process of polypropylene woven fabric to be carried out in circular looms with a higher spacing in the distance between the vertical tapes distributed transversally to the set of horizontal tapes measured in the projected plane, spaced evenly which provides a high performance and higher productivity of circular looms. For products with dimension per unit smaller than the distance among the vertical tapes and horizontal tapes a coating/lamination intermediary process is realized among weaving and printing processes, in order to avoid loss of product to be packaged. Due to the additional cost of the lamination process sealing of the raffia packages, in case of products with dimension per unit greater than the distance among the vertical and horizontal tapes the coating/lamination process is not realized, and the product is defined as raffia packaging of conventional type.

Considering the raffia packaging manufacturing plant, nine VSMs were designed to identify activities critical to production lines. In this case, the VSM of family 2 line has been selected due to its production flow working in all processes related to manufacturing, as well as the fact that family 2 demands represent around 27 % of the total demand of products manufactured by the company. Family 2 is made up of 26 products.

The demand for each product was determined respecting the sales projection and factory capacity according to the VSMs. For this reason, we considered production processes data from family 2. The demand for each product was determined respecting the sales projection and factory capacity, in accordance with the VSM of family 2. Between manufacturing processes, the main constraint is on the printing machine. This led us to study the lamination and printing processes, aiming to improve the performance of the processes individually and to analyse the possibility of installing an overhead crane to transfer the rolls between these processes.

Fig. 2 shows VSM of family 2 considering only the processes coating/lamination and roll-to-roll printing, the most critical activities. Table I shows the operation parameters of the machines. The printing speed of Thunder COMAT and Padane machines varies from 60-100 m/min. The company operates with two dimensions of rolls, 2,882 and 3,500 meters. For this study proposal, we opted to standardize the size of the rolls at 3,500 meters.

In Fig. 2, the processes data in the data boxes of the map, Coating/Lamination, Industrial Printer (1) (Thunder COMAT), and Industrial Printer (2) (Padane) were calculated based on the roll of 3,500 meters.

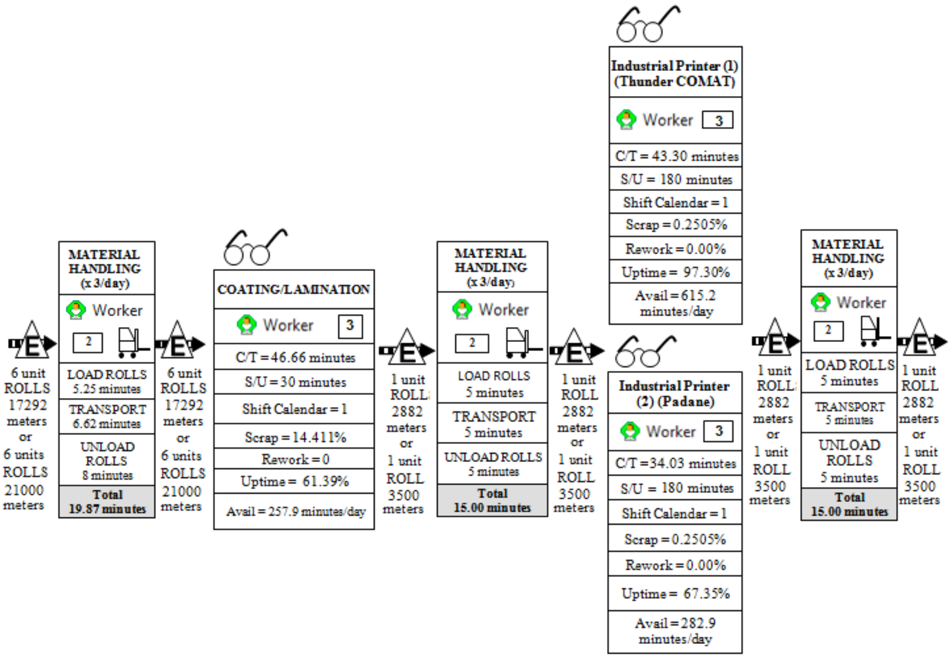


Figure 2: VSM of family 2 (processes: coating/lamination and roll-to-roll printing).

Table I: Operation parameters of the machines.

Machine		**Operation parameters**		
The Coating/Lamination speed of the machine		Speed = 70 m/min		
The printing speed of machines		Speed = varies from 60-100 m/min		
Shift Calendar	**Shift (1)**		**Shift (2)**	
Shift	**From**	**To**	**From**	**To**
Monday – Friday	7 pm	5 pm	7 pm	5:15 pm
Saturday	7 pm	5 pm	7 pm	5:15 pm
Pauses	12 am	1:10 pm	12 am	1:05 pm

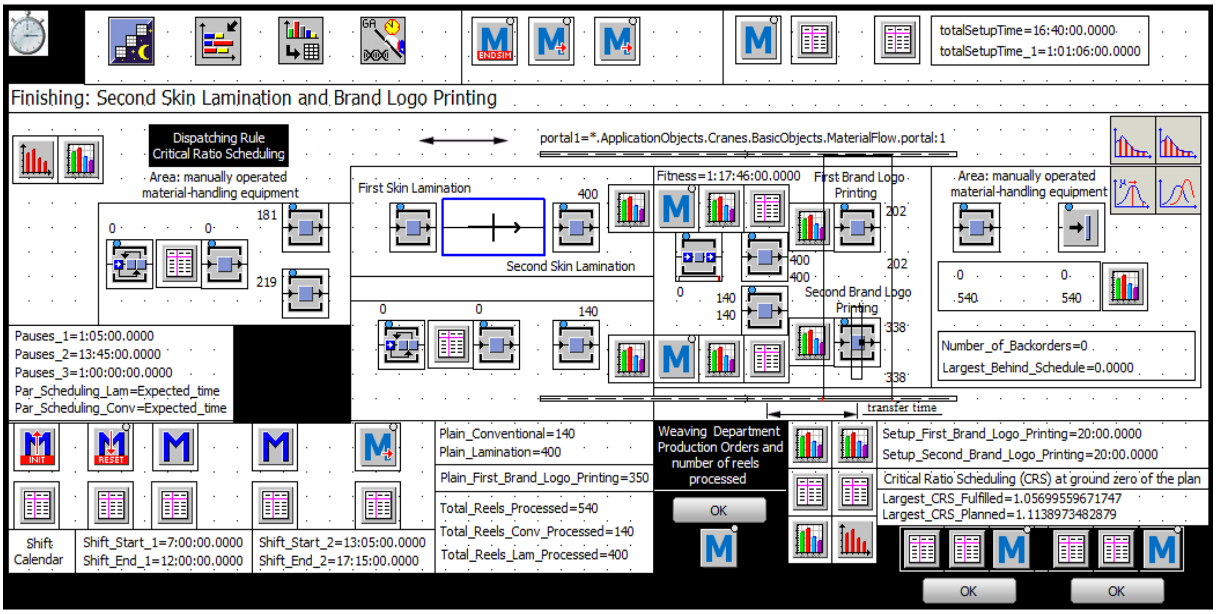
The collected data are referred to the printing machine setup time with the device used for fixing the plate with rotogravure customer´s logo on the printing cylinder, for printing raffia packaging on laminated and non-laminated fabric (conventional type).

Therefore, the proposed approach, which combines DES and a hierarchical approach, will be implemented in the family 2 manufacturing process. In this case, we intend to optimize decisions related to production planning, mitigating and reducing wastes, which is in line with the Lean principles.

Finally, after defining the scope, we reinforce that the proposed approach (DES combined with hierarchical approach based on Moore-Hodgson’s algorithm and GA) will be implemented to optimize the production planning, supporting decisions about production scheduling activities. Moreover, considering the Lean principles, we will also evaluate the implementation of new equipment in the line, focusing on materials handling and setup time since they refer to important wastes that must be reduced/ mitigated. Regarding materials handling, DES will support the assessment of the implementation of materials handling equipment between the operations. Furthermore, we will also evaluate the implementation of a device for fixing the harder printing plate on the printing cylinder to reduce setup times.

3.2 Actions implementation (DES + hierarchical approach)

The DES model was developed through the Plant Simulation® software, as represented in Fig. 3. It illustrates the layout of the processes studied and the operational aspects of the production flow. The dimensions of the layout are nearly 1061 meters in length by 493 meters in width.



totalSetupTime=16:40:00.0000
totalSetupTime_1=1:01:06:00.0000

portal1=*.ApplicationObjects.Cranes.BasicObjects.MaterialFlow.portal:1

Fitness=1:17:46:00.0000

Pauses_1=1:05:00.0000
Pauses_2=13:45:00.0000
Pauses_3=1:00:00:00.0000
Par_Scheduling_Lam=Expected_time
Par_Scheduling_Conv=Expected_time

Number_of_Backorders=0
Largest_Behind_Schedule=0.0000

Shift_Start_1=7:00:00.0000
Shift_End_1=12:00:00.0000

Shift_Start_2=13:05:00.0000
Shift_End_2=17:15:00.0000

Plain_Conventional=140
Plain_Lamination=400

Plain_First_Brand_Logo_Printing=350

Total_Reels_Processed=540
Total_Reels_Conv_Processed=140
Total_Reels_Lam_Processed=400

Setup_First_Brand_Logo_Printing=20:00.0000
Setup_Second_Brand_Logo_Printing=20:00.0000

Critical Ratio Scheduling (CRS) at ground zero of the plan

Largest_CRS_Fulfilled=1.05699559671747
Largest_CRS_Planned=1.1138973482879

Figure 3: Simulation model, which contains the layout of the lamination and printing processes.

To build the DES model, we considered several steps from data collection to computational programming, as highlighted in section 3. Furthermore, as applied in the case study presented in the work of Ku et al. [20], we configured the system to collect data from the Programmable Logic Controller (PLC) that includes order information and machine information. It is an approach that facilitates the data collection, allowing an agile project that is in line with DES modelling in the Industry 4.0 context [22, 23].

One of the objectives of the study is to evaluate any variations in the volume produced in the defined production area concerning the implementation of a materials handling equipment among the stages of lamination and printing machines (conveyor belt). In addition to this, we configure the size of the capacity and Dwell time buffer through an iterative process with GA-based optimization.

In addition, at the beginning of the production flow, we have created a method based on the Moore-Hodgson algorithm for minimizing the number of late jobs through the execution of the sorter object. In this case, an object in which production orders were generated after importing sale orders. In this work, Moore-Hodgson algorithm is designed based on the work proposed by Cheriyan et al. [24].

The model's input data were collected during the factory's operation over a period of one month through PLC and accomplished through VSM design. The data for the process (i.e. the lamination time, printing time and delivery date per production order for each of the orders, among other) were imported from the company's system into spreadsheets and from spreadsheets to specific tables configured in the simulation software through specific import methods. The same was adopted for the product´s setup matrix after installing the device for changing the logo print of each sale order. Moreover, the production flow was defined from receiving the woven fabric on rolls from the weaving area directly to two transfer stations via the overhead crane to one of the two printing machines for both conventional and laminated woven fabric on rolls.

Table II: Results of the Iterative process to generate new and better solutions address the minimization of sequence-dependent setup through GA.

Results	**Value**
Running time of the optimization	7:49:52.0400
Best fitness (Total Setup Time)	01:18:19:00.0000
Buffer capacity = 14 and Dwell time = 4:00:00	
Fitness (after optimization)	01:17:46:00.0000
Buffer capacity = 12 and Dwell time = 3:00:00	
Total Setup Time First Brand Logo Printing	00:16:40:00.0000
Total Setup Time Second Brand Logo Printing	01:01:01:06.0000
Number of backorders	0
Largest Behind Schedule	0.0000
Largest Setup First Brand Logo Printing	20:00.0000
Largest Setup Second Brand Logo Printing	20:00.0000
Critical Ratio Scheduling (CRS) at ground zero of the plan	
Largest CRS fulfilled	1.05699559671747
Largest CRS planned	1.1138973482879
Production plan: conventional woven fabric on rolls	140
Production plan: laminated woven fabric on rolls	400
Total production plan	540

In association with the buffers´ dimensioning process, capacity, and Dwell time, an iterative process to generate solutions for an optimization setup time on four-colour and six-colour printing machines was conducted. In this case, GA has been implemented on the simulation model according to an iterative process (Genetic Algorithm module – GA Wizard): (i) Initial settings (parameterization of the Genetic Algorithm); (ii) Experiments; (iii) Evaluation; and (iv) Results.

Table II shows the results that were obtained using an iterative process. Both default genetic representation of the problem to be solved (chromosomes) and crossover and mutation operators of GA Wizard were not modified. In this work, the GA searched for the good enough solution considering the scheduling for each printing machine aiming for minimum setup time.

3.3 Results assessment

In the results assessment phase, we carried out experiments based on three phases:

1) Simulation model design based on the VSMs including the device used for fixing the plate with rotogravure customer´s logo on the printing cylinder, for printing raffia packaging on laminated and non-laminated fabric (conventional type);
2) The simulation model is improved through the inclusion of a collecting conveyor belt between two lamination process stages. Moreover, a Portal Crane is included among an intermediate stage for material handling of the buffer to the printing machines;
3) The study is improved through the implementation of production sequencing and scheduling methods, including the optimization of resources and buffers. In this case, we adopted the key performance indicator (KPI) “Critical Ratio Scheduling” dispatching rule, which refers to the time to due date remaining by the expected elapsed time to finish the job, according to Gartner Glossary, including (1) Largest Critical Ratio Scheduling Fulfilled; (2) Largest Critical Ratio Scheduling Planned; (3) Total Orders Planned; (4) Total Orders Processed; (5) Number of Backorders; (6) Largest Behind Schedule; and (7) printing machines Total Setup Time.

Moreover, to evaluate the experiments, we considered five scenarios: Scenarios 1, 2, and 3 are related to the first phase with different material handling team sizing. In scenarios 1 and 2, a team of two workers transported rolls from lamination to printing. In scenario 1, this was done in one shift, while in scenario 2, it took two shifts with one team per shift. In scenario 3, two teams of two workers handled the rolls over two shifts, one team per shift. In these scenarios, we did not include any changes regarding equipment inclusion or optimization rules for production planning. In scenarios 4 and 5, a portal crane replaced teams for transferring rolls from lamination to printing, conducted over two shifts. Finally, scenario 5 is related to the third experiment phase, i.e. the inclusion of production planning methods based on algorithms.

Tables III, IV, and V show all performed experiments. The total quantity of the created production orders is 400 orders of type “laminated” and 140 orders of type “conventional”. The simulation model was executed in a DESKTOP Intel® Core^{TM} i7-3770 CPU @ 3.40 GHz, with an installed memory (RAM) of 8 GB and a system type 64-bit Operating System.

Table III: Experiments’ results considering the five scenarios – Parameters (1) to (5).

Simulation model **Scenario 1 – Shift (1)** **Scenarios 2 to 5 – Shift (2)**	**Parameters associated to the defined KPI**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Scenario 1 (one team for Material Handling)	1.599	1.135	540	379	108
Scenario 2 (one team for Material Handling)	1.392	1.134	540	393	98
Scenario 3 (two teams for Material Handling)	0.877	1.122	540	540	0
Scenario 4 (one portal crane for Material Handling)	2.575	1.130	540	474	161
Scenario 5 (one portal crane for Material Handling)	1.056	1.114	540	540	0

As we noted, considering the last configuration of the simulation model, with the proposed programming implementation of production sequencing and scheduling methods and optimizing the use of resources with the material handling equipment, the increase in the volume of products manufactured with no delay in delivery date, jumped from 379 to 540, an increase of around 42.48 %.

Table IV: Experiments' results considering the five scenarios – Parameters (6) and (7).

Simulation model	**Parameters associated to the defined KPI**		
	(6)	**(7)**	
		PM (1)	**PM (2)**
Scenario 1	08:20:47:16	13:02:00	16:11:00
Scenario 2	6:21:57:16	12:42:00	16:49:38.17
Scenario 3	00:00:00:00	00:22:38:00	01:20:09:00
Scenario 4	17:22:29:48	00:16:02:00	01:03:43:00
Scenario 5	00:00:00:00	00:16:40:00	01:01:06:00
	Critical Ratio Scheduling (CRS)		
	Evolution of the fitness values of the generations Performance of the GA		

Table V: Production volume for printing machines (PM).

Simulation model	**Printing machine – PM (1)**			**Printing machine – PM (2)**		
	Conv.	**Lam.**	**Total**	**Conv.**	**Lam.**	**Total**
Scenario 1	75	115	190	65	124	189
Scenario 2	81	116	197	59	137	196
Scenario 3	77	193	270	63	207	270
Scenario 4	50	135	185	74	215	289
Scenario 5	53	149	202	87	251	338
- Portal Crane Settings: length of the crane track: eighteen meters; width of the crane track: ten meters; number of portals: one; portal length: three meters; portal width; ten meters; portal height: eight meters; overhang: zero meters; speed: 1.0 m/s; trolley lifting height: five meters; trolley speed: 1 m/s; hook speed: 0.25 m/s; travelled distance: 4,323 meters. A roll weighs approximately 260 kg. In Third Simulation Model (configuration 2), the material handling process gives higher priority to the rolls transfer between point of supply and point of destination, in the case to the machine PM(2) than to the machine PM(1) for both types of products, Laminated or Conventional, because of the average processing time of machine PM(2) is quicker than machine PM(1).						

The results of each experiment indicate the increase in the volume produced from the first to the last simulation model, which includes all the improvements proposed in this work. Among the performance indicators considered, the critical ratio, according to Fig. 4, indicates that the expected result was achieved, i.e. the increase in the volume of products produced attends the demand, without compromising due dates.

We carried out a statistical analysis considering the results for material handling parameters. In this way, the average handling time presented no significant variation. Furthermore, the interval between the lowest and the highest value of the handling time with the installation of the portal crane increased significantly, due to the production flow. Finally, we highlight that this dispersion contributed to an increase in the printer supply frequency. Moreover, considering scenario 5 as the best one, we carried out another analysis. In this case, we evaluated the setup times of the printing machines, as illustrated by Fig. 5.

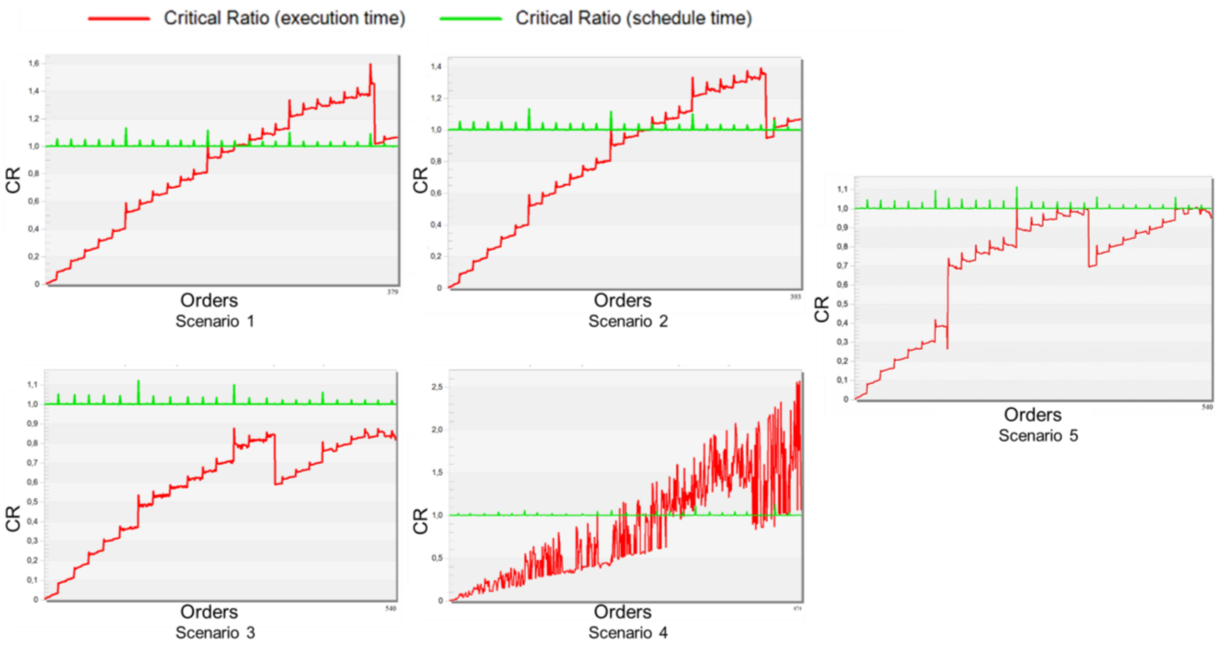


Figure 4: Critical Ratio for the evaluated scenarios.

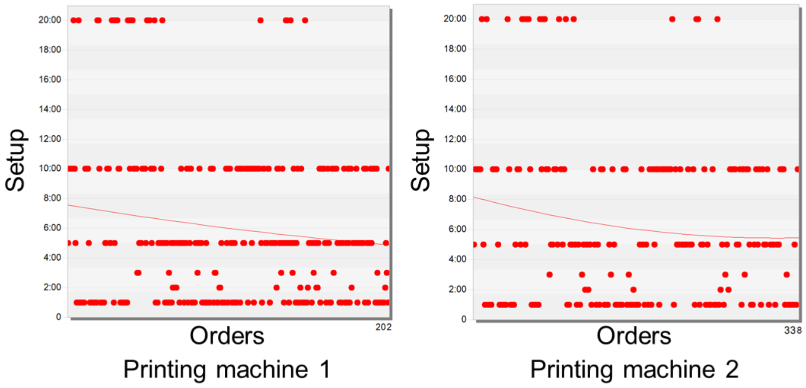


Figure 5: Setup Time of printing machines 1 and 2 considering Scenario 5.

Fig. 6 shows the performance graph of the genetic algorithm. The value of the minimal setup time is 01:18:19:00 (day: hour: min: sec) which is the fitness value of Individual 20 of Generation 2. The fitness value is the sum of the setup times of the individual printing machines.

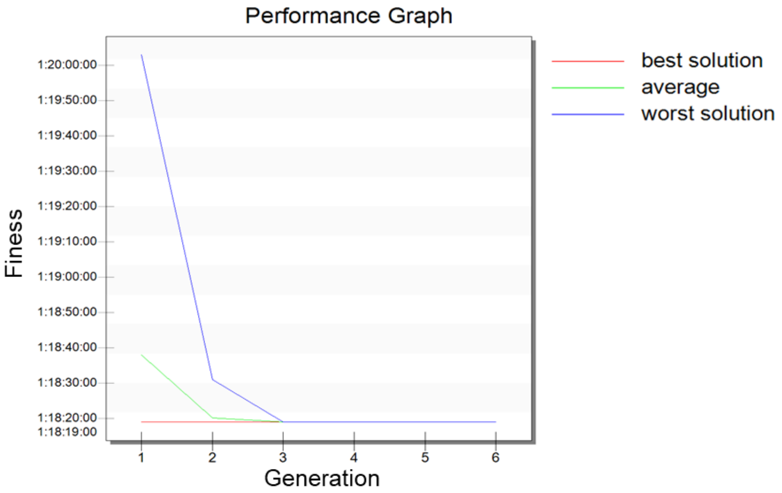


Figure 6: Evolution of the fitness values of the generations (scenario 5).

Finally, it is important to highlight that the proposed approach was prepared to operate in an integrated manner. Fig. 7 illustrates the integrated framework, including automated routines for implementation, monitoring, evaluation, and production management. In this case, the proposed approach is in line with a Digital Twin (DT) model requirements, since it allows continuous update of the model according to the current state of the process through databases [22]. Therefore, we highlight another benefit of the proposed approach since it contributes to an important pillar of Industry 4.0 [25, 26]. We reinforce Lean applications as a promising field of research that contribute significantly to the operational performance [27, 28]. In this case, the integration of this philosophy with Industry 4.0 context can increase its benefits.

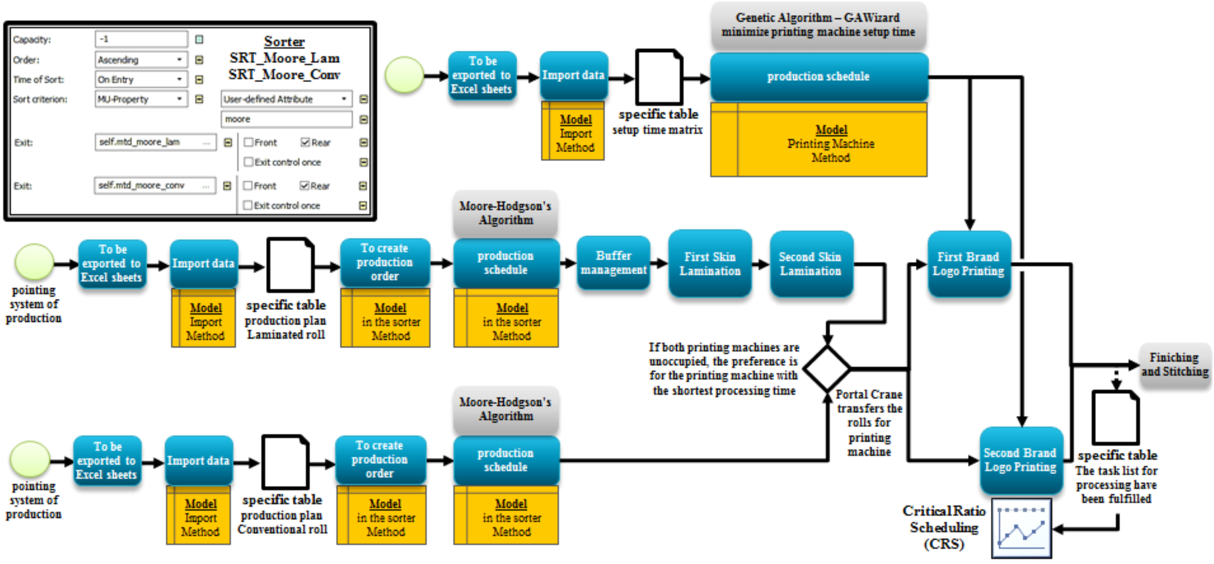

Capacity: -1
Order: Ascending
Time of Sort: On Entry
Sort criterion: MU-Property
User-defined Attribute
moore
Exit: self.mtd_moore_lam ☐ Front ☑ Rear ☐ Exit control once
Exit: self.mtd_moore_conv ☐ Front ☑ Rear ☐ Exit control once

Figure 7: Integrated framework for the proposed approach.

4. CONCLUSIONS

The proposed work reveals significant results in optimizing industrial processes through Lean principles implementation and its evaluation. In this context, this work addressed material handling and setup activities in order to mitigate wastes related to materials movements and waiting times. Moreover, the actions were evaluated through a DES model, which allowed analysis regarding production planning and equipment changes. In addition, considering production planning analysis, we integrated DES model with a hierarchical approach based on well-known techniques, the Moore-Hodgson and Generic Algorithms.

In order to test the proposed approach, we applied it in a textile manufacturing plant located in Brazil. In this case, it is a medium-sized plant focused on Raffia packaging manufacturing. Moreover, to guide this work, we proposed a three stages implementation. The first one, “Objectives and scope definition”, was proposed since implementing improvements at all process stages is impractical. We used the VSM to define the most critical process and then the objectives were set following Lean principles to mitigate the wastes. In this case, we identified the family 2 process as the most critical one and both the lamination and printing processes were selected for the improvements.

The second stage, “Actions Implementation”, involved modelling the selected processes using DES to create accurate virtual representations for decision-making, encompassing data collection, modelling, verification, and validation steps. Moreover, our approach integrated the DES model with the Moore-Hodgson algorithm and GA, to simulate scenarios and optimize decisions. This study also incorporated changes in the production line such as the inclusion of new equipment focusing on improvement of material handling and setup activities.

Finally, the results were evaluated through several key indicators. For the analysis, we proposed different operational scenarios, as evidenced by experiments conducted in scenarios 1 to 5 of the research. Results indicated that the implementation of various strategies, such as additional material handling teams and the introduction of new equipment impacted operational efficiency, significantly increasing the volume of manufactured products without compromising delivery deadlines.

It is possible to observe how the proposed improvement measures not only contribute to the literature in operations management but also promote advanced practices in process optimization and supply chain management. This approach reinforces the importance of integrating advanced technologies, such as simulation and optimization algorithms, in modern operations management to achieve efficiency, sustainability, and competitiveness. Finally, we highlight that the proposed approach is in line with the Industry 4.0 principles since it was configured to allow continuous updates of the DES model, acting as a Digital Twin model.

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