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Towards Industry Improvement in Manufacturing with DMAIC

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Abstract. Today, the accelerated development of industry 4.0 and the immersion of technologies with the DMAIC methodology, Lean Manufacturing allows higher productivity and continuous improvement of industrial processes. There are countless manufacturing companies, of which very few have invested in technology and methodologies, so they have not been able to prepare themselves to advance at the same pace as the industrial revolution. This research proposes to include improvements in the manufacture of furniture by applying software tools and methodologies such as DMAIC, which consists of combining the application of some tools such as Lean, visual management, and standardized work. As a case study, we applied to the manufacture of furniture; the results indicated that by applying DMAIC and simulation tools, a significant increase in production was achieved, with a decrease in delivery time, in addition to the optimization and reduction of waste. This research can serve as a reference for future studies related to manufacturing processes when applying DMAIC, Lean Manufacturing, and simulation software.

Keywords: DMAIC methodology · Industry 4.0 · Lean manufacturing · Process · Productivity · Simulation · Software

1 Introduction

Currently, small and medium-sized enterprises (SMEs) have become an essential source of employment in the economies of countries, and their contribution is fundamental to generating jobs in a more dynamic and competitive environment [1].

The problems in SMEs have related to the lack of 1) organization in the processes; 2) continuous training; 3) implementation of new technologies; and 4) knowledge of those who lead the organization [2]. A high number of companies vary according to the tasks they perform.

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The term Lean Manufacturing means fat-free [3, 4], so in the Lean industry and service field, it is agility and flexibility. Lean Manufacturing aims to eliminate all activities that do not add value [5], focusing on process improvements and optimization. In this research, we take as a case study, this methodology to apply in the manufacture of metal furniture. This article proposes, through the DMAIC [6] to identify the process to which the study will be focused, to measure the time of the furniture manufacturing cycle, to analyze the problems employing technological tools such as simulators to 1) identify the problems, 2) propose improvements based on the application of reading tools and 3) include control by establishing management indicators.

At each stage of the DMAIC [7], different tools were used to enable the organization to 1) to increase productivity and profitability, 2) to understand the current situation of the organization, 3) to look for the root of the problems, and 4) to propose alternatives for change.

This work proposes a change in the production process of metal furniture, with the immersion of digital technologies within the factories. The development of this field implies a considerable digital transformation in the current production processes. In the industry, all the information concerning the production process is available in real-time and can be simulated with technological tools to 1) reduce production time, 2) optimize quality levels, 3) obtain more considerable cost savings, 4) generate greater security in the processes, 5) achieve more flexible production, 6) achieve a more efficient data flow and 7) achieve greater business competitiveness.

This research can serve as a point of reference for future studies related to the improvement of the production process through the application of DMAIC, Lean Manufacturing, and embedded technology to achieve new ways of organizing the means of production and improving Industry 4.0.

Currently, social distancing [8] and connectivity are vital parameters for reducing COVID-19 infections [9]. Promoting it implies redesigning our abilities, accelerating the future through disruptive technologies, and understanding the strategy of change within Industry 4.0, which implies effective automation.

As future work, we suggest applying this methodology and simulations before the manufacture of any product. Besides, for post coronavirus era offices we suggest 1) applying data science to predict trends and preferences in furniture design, 2) design furniture that optimizes spaces and at the same time apply materials and structures that revolve around health security, 3) create furniture that applies the concept of social distancing.

The rest of the document is structured as follows: Sect. 2 presents studies related to DMAIC, Lean, and Industry 4.0. Section 3 explains the method, case study, and materials used to improve the process in furniture manufacturing. Section 4 discusses the evidence for the results. Finally, Sect. 5 presents the conclusions and possible future work that may emerge from this study.

2 Background

Today, the evolution of consumer areas, the growing demand, and the continuous search for innovation are essential elements in the industrial business model called 4.0 [10],

guided by technological and digital tools. The Industrial Revolution 4.0 [11] has been the central axis to achieve a technological implementation in this sector. In these times of pandemic, the technology, especially artificial intelligence with support in mobile applications helped to control and combat the expansion of COVID-19, as well as [12] the Internet of things, the big data, the robotics, among others, allow processes to be more optimal and efficient to drive higher productivity.

Cost management can drive profitability; because of this, most industries can find some waste to cut. It is important to remember not to cut costs at the expense of the quality of your products and services [13] since it is essential to consider suppliers, finances, and production. It is also vital to check if production processes can be adapted to be more agile, using fewer hours of work or resources to reduce labor costs.

The competition is an essential factor in fostering innovation, promoting best practices, and strategic management decisions. Besides, it enables performance improvements to be driven in various industrial activities, including cost reductions, increases in productivity levels, which involves promoting business efforts [14]. For the development of this research, we propose the following definitions that are part of this article.

Process Management: In the current context of globalization and competitiveness, companies must be more efficient every day and seek to increase profitability. In this sense, process management allows companies to identify how activities are carried out and establish the indicators that are part of a set interrelated with each other [15, 16].

Working Measure: It is the quantitative part of the study of work that indicates the result of the physical effort developed as a function of the time allowed for an operator to complete a specific task, following a regular rhythm, or a predetermined method. The measurement of work is a technique that has the objective of establishing a time standard to control a specific job, conserve resources, and minimize the costs present in it [17].

Lean Manufacturing: It is a management and administration philosophy that was born in Japan with Toyota, the objective of this philosophy is the identification of Mudas (waste), Muri (overload) and Mura (variability), that is, of all those activities that do not add value to production or service processes, and which generate high costs and long response times. Lean is based on four principles 1) long-term philosophy, 2) correct processes, 3) providers and developed personnel, and 4) problem solving [18]. For the application of Lean, tools that fulfill different functions are used, the essential tool is 5's that promote the order and cleanliness of jobs to be more productive [19]. Value Stream Mapping (VSM) [20] helps to map the entire process from the moment the customer places his orders and how the company should organize with suppliers and plan production. This tool helps identify opportunities for improvement. The tools allow us to achieve continuous improvement or known as Kaizen, that seeks to discover opportunities for improvement based on the identification of the root cause of the problems. The Overall equipment effectiveness (OEE) [20] is an indicator that aims to improve productivity by reducing costs by determining the waste present in the process.

DMAIC: It consists of five stages: 1) Define, we limit the objectives to be achieved, and the definition of the object of study. 2) Measure, we collect project performance information. 3) Analyze, we determine the root of the problems once the variables have been identified. 4) Improve, we propose all activities to improve. 5) Control, we support the changes so that the previous stage is maintained over time [7]. We applied the DMAIC

[21] to reduce waste in furniture manufacturing; this methodology can be used to find such dimensional variations. This study has been carried out successfully in a medium-scale industry that has quality management in practice. Six Sigma DMAIC was necessary for the identification and reduction of defects that arose in furniture manufacturing, and we applied to solve the problem of waste and to increase quality.

Industry 4.0: The concept of Industry 4.0 was mentioned for the first time at the 2011 Hannover Fair [22], to put into practice the concept and development of the intelligent factory associated with the fourth industrial revolution, a vision of manufacturing that includes digital technologies with all their processes interconnected through the use of the Internet of Things (IoT), now called the Industrial Internet of Things (IIoT).

Industry 4.0 [10] consists of the digitalization of industrial processes through the interaction of artificial intelligence with machines and the optimization of resources focused on the creation of effective business methodologies.

One of the objectives of this revolution is the union between digital technologies that allow the creation of new markets and the interaction between economic actors.

Industry 4.0 [22] through digitalization and the use of connected platforms allows 1) a capacity of constant adaptation to the demand, 2) serve the client in a more personalized way, 3) provide after-sales service, 4) design, produce and sell products in less time; 5) add services to the physical products, 5) create shorter and more profitable production series, and 6) use the information for analysis from multiple channels and exploit it in real-time.

3 Case Study and Methodology

3.1 Case Study

The case study we apply to an SME in the city of Quito is a small company dedicated to the manufacture of metal furniture, stainless steel showcases, and metal shelves.

4 Methodology

For the development of DMAIC, we carry out an analysis in each phase; we use different tools that allow us to define the process under study, obtain data with the measurement of times and movements and the OEE, analyze the problem, propose improvements to the process and control Using key management indicators, Fig. 1, describes the stages of DMAIC.

Stage 1 - Define: In this stage, we determine the processes to be improved; it begins with the voice of the client, who indicates the expectations, preferences, and comments on a product or service on which the improvement project be defined. In this stage, we use tools such as the Kano model that allowed us to determine the critical points of the client.

Once the client's voice has been captured, we transfer the critical quality points for the selection and establishment of a project charter that mark the beginning of the improvement project.

After determining the product that is the object of this study, we proceed to survey the production process in each of the stages of sub-processes to determine the activities that do not add value. To do this, we use tools such as the SIPOC (Supplier, Input, Process, Output, and Customer) diagram and the use of flow charts that allow us to model the process.

The Pareto diagram is another tool that we use for the selection of the process under study. In this case, it was done based on the units manufactured and the invoicing data, in a period of analysis of six months, this analysis showed that the manufacture of metallic furniture represents 54% of the company's production.

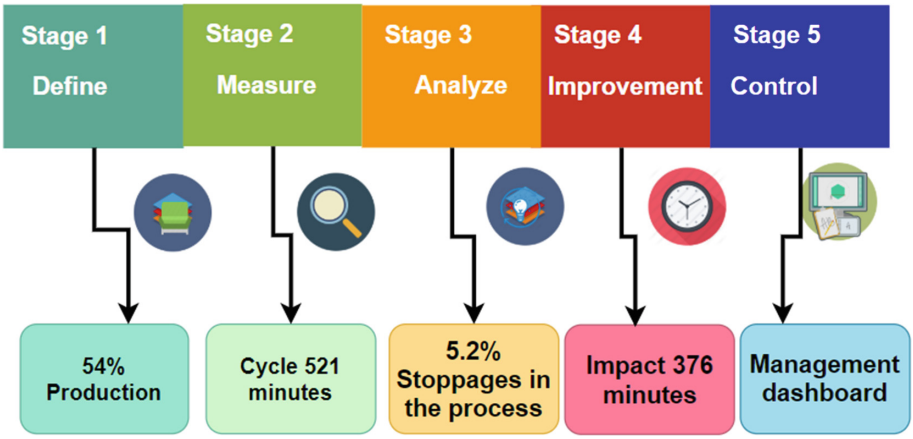

Fig. 1. DMAIC methodology.

Stage 2 - Measure: In this stage, we apply sampling techniques and take the data to analyze it and see the behavior through control charts. Then we make the control chart to understand the stability of the data, in which we identify the causes of the variation.

Besides, the OEE of the process was calculated, the value obtained was 76%, a value that represents an excellent opportunity for improvement, especially in the efficiency, we determined that the production capacity was 20 pieces of furniture based on the set times, considering that the company only makes 16 pieces of furniture on demand.

Table 1 shows include the operation, the description, the minimum time, and the takt. Table 1 presents the times and movements; we determine that the cycle time of a piece of furniture is 521.75 min; in the same way with the thread and flow diagram, we identify that 20% of this time represents the waste and 168 meters of travel.

Stage 3: analysis: At this stage, the EEO analysis, related to availability, indicates that 5.2% represents a percentage of downtime in the process, due to waiting and the nature of manufacturing. At this stage, we determine that the company can manufacture more furniture than the current demand. If demand increases by more than 20 pieces of furniture, the company has delivery problems. Based on the study of times and movements, we carry out the mapping of the value chain (VSM), where improvement opportunities can be identified.

Table 1. Current cycle time furniture production.

Operation	Description	Minimum time	Takt
1	Cut pieces	61.09	512
2	Tracing	15.36	512
3	Blunt	7.87	512
4	Bent	75.96	512
5	Armed	145.67	512
6	Prepared	78.55	512
7	Painted	87.95	512
8	Final enlistment	49.3	512
Total cycle time		521.75	

The generation of waste is the result of the inadequate design of the production plant; this cause can be analyzed with the threading diagram, see Fig. 2.

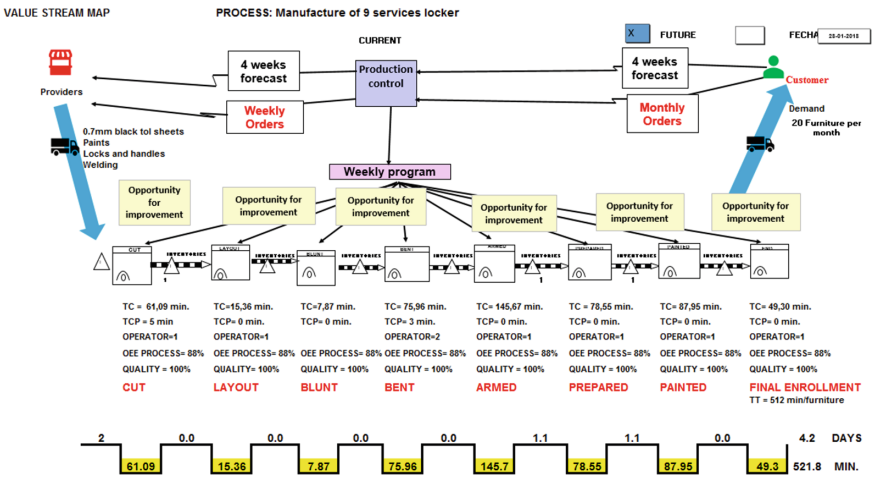

Fig. 2. VSM process

Stage 4 - Improvement: In this stage, we take as a base the root cause found in the previous stage; in this phase, some tools and methodologies can be applied, such as Lean Manufacturing, optimization, process standardization, and software simulations.

In this case study, we apply the tools of Lean Manufacturing and the software FlexSim [23]. Then we start with an implementation approach for the 5'Ss program, said program includes a training plan for the personnel, to subsequently carry out the implementation of

each "S" with the assistance of red cards. To control the OEE, we propose the generation of formats that help control the start of activities and the stoppages generated in the production process.

To reduce waste and manufacturing times, we propose a change in the physical distribution of the machines; this change allows a higher flow to the process. This change added to the improvements of each thread has an impact on the new cycle time, which is now 376.31 min with which the production capacity can be increased to 28 units, the waste times in the proposal are 36.65 min, and the distance traveled is 69 meters, the times are shown in Table 2.

Table 2. Cycle time proposed furniture manufacturing.

Operation	Description	Minimum time	Takt
1	Cut pieces	22.39	512
2	Tracing	13.53	512
3	Blunt	7.46	512
4	Bent	68.70	512
5	Armed	126.17	512
6	Prepared	54.45	512
7	Painted	57.15	512
8	Final enlistment	26.46	512
Total cycle time		**376.31**	

For quality improvement, we apply Poka-Yoke [24] that allows preventing errors at the source before the defect occurs.

With the data obtained, we applied simulations with FlexSim [23], a 3D modeling and simulation analysis software. The FlexSim tool was selected in this case study because it allows: 1) 3D visualization, so each phase of the simulation can be observed. 2) Greater ease of use compared to other simulation software is a friendly and very intuitive software. 3) It is not necessary to be an expert in programming to use the tool. 4) It offers several user levels. 5) All option list-objects make modeling more accessible. 6) Eliminates waste, by analyzing a system with a well-constructed simulation model, you get the relevant data to discover and eliminate waste. 7) Increases usability, allows modification and testing to find the changes that optimize the process, and generate more excellent usability and productivity. 8) Customization in report generation and analysis. One of its limitations is that it is a paid software.

With FlexSim, we transformed the existing data into predictions and obtained the results presented in Fig. 3, we observed that with the new production times, a piece of furniture could be made in the eight working hours, and the second piece of furniture is in process.

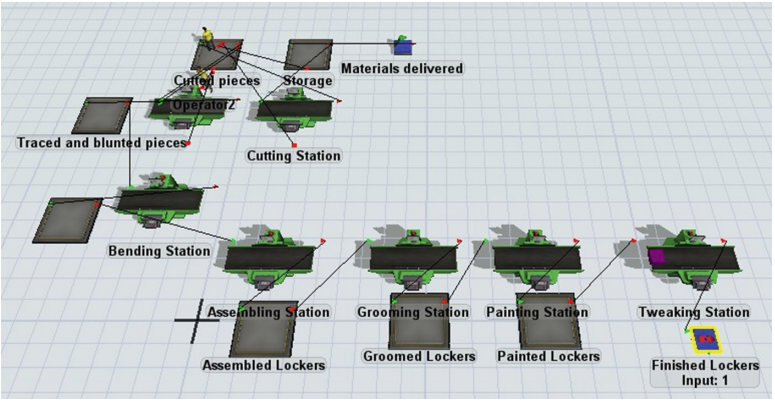

Fig. 3. Simulation of production times with FlexSim

Figure 4 shows that at the end of the working day, the second piece of furniture is in the final preparation process.

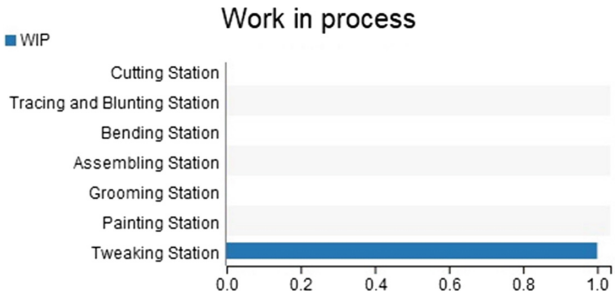

Fig. 4. Final enlistment process

Figure 5 shows that the waste represented in Setup has decreased concerning the current process.

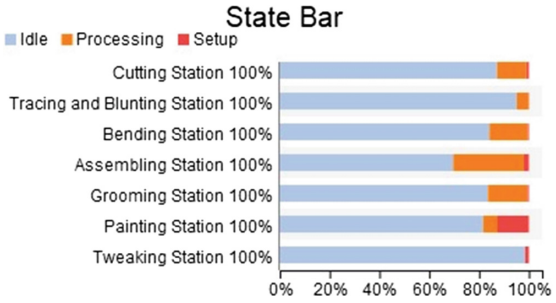

Fig. 5. Current process

Stage 5 - Control: In this stage, we propose management indicators that allow the organization to control the operation; these indicators are based on the activities performed in each previous stage.

To manage the indicators, we suggest the creation of a visual management and administration scorecard that is fed with data collected monthly to allow for continuous improvement in the process cycle. To standardize the new process, we developed standardized worksheets that help in the implementation of the new method.

To generate a culture of order and cleanliness, we designed a checklist that allows the organization to perform periodic audits of the work in the production area.

5 Results and Discussion

With the implementation of Lean tools, the results can be shown in Table 3, indicating the improvements concerning the cycle time of the manufacture of a piece of furniture and the impact on production capacity and productivity. More detail on experimentation and data analysis is available in the Mendeley repository[1].

Table 3. Evaluators' Comments.

Indicator	Current situation	Proposal	% improvement
Partial productivity in relation to the time spent	0.11 furniture/hour	0.16 furniture/hour	45%
Partial labor productivity	5 furniture/operator	7 furniture/operator	57%
Production process time	417.65 min	339.66 min	77.99 min optimization
Waste time	104.11 min	36.36 min	67.76 min optimization
Total standard manufacturing time	521.76 min	376.31 min	145.45 min optimization
Distance traveled in the manufacturing process	168 meters	69 meters	99-meter optimization
Production capacity	20 furniture/month	28 furniture/month	8 pieces of furniture/month representing a 40% improvement

Figure 6 presents a summary of the development, availability, efficiency, and quality of EEO compared to real-time and available. Figure 6 shows the unscheduled stops present in the production process that affect availability. During the analysis phase, some

[1] 10.17632/69wsz4p8n9.1.

interruptions related to the absence of operators and delays in time and movements were identified. As a result, we obtained an availability value of 94.8%.

The efficiency is related to the real production over the theoretical production; that is derived from the capacity that has the company; as a result, we obtained 80%.

The quality is related to defective products or problems that have been identified during the manufacturing process, in this case, no defects were found, so the quality is 100%.

The calculation of the OEE is made by multiplying Availability by Efficiency and Quality, which results in 76%, this result indicates that the process must be improved.

The generation of waste is the result of the inadequate design of the production plant; this problem can be identified by applying an analysis with the yarn diagram.

In the analysis, it is fundamental to determine the problem presented by the company, identifying the root cause of the problem. At this stage, we apply the cause-effect diagram or Ishikawa diagram [25] that shows us the root causes based on the 6 M's (Machinery, Manpower, Management, Money, Materials, Milieu).

In the study applied with the cause-effect diagram, we found that the root causes of the problem are found in the poor physical distribution of the operating space and the lack of technology in machinery used in the manufacturing process.

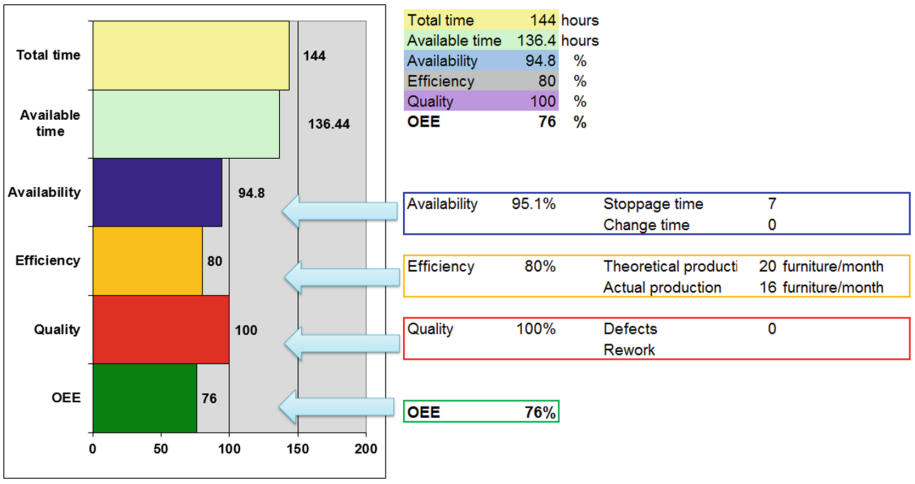

Fig. 6. Preparation of OEE.

6 Conclusions and Future Work

The organizational culture must be global with the inclusion of technological tools that generate a capacity for constant adaptation to the demand and the environment.

This work proposes a change in the furniture manufacturing process by including Lean Manufacturing tools, together with DMAIC methodology and Industry 4.0, through the incorporation of technological tools that promote the development of processes.

We suggest the use of production line simulation software such as FlexSim that allows the simulation of manufacturing processes and the identification of phases in which processes can be optimized and waste reduced.

Simulation tools are innovative tools with predictive technology used to know in advance the behavior of a system under different configurations or operational policies. The methodologies and tools applied can be applied to any type of organization and product, regardless of size, location, or market segmentation. The limitation would be in not committing to change, so it is essential to break the paradigms that organizations have that resist change.

As future work, we suggest: 1) incorporating technology based on Lean Manufacturing in each phase of the process to design, produce, and distribute the products. 2) Store the information generated in databases to analyze and make timely decisions. 3) Apply DMAIC, Lean Six Sigma, and Industry 4.0 in furniture design with the concept of social distancing to avoid COVID-19 infections.

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