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ORIGINAL ARTICLE

Integrating value stream mapping and discrete events simulation as decision making tools in operation management

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Abstract Focusing on competitiveness, many companies seek methodologies in order to increase the productive performance. Process optimization focused on quality, productivity improvement, and cost reduction tools has excelled in industrial environments based on the results achieved by many companies. However, the lack of a production simulation system to evaluate advanced scenarios does not effectively address numerous solutions. As a result, this paper aimed to apply the value stream mapping (VSM) and discrete events simulation as decision-making tools to direct the management invest in the best option among the available scenarios generated by simulation system. The analysis was realized in a manufacturing cell part of a Brazil's metal industry that needs to increase the production capacity in a context of high fluctuation of demand. The results showed the efficiency of VSM and simulation integration as decision making tools. It was possible to display a table with all data sets for both current and future scenarios. From process data, it was possible to calculate the production, unit cost for each piece produced, investment cost, productivity (total of operators), and layout.

Keywords Simulation · Operation management · Value stream mapping · Decision making

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1 Introduction

Global market and increased competitiveness have driven companies to seek methods and tools that make them more competitive and have forced the manufacturing systems to able to react to demand changes. In general, it is necessary somehow to improve the production system through the reduction of time and costs.

In this sense, searching for a structured manufacturing process with low levels of intermediate stocks, higher productivity, and shorter delivery times is the great challenge facing businesses nowadays [1]. In Brazil, the competitive conditions were faced basically through the adoption of rationalization of resources.

In addition to the customers requirements related to quality of products or services, companies pursue competitive advantage in agility production flow. Flexibility has been the key to achieving effective and efficient responses to customers demands [2].

In this context, the lean manufacturing application stands out in the industrial environment. The essence of lean manufacturing involves the efficient use of resources by eliminating waste [3–5].

Alvarez et al. [6] studied the use of value stream mapping (VSM), kanban and milk-run techniques in lean manufacturing implementation on an assembly line and concluded that the combination of lean tools have been a way for routing increased flexibility and process improvement for any industry.

To reduce wastes in a production system, Gurumurthy and Kodali [7] considered the following steps to achieve the lean manufacturing:

- Balancing production line to ensure continuous flow process

- Changing layout to reduce unnecessary employee movement and material transportation
- Cleaning methods and standardization (5S tool) to keep the workplace organized
- Improvement control of parts in stock for inventory reduction
- Manufacturing processes continuous improvement to simplify/combine operations and eliminate unnecessary operations

In order to identify the production system elements, the tool VSM was used. This tool was first used by the car manufacturer Toyota that sought to eliminate waste and ensure a continuous flow of products and information throughout the supply chain [8].

The typical approach proposed by Toyota to improve processes involves (i) identifying a repeatable process to improve, (ii) applying the VSM tool to identify wastes in the current process and a future VSM with wastes removed (method for mapping the process steps and show value-added and non-value added), (iii) implementing changes, and (iv) celebrating success [9].

Despite being efficient in mapping value-added and non-value added activities, VSM is not able to explore and experience the reality of the process. In order to evaluate the changes proposed by VSM, production systems simulations can be used. Simulation has been defined as a computational technique that attempts to develop a mathematical model that best represents the system under study [10].

Han et al. [11] applied a simulation tool to evaluate the manufacturing system after the proposed improvements based on lean manufacturing principles.

Gurumurthy and Kodali [7] designed the current VSM, applied lean manufacturing principles, and process results were improved. Current and future VSM data were compared using a simulation system of production.

Melouk et al. [12] employed simulation to optimize a steel manufacturing process, where the main objective was to reduce costs. Experiments showed the reduction of costs through changes in inventory practices. The simulation allowed evaluating scenarios of improvements to the production system in a short period.

However, the successful application of lean manufacturing, as well as the application of discrete events simulation is associated with the integration of the technical aspects and human factors. Black [13] highlights the importance the right balance between people and technology in the search for competitive advantage. Yang and Yang [14] emphasized, through a survey in Taiwanese Firms manufacturing, the importance of human factors in the successful implementation of lean manufacturing.

In the context of using VSM and simulation as a decision making tool in an industrial environment, this study aimed to apply VSM plus simulation to support managers decision to invest in the best option among different scenarios of production.

This study was realized in a manufacturing system in an enterprise lay in Sao Paulo/Brazil, where managers should make decisions to meet production demand increasing. The production cell has manufactured 30 different part numbers. The manufacturing process was operating normally and scaled to meet a production of 2.332 part numbers/day using 13 operators, 2 cutting machines, and 9 burring workstations comprise by 8 h each.

Two scenarios were proposed in order to meet demand rising. The first one involved increasing resources proportionally, while the second one included performance improvement by changing process technology. In order to use the VSM and simulation in the evaluation of the proposed scenarios, the following method approach presented in Fig. 1 was development basing on Law and Kelton method [10].

First step aimed to characterize the company and the production process to be studied. This characterization involved the description of production flow activities.

Second step included a visit to the production system of the respective company to collect production and information flow data required for current VSM design. These data were composed of customer demand, workstations, operations flow, inventory, finished and in process products in process, cycle time and setup for each operation, and information flow from customer to supplier.

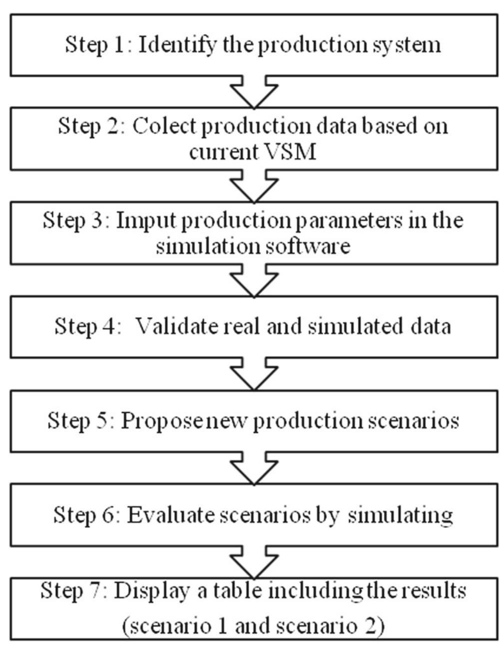

Fig. 1 Research method

Third step consisted in insert VSM data in chosen simulation software. The production system simulation was developed in Tecnomatix Plant Simulation by Siemens PLM Software.

After simulating the production system, in step four, the model was validated by comparing real parameters to the respective simulated parameters. Only adhesion values above 95 % can be considered valid.

Step five proposed new scenarios as investment options. Step 6 simulated these scenarios and evaluates certain production parameters.

Finally, at step 7, simulation results were presented on a table in order to support managers decision. Some parameters were used for this evaluation: parts produced per day (Un.), average unit cost ($), cost of investment ($), number of operators and layout area (m^2).

2 Literature review

The principle of lean manufacturing was first cited by Krafcik [15], but became known worldwide through Ohno [3] in Toyota Production System: Beyond Large-Scale Production and through Womack et al. [4] in The Machine That Changed the World [16, 17]. Womack highlights that lean manufacturing and the Toyota Production System can be considered synonymous.

According to Maleyeff et al. [18], the focus of lean manufacturing has been the reduction of waste using resources available for the production system.

Ohno proposed that the losses present in the production system were classified into seven major groups [3]:

- Overproduction (quantity and early production)
- Waiting (operator, material, or machine)
- Transportation
- Inappropriate processing
- Unnecessary inventory
- Unnecessary motion (operator, material, or machine)
- Defective products resulting in rework

Womack and Jones [19] created a method for implementation of lean manufacturing based in five principles:

1. Identify losses in the process
2. Identify VSM
3. Achievement of flow through the process
4. Pacing by a pull (or Kanban) signal
5. Always pursuit for perfection

VSM has been highlighted when checking out all lean manufacturing tools. The reason has been that it allows mapping of all operations that add or not add value to the process, from raw material to the customer [20]. VSM has been used to create a common basis for the production process and remove all of the wastes as overproduction, waiting, transporting, unnecessary moving times, unnecessary stock, and defective products [21].

In addition to mapping the value stream, using this tool adds knowledge regarding the process and improves VSM level implementations for future [8].

Singh et al. [22] analyzed the available literature on VSM and found that 38 % is published as case studies, 32 % as conceptual work, 24 % as empirical-modeling work, and 6 % as survey articles. It also described VSM as an effective technique for identification and reduction of process wastes. It obtained by a case study an Indian industry improvements of 80.09 % in work in process inventory, 50 % in finished goods inventory, 82.12 % in product lead time, 3.75 % in station cycle time, 6.75 % in change over time, and 16.66 % in manpower required.

Considering the importance of the value stream mapping tools, it has been integrated with other technologies as decision making tools. Tabanli and Ertay [20] analyzed the benefit-cost the integration of VSM and an electronic Kanban System in an automotive industry. The Electronic Kanban system was development based on radio frequency identification (RFID) technology, which uses radio waves to convey the identification information of an object or personal ID, wirelessly. The real-time visibility of the inventory resulted in better decisions about the inventory management.

On the other hand, Gurumurthy and Kodali [7] address the following shortcomings of the VSM: (i) the VSM is a static tool and it shows a picture of the production cell in a particular day. Thus, it tends to vary depending on the situation in which the factory is (on maintenance, including delays, etc); (ii) the VSM future is based on the assertion that all problems will be solved; however, this may not happen in reality; (iii) the targets (values) are estimated and may not be achieved; (iv) changing the VSM drawn by hand is laborious and time consuming.

Accordingly, the discrete events simulation (DES) can be used as a complementary tool to VSM. DES aimed to quantify the gains during the initial planning and evaluation stages, besides being able to define the resources needed and show future process performance [23].

Baykasoglu and Durmusoglu [24] used a DES model, developed in SIMAN, to make decisions about the effects of flexibility on flow time performance in several scenarios in a hypothetical job shop system. The scenarios were composed with four flexibility levels, two different machine selection rule, and three types of dispatching rules.

Greasley [25] showed the advantage of using DES as a tool that reduces decision risk. It was possible to verify the need for improvement in the current manufacturing system before any investment decision in order to meet the requirements of the manufactured product.

Joseph and Sridharan [26] analyzed the performance of a flexible manufacturing system under various level of routing flexibility using a DES model to describe the operation of the chosen the system.

Marvel and Standridge [27] justified the use of discrete event simulation in the design of lean manufacturing. The authors highlighted the shortcomings of a lean project and showed how simulation helps to overcome these deficiencies.

Renna and Ambrico [28] used a discrete event simulation developed by Rockwell Arena to investigate the performance of classical cellular manufacturing system (CCMS) compared to fractal cell (FCMS) and remainder cells (RCMS). For CCMS, parts arrive in the system and each family has its own cell competence. For FCMS, the work is based on the *N* identical cells and for RCMS, there are *N* cell for *N* product families. The work was conducted with demand fluctuations in terms of volume and in terms of type of products required.

Renna [29], in other study, proposed a multi-agent architecture build in a discrete event simulation environment developed in ARENA® package for the capacity reconfiguration problem in a reconfigurable manufacturing systems. The simulations were conducted in several demand scenarios to test the approach in a static and dynamic context. The results showed that the proposed approach leads to similar performance to flexible manufacturing system.

Although there are many production systems simulations, they all have the same goal: providing the operation management the more reliable analysis of data involved in the process.

3 Discussion and results

For Brazil's companies, high fluctuation of demand has contributed to making decisions about manufacturing process optimization considering the characteristics of flexibility and agility together with quality, productivity, and cost. Thus, the case study presented in this paper has the challenge to find a better decision to adjust the production to a new increase demand. The increase was from the quantity of 2137 parts to 4000 parts per day (87.2 %).

After visiting the company under study, the current VSM was detailed as showed in Fig. 2.

VSM shows that product flow is composed by four operations: load bars in the oxi-cutting machine (Load); cutting (CutBar); unload parts (Unload), and deburring. The load and unload cycle time is constant, respectively, 120 and 5 s. The cutting and deburring cycle time presented fluctuation as shown in Table 1. For mapping, this fluctuation were used the production of 30 parts.

From Fig. 2, it was possible to find out some characteristics of the process under study:

– Takt time value was 35.0 s and referred to the need for assembly line, which was considered the customer and used the quantity of pieces per day

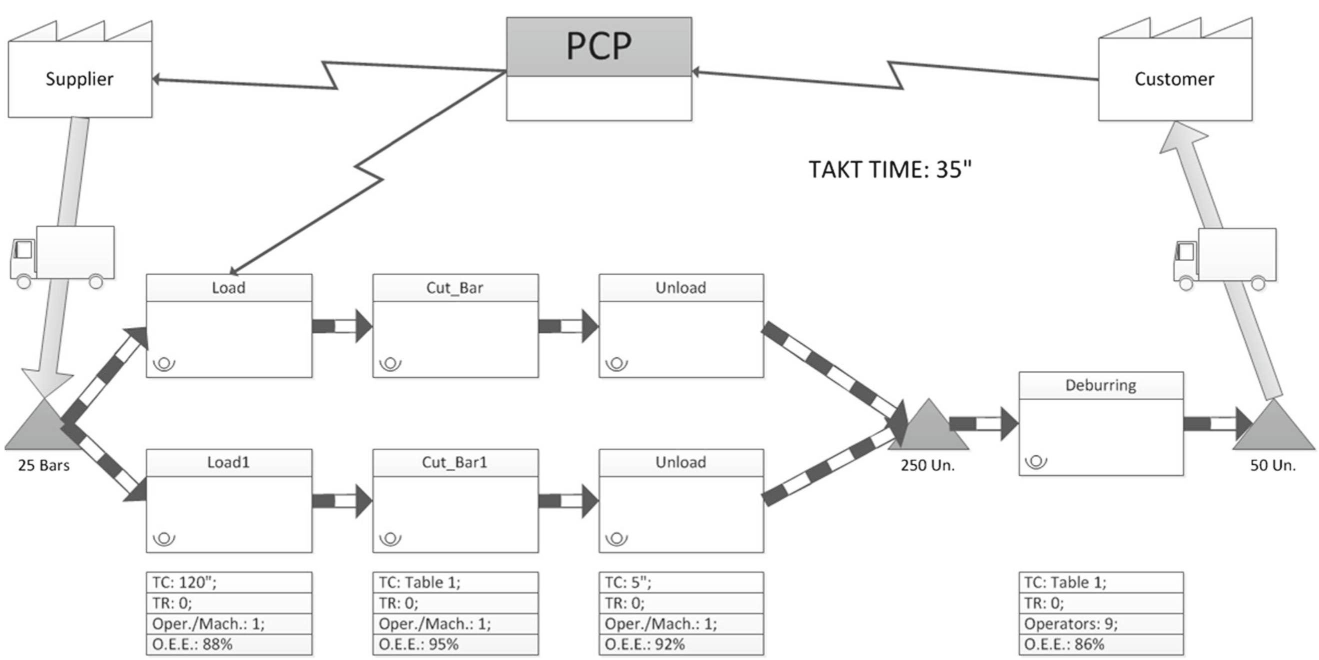

Fig. 2 Current value steam mapping

Table 1 Cutting and deburring cycle time (s)

Part	Cutting	Burring	Part	Cutting	Burring
1	35.25	252	16	27.75	215
2	41.25	220	17	31.50	220
3	39.00	301	18	33.00	225
4	41.25	310	19	33.00	225
5	36.00	255	20	32.25	235
6	39.00	301	21	41.25	312
7	39.00	300	22	41.25	307
8	40.50	302	23	41.25	309
9	27.75	220	24	29.25	225
10	33.75	230	25	39.00	301
11	32.25	227	26	41.25	295
12	36.00	257	27	39.00	287
13	39.00	305	28	35.25	256
14	39.00	303	29	31.50	289
15	40.50	302	30	33.75	280

– Two oxy-cutting machines and nine deburring workstations in parallel were needed to achieve the takt time
– Thirteen operators are needed working for each shift
– VSM was calculated considering 21 h working per day.

Due to increasing demand for parts used by the customer, it was necessary to identify new production scenarios as options for managers to invest.

Table 2 Real and virtual system comparison

	Production in real system	Production in virtual system	Systems adhesion
30 days producing	51298 (units)	51940 (units)	98.76 %
365 days producing	615582 (units)	621615 (units)	99.02 %

Two production scenarios were proposed to meet the new demand:

– Scenario 1: increasing current resources proportionally
– Scenario 2: performance improvement by changing process technology

All the new technologies data were obtained from the manufacturer visiting companies that are already using this solution. On this study, simulation has the target to compare both scenarios—current and future—supporting decision making by managers for investment.

Data collected from process state (current and future VSM) were charged in Plant Simulation software for simulations and comparison between both. Manufactured parts amount was considered in the same period as primary evaluation criterion to both proposals, and secondarily but also relevant, manpower resource was considered as a factor analysis for comparison. Figure 3 shows the simulation

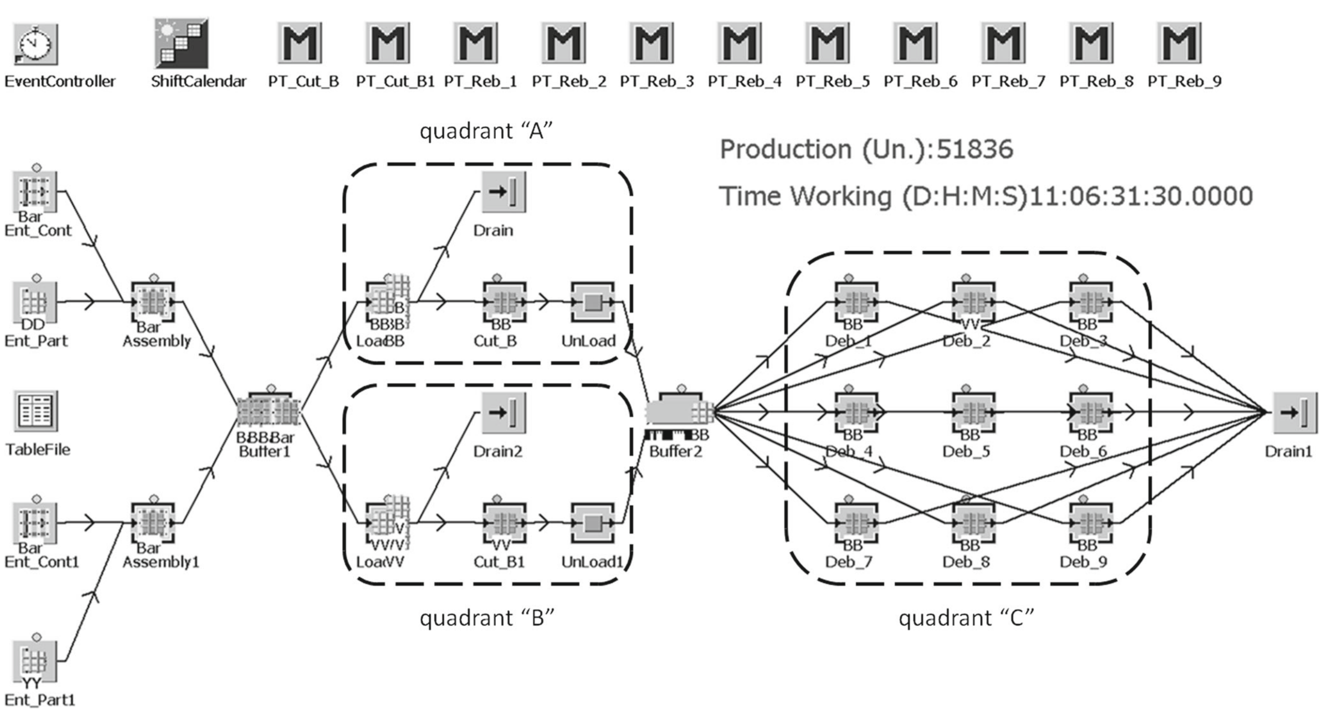

Fig. 3 Discrete-event simulation model

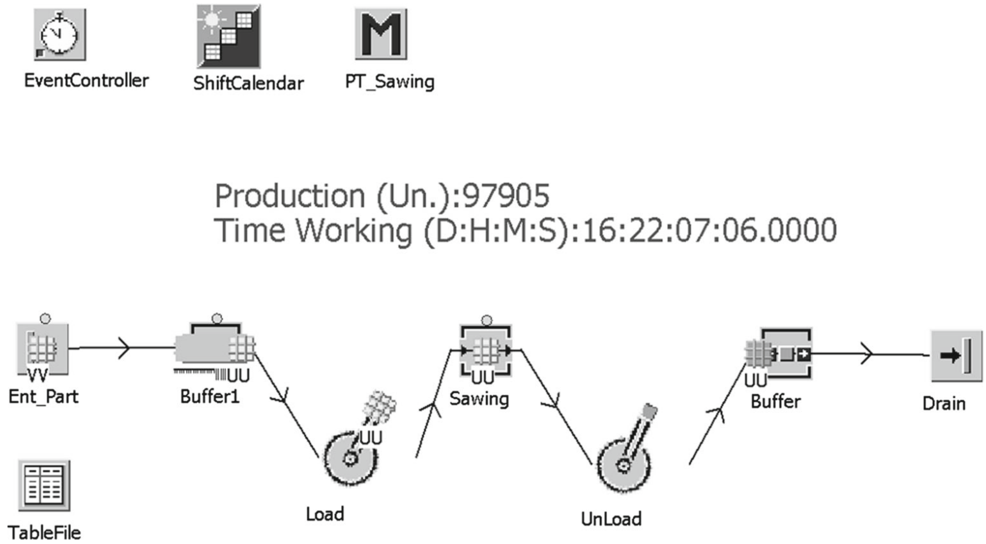

Fig. 4 Scenario 2 process simulation

model constructed to represent current process state. This picture contains three quadrants: A and B represents two workstations during cutting process while quadrant C represents nine deburring workstations plus storage on deburring operation beginning. This diagram allows analyzing the operators movement between both loading and unloading workstations, which was an average of 7 m.

Figure 3 represents a discrete event simulation model for current state, which is related to scenario 1, where current process resources were duplicated to attend the new demand. Comparison between parts quantity produced in a period of 30 to 365 days was performed in an effort to validate the simulation. Table 2 shows adhesion between the real and virtual system.

Adhesion between the real and virtual systems represented 98.76 % considering 30 days of production. When considering 365 days producing, the results represented 99.02 %. From these adhesion values, data provided by the virtual system can be considered reliable, as they are similar to real data.

Figure 4 shows the future model simulation for scenario 2. It is possible to identify only one workstation running, where operators movement is unnecessary during cutting operation. From this new technology, cutting process presents two changes when compared to oxy-cutting: (1) using robots to load and unload parts and (2) elimination of deburring operation, whereas the amount of burr is relatively low in sawing process and even if some burr operation is necessary, operator can execute it during machine time (DMT).

Simulation was based in a period of 30 days worked and all programmed stops (shutdowns) were considered, as weekends and mealtime. Besides these data, machine failure history and refused parts were also considered, thus all relevant variable were involved to the study final outcome.

Figure 5 and Table 3 represents the graphical and production data for scenario 1.

From Fig. 5, it was possible to check out that cutting operation is about 38 % working due to operations of loading and unloading are carried out while the machine is

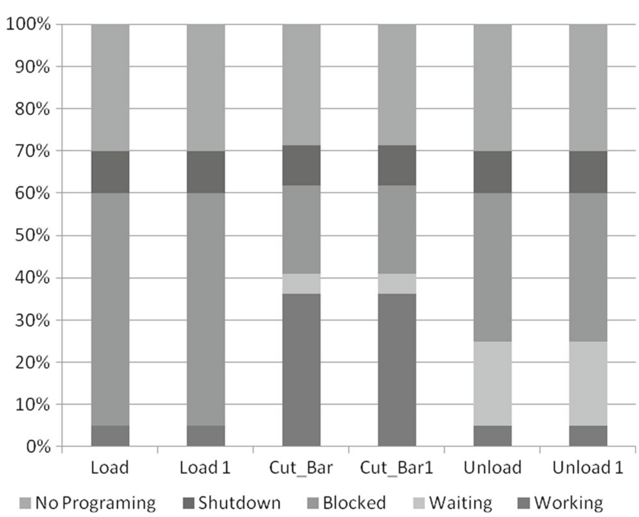

Fig. 5 Scenario 1 graphical representation

Table 3 Production data for scenario 1

Activities	Working	Waiting	Blocked	Shutdown	No programming
Load	5.00 %	0.00 %	55.00 %	10.00 %	30.00 %
Load 1	5.00 %	0.00 %	55.00 %	10.00 %	30.00 %
Cut bar	38.00 %	5.00 %	22.00 %	10.00 %	30.00 %
Cut bar 1	38.00 %	5.00 %	22.00 %	10.00 %	30.00 %
Unload	5.00 %	20.00 %	35.00 %	10.00 %	30.00 %
Unload 1	5.00 %	20.00 %	35.00 %	10.00 %	30.00 %

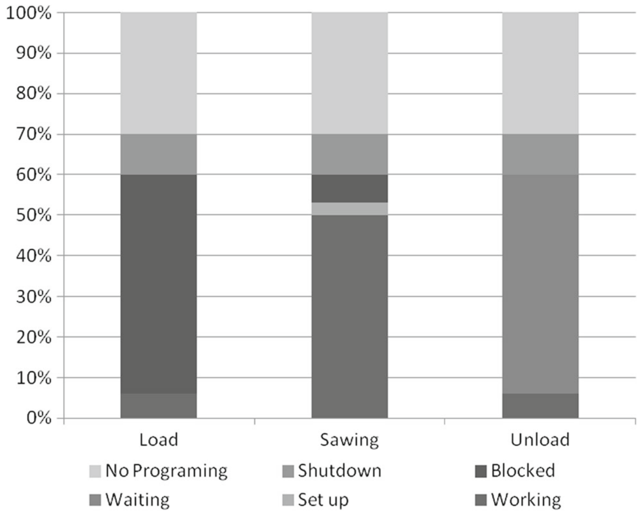

Fig. 6 Scenario 2 graphical representation

off. Both states "No programming and scheduled stop" relate moments when production is not running, whether for holidays and weekends or for daily meals or meetings, respectively. Deburring operation was not represented in current state graph as its not considered a critical operation as a bottleneck.

As scenario 1 considers current resources duplication, it can be concluded that these indicates will be repeated if this option is chosen to meet the new demand.

Figure 6 and Table 4 represents the graphical and production data for scenario 2.

Tables 3 and 4 were used to show the operation status during the discrete-event simulation. It was classified as:

– Working: time (percentage) that the operation was manufacturing
– Setup: time (percentage) that the operation was adjusting the process or machine
– Waiting: time (percentage) that the operation was waiting for the previous operation
– Blocked: time (percentage) that the operation was waiting for the next operation
– Shutdown: time (percentage) that the operation was in a scheduled stop (maintenance or others scheduled activities)
– No programming: time (percentage) that the operation was stopped without scheduled production (weekends and holidays)

Table 5 Current and future scenarios comparison

	Current	Scenario 1	Scenario 2
Parts produced by day	2137	4274	4079
Average unit cost ($)	97.52	92.30	64.47
Investment cost ($)	–	700000	1250000
Total of operators	39	78	12
Layout m^2	168	284	155

Figure 6 showed the graphical representation for scenario 2 and demonstrated increasing percentage value for in process time and reduced of blocked and waiting activities. This is due to load and unload operations running parallel with cutting machine, as these operations are executed by automatic manipulators.

Simulation of these three scenarios enabled to develop a table with all the results. These data will be used to support managers decision on acquisition of a new technology (scenario 2) or duplication of the production line (scenario 1). From process data, it was possible to calculate the production, unit cost for each piece produced, investment cost, productivity (total of operators), and layout. Results related to current and future scenarios are presented in Table 5.

The scenario 1 presents the lowest cost of investment, the higher cost per unit (in relation to scenario 2), and greater flexibility (production based on the increase of manual work). Scenario 2 presents the largest cost of investment, the lowest cost per unit, the better productivity (12 operators), and less flexibility (production based on the acquisition of new technology).

4 Conclusion

This study aimed to apply the value stream mapping (value stream mapping) and simulation as decision-making tools to direct management to invest in the best option among two scenarios proposed due to increased demand required by the customer.

Using simulation in this study enabled to identify a potential for reducing the risks associated with decision making, especially in situations where large volumes of data are considered. Simulation helped with reliable results that generated a comparative table for future scenarios.

Table 4 Production data for scenario 2

Activities	Working	Setup	Waiting	Blocked	Shutdown	No programming
Load	3.00 %	0.00 %	0.00 %	54.00 %	10.00 %	30.00 %
Sawing	50.00 %	3.00 %	0.00 %	7.00 %	10.00 %	30.00 %
Unload	3.00 %	0.00 %	54.00 %	0.00 %	10.00 %	30.00 %

Tables 3 and 4 showed that the machining operation cut bar and cut bar 1 for scenario 1 and sawing for scenario 2 presented different condition in Working status, respectively, 38, 38, and 50 %. Thus, the sawing operation in scenario 2 presented better efficiency. By the results showed in Table 5, the management may decide which option investing: either double the existing resources (scenario 1) or work applying a new technology (scenario 2). This case study evidenced that the integration of value stream mapping and discrete events simulation tools can be used to quantify the output production variables according to the input production variables, and these information will be used to make decision. However, the final decision depends on technical aspects and human factors.

The effort to develop the discrete event simulation model used was not necessarily lost with the end of the study, and it can still be used to simulate other scenarios in order to evaluate the capacity among other proposals.

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