Chapter 5
Lean-Sigma as a Strategy in Supply Chain Management During the COVID-19 Pandemic Crisis-Lessons Learned

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Abstract The World-Class Manufacturing Systems were tested for their adaptability and flexibility during the COVID-19 outbreak imposing restrictions and disrupting the supply chains. This chapter describes using Lean-Sigma for three case studies addressing the lessons and critical tools for overcoming uncertainty and challenges in a Latin American facility. Case 1 describes actions for expected sales increasing in a home-improvement product processing. The challenge, in this case, was addressed by using the eight wastes of Lean manufacturing. It is also supported with a layout redistribution and 5S, observing improvements in productivity levels and new technologies upgrading the process connectivity to elements of industry 4.0. Case 2 is a medical product; rapid demand and sales increment is the scenario to decide to adopt a dial-processing system with a robotic arm to automate four activities of the process. Adopted actions increase quality levels by 50% and a more significant efficiency in implementations, which reduces costs from 5.33 to 0.9 IEU/pc taking only two weeks for the ROI. Case 3 shows developments on a new health-related product, using DMADV of DFSS and reengineering as critical strategies for increasing the usability of equipment and resources available in the production area, resulting in a quick ROI and the newcomer successfully introduced to the market.

Keywords COVID-19 · Supply chain · Production system · Productivity

5.1 Introduction

Critical moments in life can show us the level of our strengths and weaknesses, and the reaction time in confronting the unknown can help us in measuring our readiness, adaptability, and flexibility and will help to measure our ability to take advantage of opportunities. During an economic crisis, Enterprises face the same

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challenges, and managers must help the company keep its profitability or balance the effect of a crisis. Forecasting or futuristic vision and experience can help prepare for such critical moments. The management strategies are used to adapt to the market conditions, requiring managers to take advantage of the moment and use the best tools available to make a profit or survive during these periods.

Managers must consider that the faster the response to critical changes, the more profitable the decision. Such considerations have occurred to managers and markets in recent decades, facing a different economic crises, wars, sanction blockades, and political collapses. However, a supply chain total disruption has not been experienced by the markets since the Second World War (WWII). Supply chain disruptions like the ones occurring between 2020 and 2022, with the COVID-19 pandemic crisis, created an instant need for new products (medical supplies) and the lack of demand for other products or services; at the same time, creating restrictions in the supply chain by constraining the export and importation of goods and raw materials, and the disruption of the regional and international transportation systems. During the mentioned period, management strategies were also tested, for their adaptability and flexibility, showing that some succeed better than others in reacting to sudden changes in the market conditions. For the decisionmaker, these conditions were present daily during the COVID-19 pandemic.

During the pandemic period, manufacturers suddenly had to reorganize their work and infrastructure, reviewing departmental layouts to support social distancing while must adapt recent technologies and strategies such as remote work, for managing and making decisions with immediate repercussions on operational and above all, economic efficiency (Ivanov 2021; Ardolino et al. 2022). There were several key factors in achieving a level of profitability, some by taking advantage of the given opportunity: first, the efficiency in using strategic tools to understand the moment; secondly, by understanding the market conditions, the cultural reaction of the society, and how this reality affects the organization. Then, to have the ability to measure the organization's capability to adapt and to use its resources and supply chain strength to take advantage of these conditions. Finally, using the proper engineering tools to adjust production rates and modify the production systems and manufacturing processes.

As in the rest of the dedicated manufacturing regions, the supply chains linked to the Paso del Norte region were immediately shocked after the COVID-19 pandemic. Suppose we consider that most of the operations in this region are close to or final assembly points for many products before entering the USA market or getting distributed worldwide (such as automotive components, medical products, aerospace, and energy supplies). In this context, several disruption points were listed by Ardolino et al. (2022). These include 1. The weakening demand for several types of products (Automobile, public transport, and textile products) 2. Sudden rising demand for strategic products (thermal scanners, ventilators, face masks, sanitizers, PPE, and essential food items) 3. The Failure of supplies due to the lockdown policies, creating uncertainty in the raw material supply 4. Impacting ability to ship and receive products on time due to shortages and logistics bottlenecks 5. Ensuring workforce capacity to assemble and ship products restricted by staff turnover.

The sudden changes occurred later than in China and the other primary components' fabricating regions. The affected supply chain force managers to hold orders and stop the production processes or to face the sudden demand increase for different products. The growth in backorders from the supply chain and the forced acceptance of incoming no longer required raw materials or components (previously ordered and shipped by the vendors) created a jam in the warehouses. However, the efforts to stop the materials no longer needed for products on hold kept arriving from vendors were unsuccessful. The materials from orders in transit continued to fill the warehouses with components and parts no longer required from the supply chain. As the investment continued to pile up in warehouses instead of the production and manufacturing areas for many businesses, it was the leading cause of temporary closures and led to permanent closure for some. All this happened while the production requirements changed daily, and the reaction time to these changes represented the principal reduction of profits and the increment of the logistics chaos. The global supply chain had a specific crisis coming from the very initial links, the COVID-19 outbreak. Due to the growing number of COVID-19 cases, lockdowns, and government-imposed restrictions, particularly in Malaysia and Vietnam, demonstrate the disruption of even the most reliable and well-maintained supply chains (i.e., Automakers) due to simple components such as harnesses and microchips (Bloomberg 2021; Ivanov 2021).

Managers encountered overwhelming requirements for newly essential products and saw some products in the market as customer targets (such as triple layer and KN95 masks, fitness equipment, personal computers, Etc.). The requirements and priority of COVID-19-related products force the supply chain to move materials and resources toward fabricating these products. In some cases, it caused the production systems to respond to exponentially growing demand. In other cases, it forces companies in ventures from exploratory production to create new flag products for their facilities. The requirements for these COVID-19 products increased dramatically, while others lost their importance (school supply equipment, leisure equipment, and several more services). Managers have then to decide on implementing a manufacturing repurposing, decide and define how to use Remote work, how to adapt Workplace redesign and workforce reorganization and create Business models thru innovation and strategic changes (Ivanov 2021). Managers keep observing with chained arms while the abrupt fall of the requirements takes their operations to the ground.

Moreover, the global supply convulsion stopped the general supply chain flow. Many components were kidnapped in warehouses worldwide, stopping further linked production processes and shooting down more of the production of several demanded and essential-needed products. In the best scenario, managers face the reality of lacking or limited resources to fulfill the arriving purchase orders. At the same time, an increased accumulation of on-hold or canceled orders from customers for products with raw materials and components available in the warehouses.

In several cases, there were strenuous efforts to keep the mobilization of components for those few products that kept their production rates. Other measures included using raw materials and equipment available in the stock (for these or other projects), increasing orders to relatively close vendors, or self-subcontracting conditions where the warehouse has available raw materials. Under such a scenario, the short-capitalized Entrepreneur ventures and operations with limited investment buffers suffer to a greater degree than those well-grounded enterprises. Equipment investments and projects were on hold or modified to adapt and react to the COVID-19 pandemic period crisis. Resources increase their value and costs and become less available. Also, if considering the case of complex operations (which requires a lengthy training process and experience), letting go of skilled and experienced personnel was more than an immediate economic loss. It was the loss of longtime investments and losses in the development, havening the entire productive systems in jeopardy.

According to Farooq et al. (2021), the frequency and severity of different disasters like the COVID-19 pandemic and SARS, MERS, AIDS, and others have gained the interest of researchers and scholars because the effects of these outbreaks the economic impacts have been worsening, causing unprecedented losses. All Supply Chains at different levels (local and global) collapse while impacting and disturbing business operations on a large scale. Companies get affected and face challenges in ensuring the logistics and manufacturing operations continuity. The recent epidemic outbreak shows that these events will repeat and will expect to occur as forecasted for the near future. Early detection of major disruptions, the learning of quick responses, and reconnoitering points can increase the readiness for implementing remedial actions and can allow industries to lower the impact of current and future shocks. In their words, the possibility of a near-future outbreak created the urgency to insist on building reliable and sustainable system designs, having fast-responder production systems and a reliable & flexible supply chain to achieve robust operations, and improved logistics for accessing the actual customer. Given the importance of this topic and the supply chain's readiness, this chapter describes the lessons learned from three different case scenarios, portraying the flexible reaction of a managerial group and the critical tools used. Also, it documents the follow-up of the leading strategies and methods used in an operations facility between the beginning of the second quarter of 2020 to the first months of the second quarter of 2022. This period can be considered the main of the COVID-19 outbreak.

5.1.1 Supply Chain Disruptions

A literature review can show that the mainstream of the lessons learned after the COVID-19 pandemic is more related to economic on social aspects; however, the operations and activities related to the production systems remain mainly in the shadow. They are generally discussed through advice or general considerations instead of practical studies or clear examples, as mentioned by Eldem et al. (2022). The same author highlighted that the automotive-industry operations suffered significant losses due to the COVID-19 pandemic. These industries were and still are affected due to their dependence on China's production outcomes. During this pandemic over the last decades, China has been considered the global supply chain center. The shortage of raw materials and spare parts, availability in transportation, availability of labor, and demand fluctuations were not only challenges for the automotive industry but all the members of the intricated global supply chain. The observations described by Eldem et al. (2022) also apply to the three case scenarios exemplified in this chapter and are part of the lessons learned from the COVID-19 pandemic. Demonstrating that flexibility and adopting the best practices are the more reliable way to avoid or mitigate the negligible impact on any business activities.

Four main adaptation strategies can be highlighted: intertwining, scalability, substitution, and repurposing. Moreover, the strategies described by Ivanov (2021) and Ardolino et al. (2022) were used independently as a managerial reaction in the example cases. The three case studies showing the practicality of these strategies as solutions in a manufacturing facility are shown later in this chapter. As previously mentioned, during the COVID-19 pandemic, the different management strategies were also tested for their flexibility and adaptability and to keep the profitability of the production systems. In general, Management strategies show different negative results, having as a common characteristic the reacting time, which was well behind the expected value. Moreover, World Class Manufacturing Strategies (WCMS) such as Lean Manufacturing and Six Sigma were tested for their reaction time and adaptability to sudden changes in the production systems to match the market needs. Even before the COVID-19 pandemic, success rates are reported in the literature at unexpected levels of 40% for Six Sigma projects and 30% for Lean Manufacturing projects (Roser 2017).

During the COVID-19 pandemic outbreak, the WCMS exhibited weaknesses, such as the lack of flexibility and their related managerial strategies. The need for the WCMS for a stable flow in the supply chain and predictable sales make them fail to accommodate during the outbreak reality. Moreover, efforts to move production rates to the proper levels were considered waste. In this way, the main goals of the WCMS were not ready for the sudden changes in the global markets.

As mentioned by Tissir et al. (2020) and primarily discussed by Sarkis et al. (2020), the coronavirus put under question the general strategy of lean management, especially one of the pillars, Just in Time (JIT). The strong relationship and interdependence of the members in the supply chain in JIT have demonstrated its weaknesses. Despite being used to improve efficiency and production flexibility, just in time delivery systems shown to be highly vulnerable to the high operational stress caused by the COVID-19 disruptions.

The Lean Manufacturing strategy's non-readiness can be justified by the Lean manufacturing focus on keeping the flow of the production rates. Failure rates of the Six Sigma methodology were scored mainly by the characteristic emphasis of Six Sigma on the continuous improvement of the production systems. Successful implementations of the Six Sigma methodology require stable production rates to reach their maximum potential. Failure rates of the Six Sigma methodology were scored mainly by the characteristic emphasis of Six Sigma on the continuous improvement of the production systems. Then, because of the unstable conditions expected during any crisis and COVID-19, the successful implementation rates continued to decrease, accounting for many users struggling to react efficiently to the pandemic market conditions.

For example, as described by Bloomberg (2021), Automaker's attempt to be Lean reduces waste, eliminates redundancies, and works with vendors outside the regional hubs. The automakers considered that it is more efficient compared to the opportunity loss worldwide, as is the case of controlling inventory levels to a minimum to reduce waste because of inventory. The COVID-19 pandemic experience has created questions about the managerial and market strategies, our definition of efficiency, the values to prioritize to be efficient in terms of inventory flow, what it means to maintain a minimal inventory, and how to invest in a more resilient approach for the post-pandemic time. By using a convenient tight lead-time, for example, of 6 to 8 weeks with the vendors' Supply chains, the Lean systems proved to have a significant dependency on the supply chain health, and their strength depends on the weakest link in the chain. The pandemic outbreak shows that the WCMS is more vulnerable to external shocks with the described strategy. Then, a redefinition of the term waste in the Lean manufacturing strategy is needed. Furthermore, reevaluating the redundancy concept will be crucial to the future adaptability of WCMS. After the initial analysis, the conclusions remark that every system needs a degree of redundancy to remain resilient to dramatic changes and become more critical if the system faces a near-future crisis (Sharma et al. 2020).

5.1.2 Strategic Approaches for the Supply-Chain Disruptions

It is considering that conditions such as sudden changes in product demand, the lack of or reduced raw materials availability, transportation disruptions, and own resources shortages can create case scenarios for decision-making. These scenarios can be mapped with a decision chart or decision tree, helping the manager prepare to act more efficiently in front of the changes and challenges during a crisis. Using a decision chart during a critical time, the manager can change his mindset from the administration of stable, predictable processes and their decisions to more dynamic or complex conditions, where an adaptable administration is needed to adjust the processing systems.

As seen in Table 5.1, a sales order can be related to a decision chart. The Demand-availability decision chart shown in this Table illustrates how a purchase order comes from the customers; the gathered data sets the base for creating a management action plan. The scenario, when the most straightforward, is the more profitable and most desirable condition, is when the required product has a stable demand. A catalog product is to have the materials, equipment, and resources available, then be able to schedule its production with reasonable rates and produce them with the delivery conditions for reaching the customer warehouse on time. This scenario creates conditions for maximum profit or value added to this production system. For the manager, such conditions fit for using a managerial strategy such as Lean manufacturing and

Table 5.1 Product demand-availability decision chart

Requested product	Catalog product?	Production availability	Delivery conditions	Production rate	Decision
Yes	Yes	Yes	Yes	Stable	Schedule
Yes	Yes	Yes	Yes	Increased	Adjust the production system and Schedule
Yes	Yes	Yes	Yes	Decreased	
Yes	Yes	Yes	Yes	Initial	Design the production system and schedule
Yes	No	Yes	Yes	Increasing	
Yes	No	Yes	Yes	Decreasing	

configuring the production process into an assembly line arrangement with the proper strategic tools to eliminate waste while keeping a stable production flow.

Also, in Table 5.1, other conditions are shown, and a second scenario occurs when it is required to increase or decrease the production rate. The gradual or unexpected reduction in sales reflected in the production orders can be part of the natural or accelerated Ramp-up or Ramp-down in the life cycle of a given product (see Fig. 5.1). The "natural" product lifecycle and behavior can be modified and disrupted by an early decline or an extension in the life cycle of a given product. Figure 5.1a shows the conventional life cycle, compared to Fig. 5.1b, which represents the product lifecycle during the pandemic crisis due to COVID-19 or any other significant disruption. In the case of an abrupt extension in the life cycle of a given product may be the opportunity to use strategies such as the continuous improvement and optimization of the production conditions. However, more significant investments are calculated and expected when the product demand increases if the life cycle extension also increases the product demand to the point that forces investments in manufacturing equipment, labor training, and facilities.

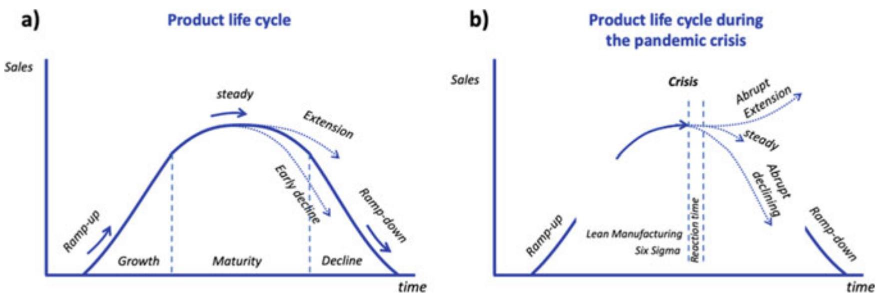

Fig. 5.1 Product life cycle representations of the **a** conventional and **b** modified due to a crisis

Conditions like these can take the production system to an assembly line or a continuous process that requires highly specialized equipment with significant investments, creating a white elephant to comply with the customer's needs (making a financial burden to maintain). Such inconvenience takes resources that can also delay the introduction of new products and investments. On the opposite side, a fast decline or fast Ramp-down creates the sub-utilization of the resources, labor, and equipment, causing a drop in the OEE (Overall Equipment Effectiveness) measurements. Here it is possible to switch to a production system based on group technologies or automated batch production, merging the ramp-downing product with other members of the same family or with similar processing steps.

As previously discussed by Alba-Baena et al. (2020), the use of strategy, activities, and tools helped in the integration, and an automation adaptation was the critical factor for adjusting the production rates while keeping the OEE values as expected. In the case of the COVID-19 scenario, the decrease may be part of the market's reactions to the conditions created. The first action in the production process is to make a Plant redistribution to accommodate more than one product. When the reconfigurations are insufficient, and the decreasing production rate keeps falling over the expected, menacing the system's profitability, it is convenient and appropriate to shift the product to a reconfigurable batch system. Here engineering tools such as DFM, DFA, programmable electromechanical configurations, automation, and robotic systems (or mechatronics systems) help adapt during ramp-down conditions, especially the automated and robotic systems provide an ROI fast enough to catch the production rates and sales profits. If the sales for this product grow or have a later recovery, then the proposed configuration is duplicated to catch up with the increase in sales.

The same actions are to follow in the case of the recovery of the natural climb of a given product. For the case of the natural ramping-down, the steps are to adjust the production rates by reducing production groups as described by Alba-Baena et al. (2020). The last section in Table 5.1 shows the cases when an opportunity presents to invest in a new venture. Some considerations for taking the opportunity include measuring the opportunity loss (OL), ROI, time for R&D, introduction and ramp-up times, forecasted sales behavior, and the production system capabilities. Here the recommended strategy is like the proposal for the ramp-down conditions by pushing to design the production system based on automated and robotic systems. The production system must be flexible enough to grow or contract with the production rates following the sales behavior. Another characteristic of this system is that it has a fast ROI and the advantage of easy readiness for industry 4.0 and its management strategies. Moreover, given the lessons and impacts of the COVID-19 crisis, Kumar et al. (2020) states that this is the right time for industries to adopt and implement industry 4.0 and to invest in digital technologies in manufacturing, to adopt virtual capability-building programs and urgently review of human resources policies for social sustainability.

Other scenarios may include no demand for Catalog products with existing production kits. Then it is necessary to calculate and consider it as passive capital. If there is a sales demand for Catalog products, but there are incomplete production kits, reschedule, place it as backlog, and consider it passive capital. When there is demand for an Opportunity product, but there are Incomplete production kits, it is possible to calculate the stagnant worth and the Expected Opportunity loss (EOL). Also, suppose there is a lack of demand for an Opportunity product with complete production kits. In that case, it is possible to calculate the acquired success of this investment and the distance (positive or negative) to the ROI (return over investment). Also, availability is restricted by programming, maintenance, repairing processes, Labor skills for using this equipment, and layout arrangements. Then, the production capacity can be related to the possible production rates and the inventories, together defining or redefining the production logistics, scheduling, programming, and production outcome. Once the product is ready for dispatch, new challenges are presented, such as local transportation availability, international customs restrictions, international transportation conditions, and the customer's warehousing availability.

5.1.3 Strategies for Overcoming the Supply Chain Commotion

Recent developments show alternative strategies for the decision-making process under restrictive environments to address the described conditions and confront sudden changes in the requirements. With methods and techniques more flexible and adaptable methods and techniques, the use of Lean Sigma as a problem-solving strategy has been used successfully before and during the COVID-19 pandemic. Figure 5.1 shows a schematic of the Lean Sigma strategy, which uses Lean manufacturing and Six Sigma to solve manufacturing process problems. Uses Lean manufacturing tools to solve visible issues, increase efficiency, and eliminate waste. Then, while the problem requires a deeper analysis, this strategy takes advantage of the Six Sigma approach, using more statistical tools and strategic resources to solve costly and complex problems.

As seen in Fig. 5.2, the primary strategy of the Lean-Sigma approach is to use a sequence of tools moving from the lean manufacturing tool kit and starting with the elimination of the eight wastes, using the 5S method, Kanban and other tools. Then, the solution strategy moves to the Six Sigma tool kit as the complexity of the problem rises, and the root cause hides deeper from the analyst's sight. Then, the Lean-Sigma solving methodology helps in reaching the solutions thru the five basic steps: (1) Identify and Measure the problem, (2) conduct a Root Cause Analysis, (3) Solve the problem, (4) Verify the solution, and have a (5) Control plan, see (Estrada-Orantes and Alba-Baena 2014).

Following the same Fig. 5.2, the strategic approach in Lean-Sigma starts with using the E-Strategy to eliminate the common causes, as Estrada-Orantes et al. (2019) proposed, where two phases are involved in this strategy, a diagnostic phase and a solution phase. A quick diagnostic identifies and eliminates common obstacles in keeping the production process flow. Following Fig. 5.3, the fundamental questions

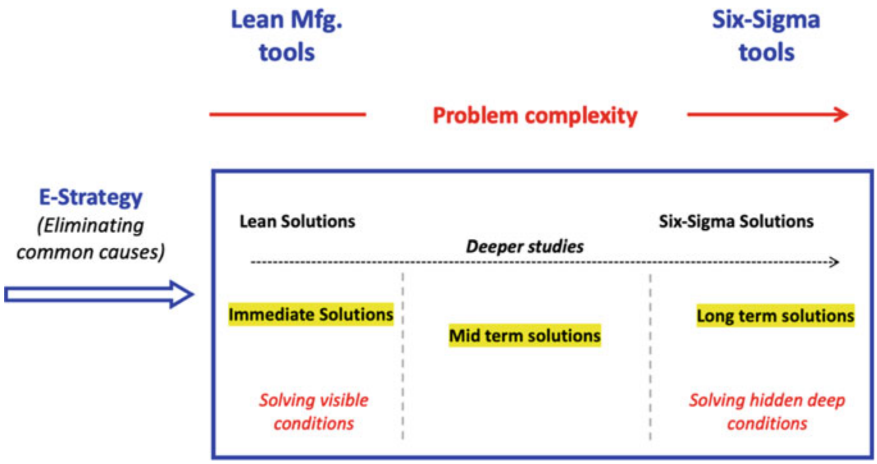

Fig. 5.2 Schematic of the Lean-Sigma strategy

originating from the root cause analysis are as follows: (a) Are prints and drawings correctly defined and used? (b) Are the tools and operating conditions working properly? (c) Is the measuring system correctly used and calibrated? (d) Is the process variation in the expected statistical control? and (e) Is the process capability in the expected values? Moving the sight from the common causes to deeper causes thru more profound analysis and statistical elements, while the solution requires complex analysis. The Lean-Sigma E-Strategy eliminates the "waste of time" and resources by adding them as needed to find a solution.

By eliminating the familiar and straightforward causes, the second phase implements the solution phase of the E-strategy paired with the Lean-Sigma approach. The solution phase includes statements related to the sequence of steps in the Lean Sigma methodology. The first statement is "let the process speak" by gathering data, then "listen to the process" by making a root cause analysis. The third step is to "talk to the process" (by running experiments) and "Find the main factors" affecting the

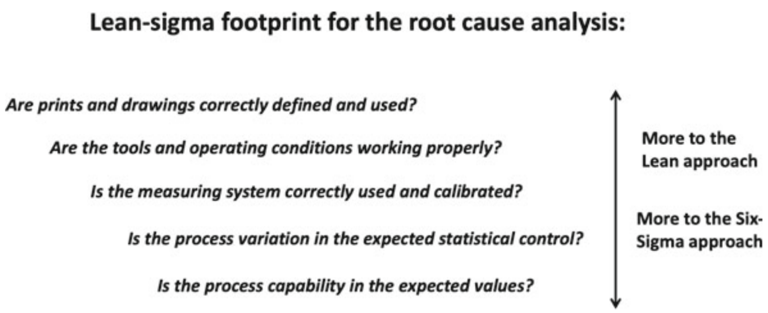

Fig. 5.3 Adapted schematic of the E-strategy tool of Lean-Sigma

conditions of the production process. Step 4 asks the leader to "develop a solution for the main factors" (a DOE, for example), and Step 5 "Validates the solution for the main factors" Finally, it is necessary to "implement the solution and update the action plan."

To describe the scenario of that stressed supply chain is necessary to extend the production-system tracking to include acquiring resources transportation, vendors' warehousing, product delivery transportation, and warehousing at the customer site (see Fig. 5.4). Figure 5.5 shows the decision-making process during this stressed supply chain condition; in the Figure, the decision is to filter and divide the products in manufacturing positions from the catalog and the newcomers as opportunities.

The demand for such products and requirements can be constant as expected, increase because of the new conditions, or the requirements constrained because of the same conditions. The inventory of it is defined (for this chapter) as a set of components, parts, raw materials, and other resources to fabricate a product. Then, these resources constitute "production kits." These may be incomplete due to different conditions such as: being in stock in the company's warehouse, part of the safety stock, the working process, expected arrivals, as placed orders, or the backlog. In parallel, the production capability includes the personnel, equipment, and Management to produce that product. In general, labor and managerial personnel's availability weakness due to absenteeism, health issues, health risks, personnel moving from their regular task to a different one, adjusted working schedule, and inefficiencies due to inexperience or a training and learning process. Equipment availability includes the sequence of machinery and tools for production using the kits.

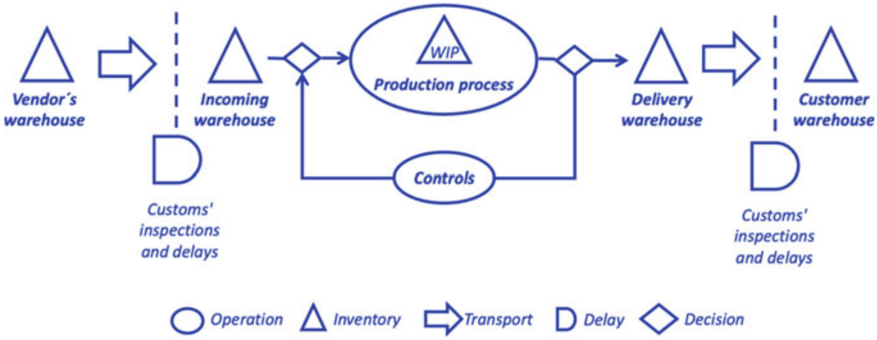

Fig. 5.4 Extended production system

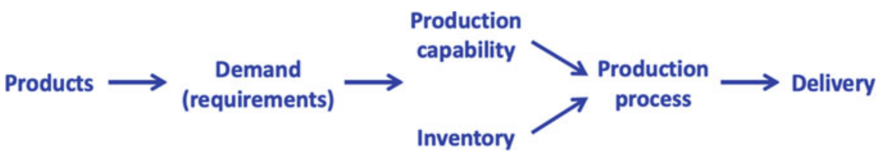

Fig. 5.5 Decision-making process flow

5.2 Case Studies

An American corporation has a facility located in the “Paso del Norte” region, a strategic region that includes Juárez (Mexico), El Paso (Texas, USA), and Las Cruces (NM, USA). A business venue dedicated to the final assembly of several product families related to home improvement and medical products. A key factor for the success of this company is that the administration takes advantage of the experienced local labor, the flexible mentality of the local talent, and the Management. They are willing to adopt different manufacturing strategies and have dynamic and diversified operations. Among such processes, several products these facilities assemble different home improvement products, medical products, and other health-related products. Three case studies and their production processes are selected to describe the different scenarios and approaches for adapting to the COVID-19 pandemic conditions; they represent three different case scenarios occurring during this timelapse. For this report, the COVID-19 pandemic is between the second quarter of 2020 and the third quarter of 2021. From when the first COVID-19 cases were outbreak in Texas, national governments (from Mexico and the USA) announced actions to the time official reports showed a reduction to a minimum of daily deaths and active cases of COVID-19. The cases are examples of products to be fabricated, assuming that the supply chain keeps moving raw materials and components to complete a final product; labor and other resources are also available. Then, to simplify that description of the given cases, for this report, the production rates are correlated to the demand, and sales, considering that a demanded product is fabricated and sold.

5.2.1 Case 1

The first case focuses on a home improvement product assembly from which the graph in Fig. 5.6 shows the tracking of the sales for three quarters before the described pandemic period to the time of this report. The same Figure correlates the events of the pandemic to the market reaction and acceptance of this product. As can be seen, before the second quarter of 2020 (during the pandemic period beginning), this product had a stable production rate of 2200 lots/wk. Occurred until the middle of the fourth quarter of 2020, when a slight rise in demand was justified because of the yearend season. However, the increasing rates in product demand and sales for this product continue in a steady growth of 2400/Q for the next three quarters of 2021. As marked in Fig. 5.6, the sales reach peaks above 300% from the base (2200 lots/wk). This dynamic and change created new challenges and opportunities for improvement and made this production system more efficient. Later, the end of the second quarter of 2021 coincides with the slower drop of sales rate of 700/Q in production and sales of this product occurring up to this report, having moments of sales dropping down to 50% below the expected 2200/wk. In the second quarter of 2020 and after, the pandemic crisis affected the entire supply chain, and these

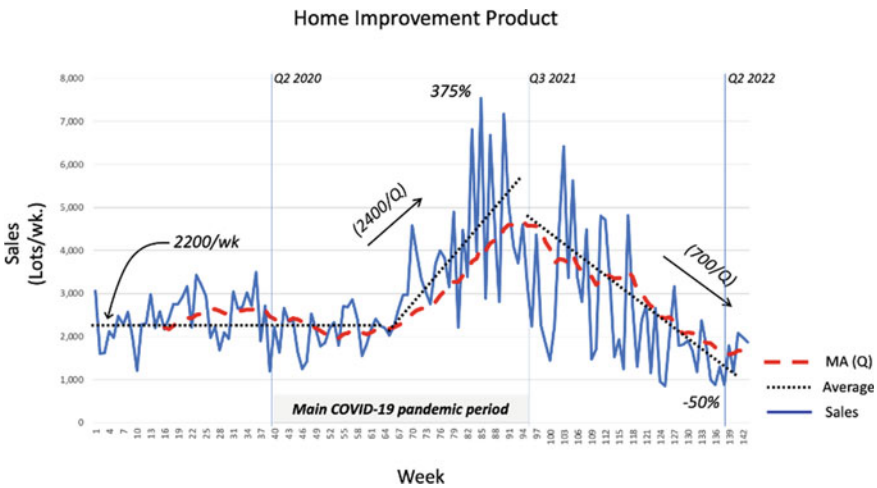

Fig. 5.6 Sales graph for case 1, a home improvement product

facilities faced a shortage of resources, imposed lockdowns, and uncertainty in labor availability and counts. The forecast shows the potential for an increase in sales of this product. By the end of the next quarter, the market will confirm this, and sales will rise at the rates previously mentioned; the Management has two quarters to react to the sales increment.

Considering that the disruptions in the supply chain affect the fabrication of this kind of product, taking advantage of raw materials available because of the disruption in the supply chain of other similar products then mostly overcomes the challenges for keeping sales. At the same time, changes occur during the COVID-19 pandemic crisis. Many conditions and challenges were happening at the same time:

- The less available labor
- The shorter shifts
- The lockdowns
- The piling on the inventory warehouse of unnecessary materials or components
- Abrupt changes in customer-placed orders (cancellation, increment, renegotiation, and others).

The first step in increasing the efficiency of the process is by using the eight wastes of the Lean manufacturing strategy; this is happening by eliminating any observed "waste" or anything that does not add value to the product (or anything that a customer would be willing to pay for).

The eight-wastes approach relates to the activities or strategies used to overcome the described conditions. Figure 5.7 shows the sequence of actions employed as part of the solution for case 1. Following the line of the 8 Wastes of the Lean manufacturing strategy (see Fig. 5.7), it is possible to describe first the "Waste of Over-production" or processing too soon or too much than required is confronted by using tools for reacting

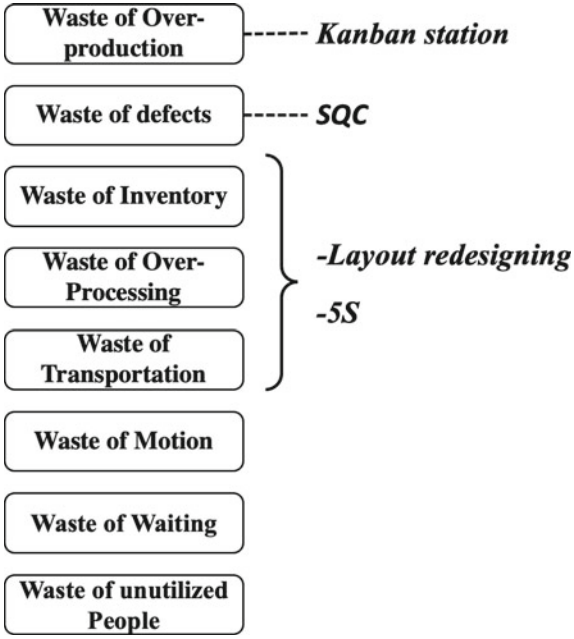

Fig. 5.7 Wastes of the Lean manufacturing strategy

faster to the market requirements. The "Waste of defects," errors, mistakes, and reworks encountered using quality improvement tools. The "Waste of Inventory," or Holding inventory more than required, is the most significant challenge. Warehousing the arriving components and raw materials for the disrupted production schedule is addressed by using the extra cargo containers available to move and select the materials at the warehouse for immediate use.

The "Waste of Over-Processing" became a critical factor in increasing productivity, analyzing the available resources and production activities, rethinking the process flow diagrams and work-in-process flow, and transportation between operations for eliminating or merging activities and wastes in the production processes. Then, actions in eliminating the "Waste of Transportation" and the "Waste of Motion" (Movement of people that does not add value to the product) are the most visible results by redesigning the layout of the production floor (see Fig. 5.8).

During this time, the "Waste of Waiting" among employees and customers is unparallel increased by the government lockdowns, restrictions, and delays at the international borders. Waitings led to less availability of transportation vendors, creating unexpected waiting times in the supply chain; hiring more transportation personnel and merging cargo containers and logistics reduced distribution and negotiation with the customers to help facilitate this waste of waiting. Moreover, "Waste of unutilized People" is the most common waste observation during the COVID-19 pandemic crisis. Due to the shortages of labor availability and production cuts, experienced employees are rearranged from their habitual activities or lose track of their actions by doing Home-Office work or filling up other positions, diminishing their

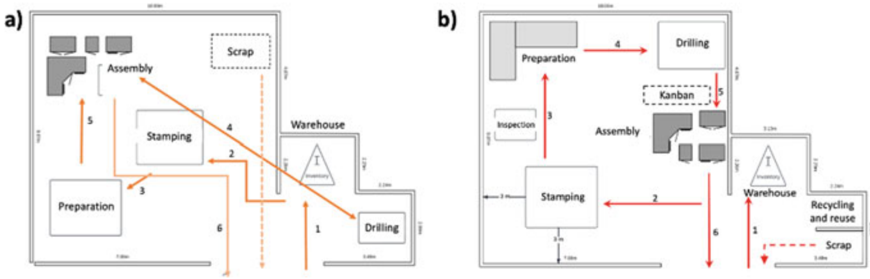

Fig. 5.8 The layout of the fabrication process for a home-improvement product, comparing the flow, **a** before and **b** after changes

outcomes. The human resources team created a series of fast training courses to efficiently adapt the employees to their new roles to address this waste. The IT team also helped create the most efficient communication system to keep all employees updated with the required information for making decisions properly. Also, the management group created scheduled team meetings to keep track of the significant changes in the production processes, the updates in the critical strategic elements, and the tracking of the market behavior and forecasting changes.

Figure 5.8b presents the modifications in the fabrication process for case 1. Where results of the implementation of the eight-wastes elimination and complimenting the described strategy, the team uses the 5S methodology and a Kanban station to complement the logistics control and add an inspection station to ensure quality control and reduce the variability in the quality factors. Figure 5.9 compares activity times for two operations shown in Fig. 5.8, the preparation area and the milling area. In this Figure, the activities are coded and numbered in the sequence of the process activities. Those activities eliminated from the process have an average time of 0.0 s after implementation and waste elimination, as seen for activity prep 6 and Mill 1.

All the activities show a reduced time (i.e., see prep 2 or 4 in Fig. 5.9a) or an increment (examples of this are Mill 2 or 5 in Fig. 5.9b) depending on the arrangement in the reconfigured layout. The resultant 51 and 54% increment in the productivity rates in these two operations outcomes is an increment of 25% in the total process productivity. After the implementation, several results are listed and highlighted; for example, the average production rate of 2200 lots per week barely satisfies the sales in the first quarter of 2020. however, after the implementation, the production time reduces by 25%. To make the production process more efficient and to be ready for the increase in sales, a robotic XY table (from a different project.) is adapted to be part of the preparation area and paired with waterjet equipment to increase the production rate.

Based on the average production rate at bottleneck operation (the "Preparation" area totals in Fig. 5.9), the productivity increases by 200%, and average sales for the first two quarters of the pandemic crisis can be satisfied with the active labor of 1.5 shifts/wk instead of the initial three working shifts/wk. Then to be ready for the expected Yearend sales and the quick sales rate increase in 2021. As a result, these a)

Wastes elimination in: Preparation area		
	Average Time (seconds/lot)	
Actiiviity	Initial	After
Prep 1	23.6	3.7
Prep 2	5.9	5.4
Prep 3	5.7	5.7
Prep 4	20.3	12.4
Prep 5	49.8	49.9
Prep 6	11.8	0.0
Prep 7	11.4	14.9
Prep 8 (transp)	63.7	2.1
Totals	**192.2**	**94.1**

b)

Wastes elimination in: Milling area		
	Average Time (seconds/lot)	
Actiiviity	Initial	After
Mill 1	35.5	0.0
Mill 2	0.6	39.9
Mill 3	8.4	1.0
Mill 4	10.2	7.6
Mill 5	1.5	11.7
Mill 6	22.8	1.5
Mill 7	27.9	22.8
Mill 8 (Transp)	80.9	1.1
Totals	**187.8**	**85.5**

Fig. 5.9 Comparison between the initial times and after waste elimination of the **a** preparation and **b** milling areas

actions created the flexibility and readiness to comply with the average sales of 4300 lots per week. Production rate is expected and required from the beginning of Q4 2020 to the end of Q2 2021. with the capability to be contracted easily to one shift to fulfill the sales requirements of the current year in an average of 1700 Lots/wk.

5.2.2 Case 2

The second case is a medical product which is one of the flagships of these facilities and has a production rate of 61,000 pieces per week before the second quarter of 2020 (see Fig. 5.10). During the pandemic period (as expected), the demand and sales increased dramatically at a rate of 13,000 per quarter, reaching a production rate above 200% of the regular weekly rates before the pandemic period.

A sudden drop in sales happened after the third quarter of 2021 (130,000/Q), attributed to different factors: relaxed COVID-19 measures, market saturation, general supply chain recovery, and new competitors or competitors' recovery. The drop in sales reaches levels close to 60% below the base weekly production rates; after one quarter, the sales recovered to 49,000 per week at the time of this report. Let us briefly forecast the rapid increase in production demand for this medical product, and some preventive actions were in place during the rampage of customer demands. Initial studies show that waste elimination and improvements were not enough to comply with the customer's needs, deciding to design and install an automated process. Figure 5.11 shows the schematic of the production process before and after the implementation. Figure 5.11a shows the assembly process of the main component, where a moving band takes the different pieces between four operators sequenced to integrate and deliver the main component at a production rate of

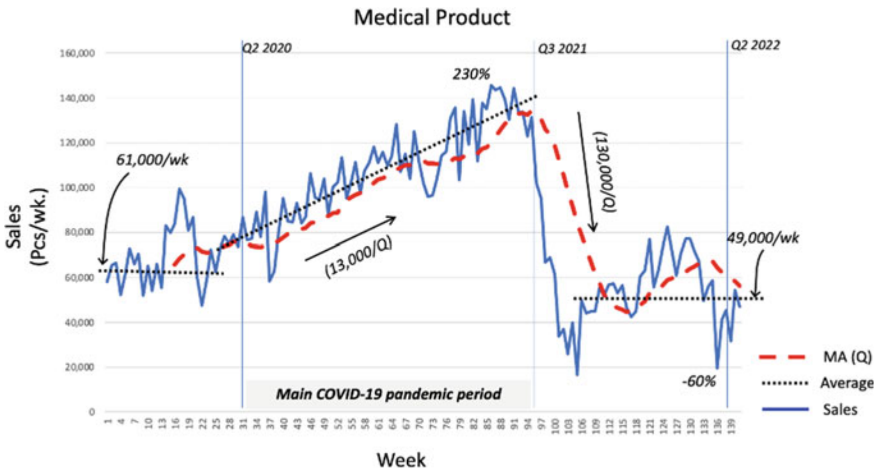

Fig. 5.10 Weekly sales chart for case 2, a medical product

550 pieces per hour, having a quality level measured with a Cpk of 1.56. Then the component is transported in batches to the next step in the final product assembly line.

On the other hand, Fig. 5.11b displays a schematic of the implemented component assembly process, which uses a dial processing system coupled to a robotic arm to automate and perform the four integration activities of the main component. Besides this, an operator helps the input and output of the pieces and components, two-thirds reducing the used space. The transportation time reduces the piece assembly process's total time and the delivery of the final product.

The implementation's production rates move to an average of 1500 pieces per hour, with the quality levels measured in terms of process capability in a Cpk of 2.07. Finally, Case 2 shows the results of selecting a strategic technology to increase productivity rates from 550 to 1200 pcs/h., Also, as seen in Fig. 5.12b, the quality levels increased by 50%, reaching a statistical Cpk value of 2.07. the overall performance on the main quality factor measures centered on the target value, and the

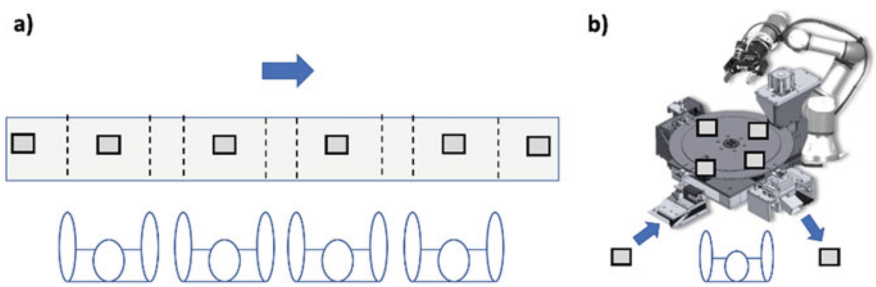

Fig. 5.11 Schematic of a change in the production process implemented for case 2

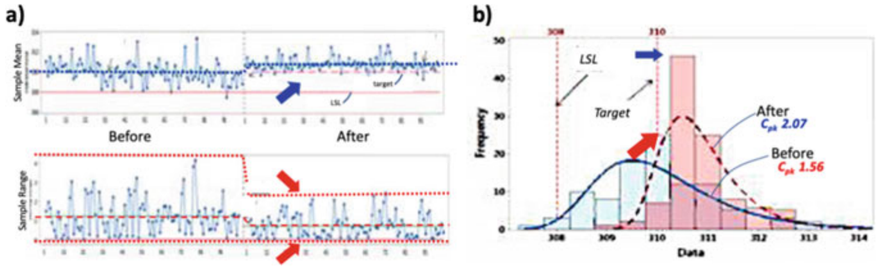

Fig. 5.12 Principal quality values before and after implementations in case 2

variability reduces (Fig. 5.12a, top graph). as seen in the same Fig. 5.12a lower graph. Because of this readiness and the efficient, quick implementations, the operational cost reduces from 5.33 to 0.9 IEU/pc (IEU, Internal Economic Units), having a successful ROI of two weeks.

5.2.3 Case 3

The pandemic also created opportunities for introducing and developing new products, exploring new ventures, and increasing the usability of the equipment and resources available. For production purposes, a health-related product is proposed and studied. A market study with a customer expectations survey is analyzed and used to determine the feasibility of this product. Due to the uncertainty of the COVID-19 pandemic period length, other considerations such as the expected product life cycle length (based on the predicted pandemic time), time for the return on investment (ROI, as quick as possible), and opportunity loss (OL, based on the time to reach the market) were key factors in the decision process. Figure 5.13 shows the development and ramp-up of this product compared to the main COVID-19 pandemic period; two quarters were required and needed to develop the new product, test the production capabilities in the facilities before the introduction to the market and ramp up the behavior of this health-related product.

Because the sales of this product were predicted and calculated during the COVID-19 pandemic, the product will have a short lifecycle with a quick return on investment. For such an initiative, the Management took advantage of the flexibility of that production system by merging this product in the production process of other family members and taking advantage of that demand reduction in other products in the same product family. After using Design for Six Sigma methodologies (DFSS), and for decades now, different companies have reported several benefits in their launched products: Reduced time to market for new or revised products, Reduced life cycle costs, an increased understanding of customers' expectations, Reduced design changes and enhanced quality and reliability among others (Antony 2002). In general, DFSS may include different solving sequences, all adapted for kinds of needs

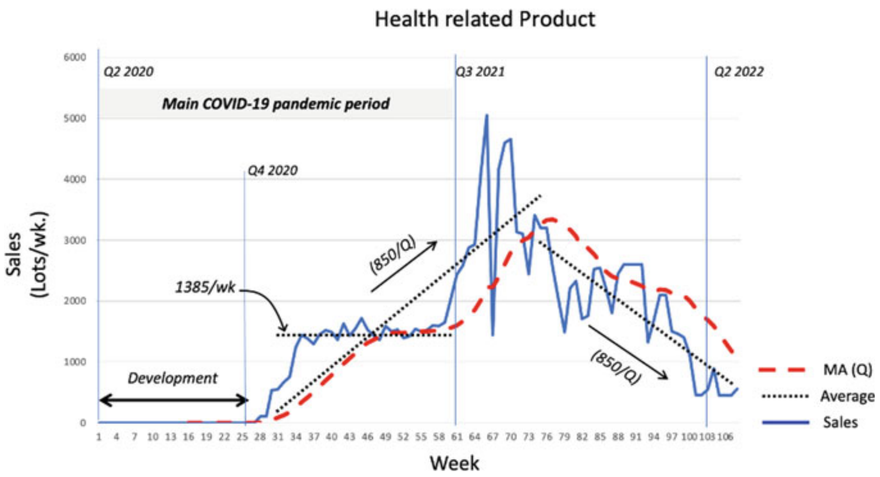

Fig. 5.13 Weekly sales chart for case 3, a health-related product

DMADV (Define, Measure, Analyze, Design, Verify), DCCDI (Define Customer and Concept, Design, Implement), IDOV (Identity, Design, Optimize, Verify and others.

All the methodologies seem to have in common that they all focus on fully understanding the customer's needs and applying this information to the product and process design, then following phases to design or redesign a product. In this case, the DMADV is the strategy used (see Fig. 5.14): In the first phase, "Define," the key goal is to organize the available resources, customer information, and market forecasting projections for defining the product design project. For this, a -Project Charter- is an efficient tool to use and organize the defined, measurable targets, such as goals for improved revenue, customer satisfaction or market share, business expectations, measurable gaps, timelines, and budgets. Also, this phase helps to prepare a -Risk Assessment Plan- to forecast the project risks, opportunity losses, and actions to take if any of the risk conditions occur. During the "Measure" phase, it is necessary to understand the customer's needs. Later translate them into design requirements (or "Must Haves" and "Would like"); for this, due to the COVID-19 pandemic restrictions, the primary source for having the required information is historical data and social media customer surveys.

The "Analyze" Phase includes efforts to convert the customer information and product requirements into measurable design performance and functional requirements. During this project, the Quality Function Deployment (QFD) tool was the main driver for the development of the product. However, assessment tools like benchmarking, brainstorming, and market and patent research were vital in successfully analyzing and providing design options. After, a Pugh Matrix was the primary decision-making tool for deciding on the final design to use. After choosing a single concept-level design during the "Design" phase, the design concept adjusts to match a similar process for the same family products by using the DFA (Design for Assembly) tool to adapt the components and fabrication process to operations and equipment in the facilities.

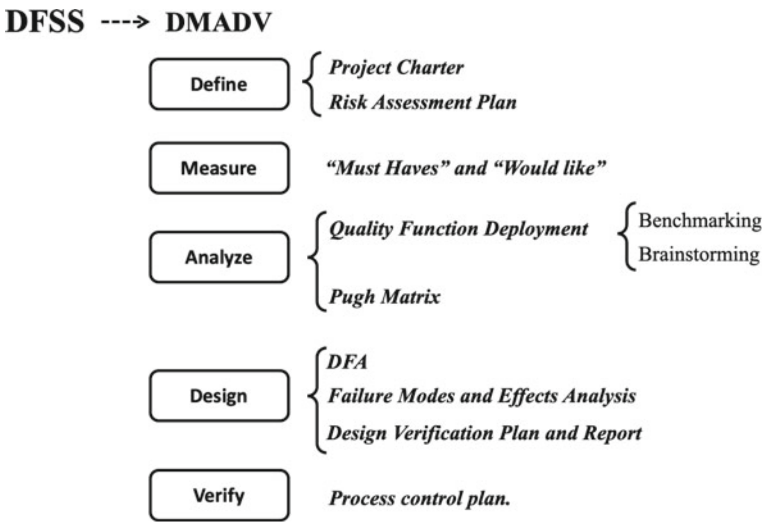

Fig. 5.14 Schematic of the use of the DFSS method DMADV

After several reviewing steps for evaluating the product through prototyping, the product adapts to the primary manufacturing process. Then, by arranging a new preparation area, annexing a molding process, and upgrading the technology used in the sanitization process. By taking advantage of the equipment and resources used in assembling a similar family health-related product (on hold because of the lack of some components and requirements), the project team adapted the manufacturing process (see Fig. 5.15). A Failure Modes and Effects Analysis (FMEA) is included as part of this step to identify the key characteristics, list of responding actions, match the potential design risks, and evaluate the main product characteristics in the quality control inspection station. Finally, a Design Verification Plan and Report (DVP&R) helps create the validation plan, including a statistical comparison through a statistical hypothesis testing process. The "Verification" phase includes running pilot trials and, with the results adjusting the product design and the manufacturing process modifications, measuring the critical aspects in productivity and quality levels. The documentation is wrapped-up with the process control plan once the expected values for this product and its process are measured and achieved.

Taking advantage of a production process for one member of the family health-related, Fig. 5.15 shows a process chart of part of the production process as it is adjusted and modified for making the new product. The first station of this section (preparation) is not eliminated or substituted in the process layout; however, aside from it being prepared, an alternative "Preparation area" is incorporated into a molding process just before the first assembly step (Assy A, as shown in Fig. 5.15). Also, the same Figure shows the position of the new sanitizing station required during and after the COVID-19 pandemic and the distribution of the five operating workers. Of these, the three workers in operations A, B, and C required a short training for

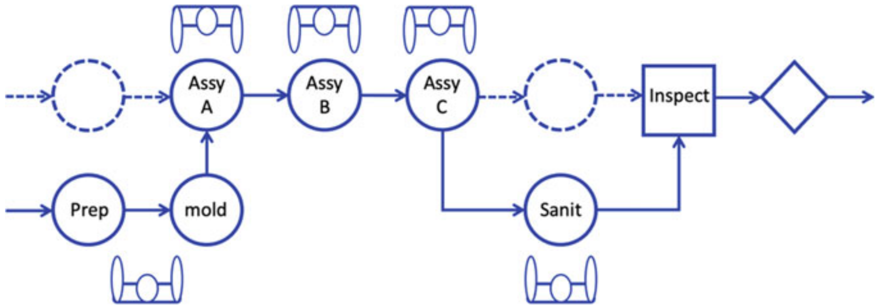

Fig. 5.15 Process chart of the production process in case 3

adapting to the new product and its characteristics. However, the two workers have the most significant adaptation challenge; a study for calculating the learning curve of these two workers is used and shown in Fig. 5.16b. A learning curve is graphed and calculated, showing a performance of around 70% attained after week 10 of continuous production.

This learning curve is also related to that growth rate; Fig. 5.16a shows the selected section of the production rates compared to the linear growth rate during the ramp-up stage of this product. Sixty-five lots per week are the ramp-up rate. Accepting that any of these two steps in the production system are the bottleneck and, without considering restrictions or later bottlenecks in other operations, the predicted equation shown in Fig. 5.16a also helps in calculating the maximum performance of this production system or up to the point of the next bottleneck operation-time restriction. Extending the Fig. 5.16a graph to observe the performance of the production rate (sales) for this product from the beginning to the time of this report, Fig. 5.17a shows the product requirements for the same period (See the criteria line). Observing that the maximum requirements were after the third quarter of 2021, followed by two-quarters of diminishing product requirements, wait for the consequent production rates reduction. Once the production system reaches its highest and the product sales reach maturity, warehouse inventory levels also pick the third quarter of 2021.

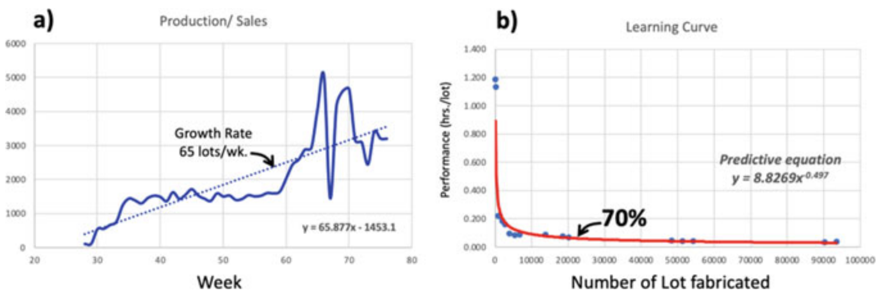

Fig. 5.16 Productivity performance graphs: **a** growth rates and **b** learning curve

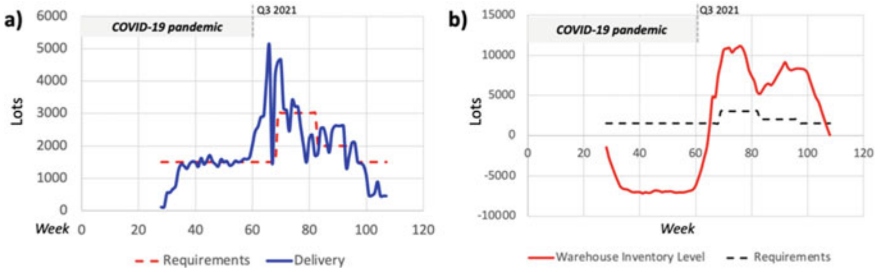

Fig. 5.17 Graphs compare **a** orders to sales and **b** orders to inventory balance

Figure 5.17b shows the inventory level's performance compared to the requirements levels. The lack of Inventory levels created pressure on the production system; however, significant inventory levels are also a problem. Warehousing final products in cargo containers was also a solution for warehousing and an investment problem simultaneously. Parking many containers in both warehouses in Mexico and the USA was a solution up to the first quarter of 2022. At the time of this report, the inventory levels were balanced, reduced to the minimum, and returned to manageable levels. After the third quarter of 2021, the requirements and sales for this product started to diminish to rate levels of 500 lots per week.

Figure 5.18 shows values of the quality performance as measured by the process capability levels of the sanitizing efficiency of the newly installed system (Technology B, see Fig. 5.18b) compared to the previously used equipment (Technology A, see Fig. 5.18a). The setting of the new lower specification limits (LSL) creates the previously mentioned need for new technology in the sanitizing process (refer to Fig. 5.15). The main goal of these changes is to reach quality levels above the LSL, and the graphical comparison shows the improvement; Cpk values make technology robust enough to assure the quality expected.

5.3 Conclusions

Global interdependence creates considerable benefits when the exchanges are free of restrictions; however, disruptions occur because of numberless factors, economic strategies, conflicts, pandemic outbreaks, and more. The frequency and severity of disasters like the COVID-19 pandemic are of interest to researchers and industrials because the trading effects and the economic impacts worsen and cause unprecedented losses. Early detection and quick responses are the keys to increasing readiness: the main priority is the Management and personnel adaptability and the use of flexible systems. Recent events have tested the World's manufacturing systems and strategies used by companies, more specifically, the ones used by the leading players in the supply chains. World-class manufacturing systems reacted to times

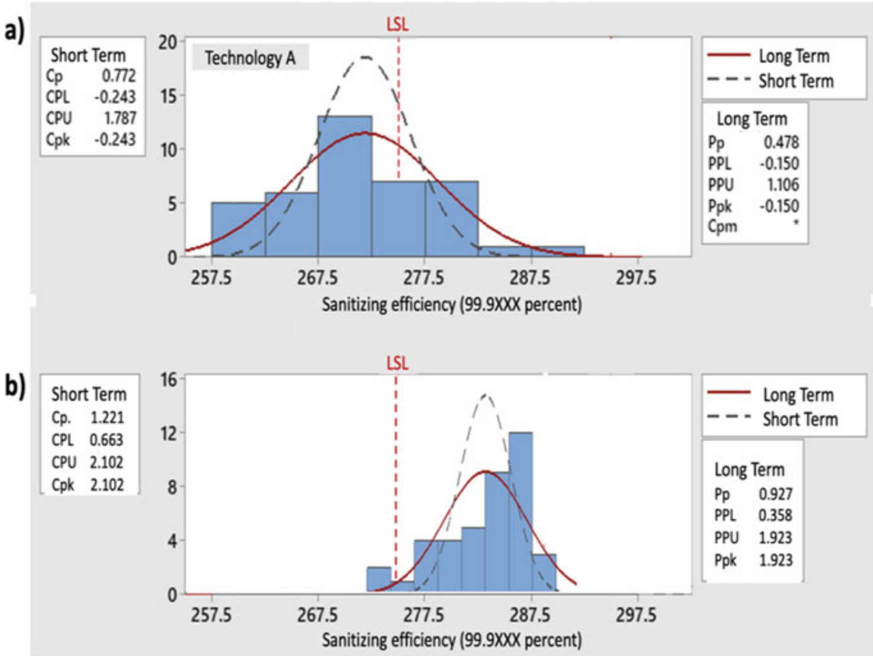

Fig. 5.18 Process capability graphs for the sanitizing operation using **a** technology A and **b** technology B

not as previously conceptualized; systems flexibility and, in general, management strategies could not surf the waves of the shocking pandemic events.

This chapter included the use of Lean Sigma and the results of testing it during the COVID-19 outbreak. Three case studies with different perspectives and conditions are described, noticing the use of a flexible set of tools and strategies under the umbrella of Lean Sigma. Each case highlights the use of different techniques and tools; the first uses the 8 Wastes of the Lean manufacturing strategy and other methods, which support the use of 5S, Kanban, and SQC to complement the logistics and quality controls. These implementations delivered the sales requirements and products to the customers. The production system advances into a more flexible configuration. In the second case, a reengineering approach was the base for adapting a dial processing system, coupled with a robotic arm integrated for manual operations in a single station, reaching a statistical Cpk value of 2.07 and an ROI of two weeks. The third case highlights a different approach, using a DFSS method (DMADV) to introduce a new product, taking advantage of the conditions generated by the COVID-19 pandemic and the available resources. The reconfiguration of the available equipment and the use of tools identified to the DMADV (Project Charter, Risk Assessment Plan, QFD, Pugh Matrix, and others) were used with DFA to succeed in a quick ROI and to take advantage of the opportunity.

The measurable results are the buffering of the outbreak's impact, resulting in customer satisfaction and, even more importantly, the trust gained from the personnel, supply chain members, and customers. These representative cases may not validate a success rate for general implementation. The success in ROI and the adaptation to increasing the usability of the on-hand resources created the resilience of the production processes in the studied cases. Moreover, the Lean Sigma strategy as a readiness alternative needs more testing and refining, and more cases are required. However, the described case scenarios have provided acceptable readiness for a manufacturing system. Increases the adaptability of the managers and their teams by using a large set of tools and provides the flexibility of managerial strategies, which are available for better readiness for future crisis scenarios.

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