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Implementing SIX SIGMA - DMAIC in Manufacturing Industry – A Case Study

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ABSTRACT

The objective of this study was to Define, Measure, Analyze, Improve and Control (DMAIC) a process that makes spare parts effectively available in stock room at the Agra Plant. To reach this objective, we defined the problem, collected data using the diagram of Ishikawa to find the causes of the problem, and selected principal causes using the diagram of Pareto. Stock room mess, stock room inaccuracy status and wrong quantity ordered emerged as the principal cause of the frequent part shortages. We then analyzed these causes using the 5 Whys technique. Two root causes emerged: stock room issues and ordering issues. For the improvement phase, we implemented corrective actions to close the gaps observed. To address the stock room issues, we focused on stock room organization and management improvement. To address the ordering issues, we focused actions on improving the process for ordering the right quantity. Running out of supplies is a serious problem, and having an oversupply is a waste of money and space. The Maximum and Minimum (Max/Min) system is a common system for keeping the right amount of supplies and to make sure that you never run out of stock. There are several variations of the Max/Min system and there are also different ways of calculating the maximum, minimum, and order quantity. In some systems, you have to make orders according to a regular schedule, for example once a year or periodically. In others, you are able to order supplies as and when you need to. The results show a decreased averages equipment downtimes, frequencies and MTTR. However, the average equipment MTBF increased significantly. MTBF value is a direct measure of reliability. More the MTBF more is the reliability.

Key words: Ishikawa, Pareto, 5Whys, Six Sigma-DMAIC, Corrective Maintenance, Preventive Maintenance, Criticality, Stock Room Management, Ordering System

1. INTRODUCTION

With increasing competition in the manufacturing environment, companies' efforts to increase production and meet customer demand are more focused on production operations. This leads them to neglect the maintenance of their equipment and facilities. Maintenance is the function to replace or repair machine or equipment in order to restore or prevent breakdowns. There are two fundamental types of maintenance, preventive maintenance and corrective maintenance. For preventive maintenance, the demand for spare parts is predictable. For corrective maintenance, it could lead to production loss due to stock outs. Therefore, spare parts are considered to be one of the most important element of the maintenance function. Spare parts are parts that are stored in the inventory to replace or in support of an existing part in a production asset. Any lack in the spare parts would create unexpected downtime, which leads to lose money [1]. Reference [2] highlighted that a portion of spare parts has slow demand, which leads to unique problems for both forecasting and inventory control. As argued by reference [3], several aspects contribute to make spare parts a complex matter: the high number of parts managed, the presence of uneven demand patterns, the high responsiveness required to downtime costs by customers and the risk of stock obsolescence. According to [4], maintenance services are depending on well-organized inventories of spare parts. According to reference [8], inventory is often categorized into finished goods, Work In Progress (WIP), raw materials and operating supplies or replacement parts. Spare parts form part of the last-mentioned category. According to [9], spare parts constitute a large portion of total inventory in manufacturing companies. Spare parts inventory differ from other common inventory in several ways; mainly in terms of their required function and the inventory policies that govern them [5]. First, the function of spare parts inventory is to assist maintenance staff to restore machines to continue to perform their intended function. Inventory of parts is held as protection against prolonged equipment downtime. Consequently, obsolescence is a problem for those parts which are rarely needed. Secondly, the policies that govern spare parts inventory are different from those which govern WIP and final product inventories. WIP and final product inventories can be increased or decreased by changing production rates and schedules and improving quality. In contrast, spare parts inventory levels are largely a function of how equipment is used and how it is maintained. This is because, unlike other items, spare parts demand is a function of equipment utilization and maintenance [9]. Thirdly, spare parts inventory are more complex than common inventories due to their uneven demand patterns [3]. An item is said to have an uneven demand pattern if the variability is large relative to the mean [6]. When time between demand moments is very long, then demand is said to be intermittent [7]. When intermittence is combined with an inconsistent pattern, demand is said to be uneven. According to reference [8], a well-balanced spare parts inventory system means having in stock exactly what you need, when you need it; thus having not too much, nor too little. Reference [1] agrees and states that the principal objective of inventory control is to achieve a sufficient service level with minimum inventory investment and administration costs. Spare parts management (SPM) is to ensure the availability of spares for maintenance and repairs of the plant and machinery at an optimum cost [10]. For reference [9], spare parts management acts is a strategic portion of the manufacturing sector since the need for spare parts arises whenever components fail, require replacement or repair. The availability of parts has an effect on asset utilization. SPM is dominated by a number of factors. Firstly, the spare parts portfolio contains a large number of items with diverse characteristics that leads to a complex inventory system. Secondly, the demand for spare parts is typically slow and intermittent [11] and [12]. Intermittent demand patterns are characterized by sequences of zero demand observations, interspersed by occasional non-zero demand occurrences, and are therefore very difficult to forecast. Finally, Spare Parts Management requires multidisciplinary decision-making. To address the topic of managing spare parts, reference [7] developed a framework for planning and control of the spare parts supply chain. It can be used by maintenance organizations to increase the efficiency, consistency and sustainability of decisions on how to plan and control spare parts. Companies need to know which and when to make the order and the quantity. Choosing the right spare parts to be in inventory with the right quantity is very important decision [13]. Parts have different usage and they can be supplied in different quantities. To address the problems of what parts to stock, of what quantity to stock, of when to reorder and replenish the stock, factors such as equipment failure rate, demand rate and number of similar parts need to be determined. Mean time between failure (MTBF) and mean time to repair (MTTF) are required for reliability analysis and spare parts forecasting [14]. With the intention to identify the minimum and maximum number level for each type of parts, companies use different technique. Reference [4] had designed the "Minimum – Maximum control" technique to be the most wildly used in inventory control. The minimum level represents the number of parts that is needed so the last part used just before the new order arrive, and then the order quantity will be the maximum level for this part. The maximum level then will be the minimum level plus the order quantity. The minimum level increases when the risk of stock out is increasing on particular part. From economic view, the minimum level should be as lower as possible and should cover any sudden condition that may delay the new parts from arrive at the expected time. The objective of this paper is to Define, Measure, Analyze, Improve and Control (DMAIC) a process that makes spare parts effectively available in stock room at the Agra Plant.

2. THE SIX SIGMA DMAIC METHODOLOGY

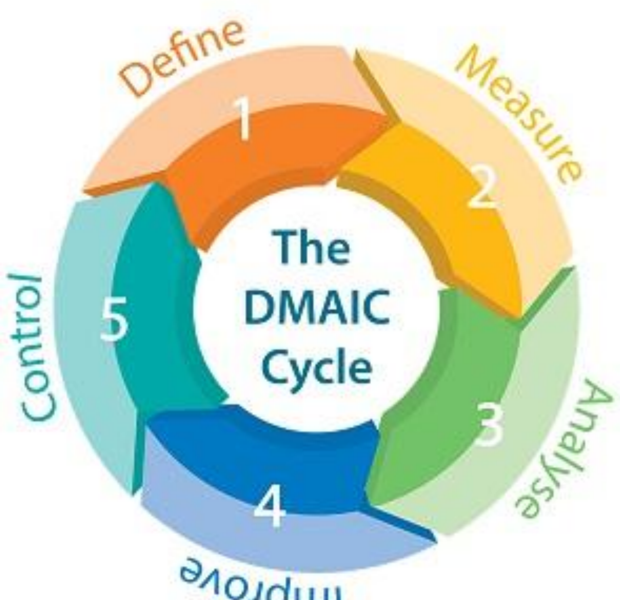

Fig. 1 The DMAIC Cycle

DMAIC (Fig 1) is an acronym for Six Sigma processes that look at the business performance guidelines used to Define, Measure, Analyze, Improve, and Control business performance. The DMAIC methodology should be used when a product or process exists already but not meeting customer specification or not performing adequately. Therefore, DMAIC is or should be used for projects aimed at improving an existing business process. The DMAIC cycle features five phases.

Phase 1: Define
The main objective of this stage is to outline the borders of the project. Stakeholders agree on the parameters that will define the project. Scope and budgetary items, as well as customer needs, are aligned with project goals. Team development takes place as the project begins to take shape.

Phase 2: Measure
The main objective is to collect data pertinent to the scope of the project. Leaders collect reliable baseline data to compare against future results. Teams create a detailed map of all interrelated business processes to elucidate areas of possible performance enhancement.

Phase 3: Analyse
The main objective is to reveal the root cause of business inefficiencies. Analysis of data reveals areas where the implementation of change can provide the most effective results. Groups discuss ways that the data underscores areas ripe for improvement.

Phase 4: Improve
The objective at this stage is to complete a test run of a change that is to be widely implemented. Teams and stakeholders devise methods to address the process deficiencies uncovered during the data analysis process. Groups finalize and test a change that is aimed at mitigating the ineffective process. Improvements are ongoing and include feedback analysis and stakeholder participation.

Phase 5: Control
The objective at this stage is to develop metrics that help leaders monitor and document continued success. Six Sigma strategies are adaptive and on-going. Adjustments can be made and new changes may be implemented as a result of the completion of this first cycle of the process. At the end of the cycle, additional processes are either addressed or the initial project is completed.

Some organizations add a **R**ecognize step at the beginning, which is to recognize the right problem to work on, thus yielding an RDMAIC methodology.

3. REDUCING PART SHORTAGES USING SIX SIGMA DMAIC METHODOLOGY – A CASE STUDY

Phase 1. Define

3.1. Plant Overview
Agra is a small sized manufacturing Plant that produces and delivers soaps to customers designed as stores and supermarket. The plant manufactures three major categories of soaps as bar soaps, powder detergent and liquid detergent. They are available in different flagrances, colors, size and packaging. Can also be customized for customers. The maintenance management of the plant is under the leadership of the newly created maintenance department. The plant used to outsource their maintenance activities. The department maintains a staff of specialized technicians in a ready-to-serve capacity and a manager. Technicians are machinists, electricians, electro-technicians, building technicians, and various other support specialists. The department uses two types of maintenance for its equipment: corrective maintenance and preventive maintenance. Corrective maintenance - When a failure is found by operators, the production manager or the shift supervisor issues an intervention request (IR) to the maintenance department. A work order (WO) is then established by the maintenance manager assigning technicians to interventions. At the plant, preventive maintenance activities consisted of lubrication operations for certain equipment with a periodicity ranging from 6 to 12 months. Due to the various skill levels and abilities of technicians, the maintenance department is effectively capable to address any maintenance problems.

3.2. Problem Statement
Currently the plant parts required to repair machines are not readily available in stock room when needed.

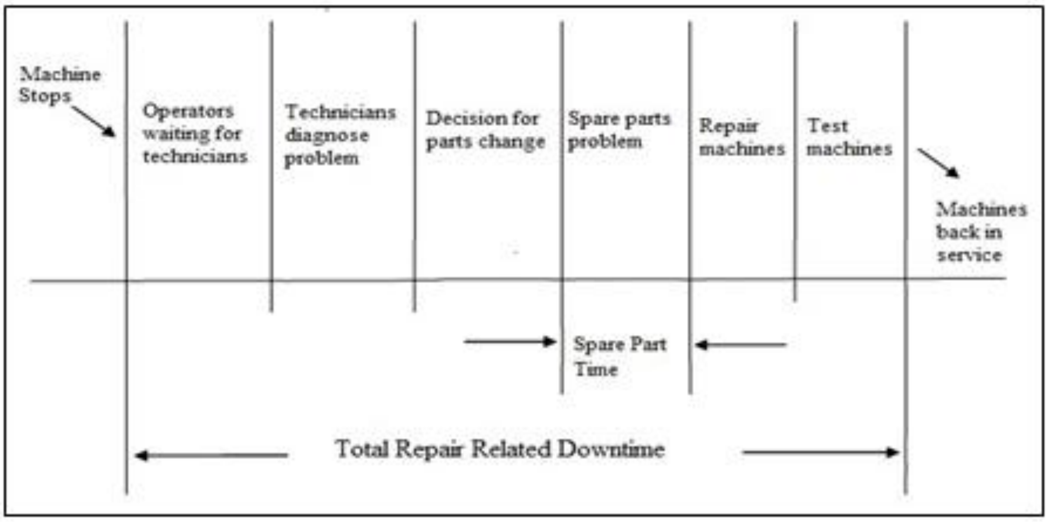

Fig. 2 Repair Related Downtime versus Spare Part Time

Part shortages are undesirables for several reasons.

- They increased downtime and frequencies;
- They increased MTTR;
- They decreased MTBF.

Table below presents collected downtime, frequency, MTBF and MTTR for each equipment over these 5 months.

Table -1 Downtimes. Frequencies, MTBF and MTTR

Equipment	Downtime	Frequency	MTBF	MTTR
Pump Process Fatty Acid	20.833	8	397.685	2.604
Pump Process Soda Pump	17.563	5	597.073	3.513
Mixing Heat Exchanger (PKO + Stearin)	23.750	3	894.063	7.917
Mixing Heat Exchanger (water + soda)	18.750	3	895.313	6.250
Dosing Pump Brine	65.500	6	504.929	10.917
Dosing Pump EDTA	29.080	11	297.577	2.644
Dosing Pump Titanium	2.833	1	1798.584	2.833
Recycling Pump soaps	2.670	1	1798.665	2.670
Group Empty Pump	54.750	6	506.464	9.125
Extruding	1.500	2	1199.500	0.750
Process Water Pump	8.670	3	897.833	2.890
Reactor Tabular	15.750	8	398.250	1.969
Conveyors 45	3.417	2	1198.861	1.709
Switchboard	12.167	1	1793.917	12.167
Hopper Bagging	21.000	2	1193.000	10.500
Sewing Machine	2.833	1	1798.584	2.833
Exchanger Tabular	18.750	3	895.313	6.250

3.3. Process Definition

The purchase department is the service responsible for the parts ordering system. The stock room is under the leadership of the newly maintenance department created. The plant used to outsource its equipment maintenance activities to a company located at 260 km. Its main objectives are to reduce maintenance costs, increase equipment reliability, minimize maintenance-free equipment downtime and increase production volume.

When orders are received, the purchasing department:

1. Stores it with the paperwork in a small room (serving as the inventory storage);
2. Keeps all the paperwork in a big stack categorized product family;
3. Then it notifies the maintenance department for parts pick up;
4. With the paperwork, maintenance technicians go to the inventory storage, retrieve all parts ordered and store it in the stock room;
5. At this time, if received wrong parts, they are returned to suppliers and adjusted to maintenance database;
6. Maintenance department notifies the purchase department to update database to the level of the part returned.

When a failure is found:

1. Operator notify verbally shift supervisor;
2. The shift supervisor issues an Intervention Request (IR) to the maintenance department;
3. The maintenance manager receives the IR and transforms it into a Work Orders (WO). The work order contains sections to be informed to establish the intervention procedures to follow. Then, maintenance manager assigns technicians according to the complexity and the nature of the interventions to be carried out.
4. After diagnosing the problem and filling necessary paperwork, maintenance technicians go back to the maintenance manager with the informed work order. Decisions are made depending on the type of service required: troubleshooting or repair. Troubleshooting is a temporary intervention to limit the stop waiting for spare parts. Repair is an original restoration of a part or machine.

   - *If for Troubleshooting:*
     a) Maintenance technicians go on maintenance database
   - *If for Repair:*
     a) Maintenance technicians go back to the floor;
     b) Perform light disassembly and back to the repair room;
     c) After a total disassembly and decision to change the defected parts;
     d) Maintenance technicians go on maintenance database.

5. If parts are NOT PRESENT in maintenance database, technicians:
   a) Notify manager who declares part shortage for stock out (out of stock parts);
   b) Notify the purchase department to initialize an emergency order request (EOR).

6. If parts are PRESENT in maintenance database, technicians:
   a) Fill up paperwork
   b) Print and fill up the stock voucher (SV) for parts pick up
   c) Get the “okay” signature from the maintenance manager.
   d) Then maintenance technicians go inside the stock room to pick up required parts for that intervention.

7. If parts are PRESENT in Stock room (means parts are present in maintenance database and present in stock room), technicians:
   a) Pick up required parts for that intervention.

8. If parts are NOT PRESENT in Stock room, (means parts are present in maintenance database but not present in stock room):
   a) Technicians notify manager and declare part shortage due to part not effectively in stock room.
   b) Then manager notifies the purchase department to initialize an Emergency Order Request (EOR).

The purchase department receives the Emergency Order Request (EOR), transforms it into an Approved Emergency Order Request (AEOR) and returns it to maintenance manager. With the AEOR, maintenance manager works with the supplier to get the required parts in the plant as soon as possible. But even if the supplier sends the materiel immediately, the whole process takes at least 3 to 4 days. The results is the long waiting time to receive the spare parts required to fix machines, creating part shortages and unavailability. Thus, the original scheduled date and time to repair machines get delayed, extending the downtime of the product line. A better synchronization between purchasers and the repair team is important to reduce part shortages.

3.4. Process Flowchart

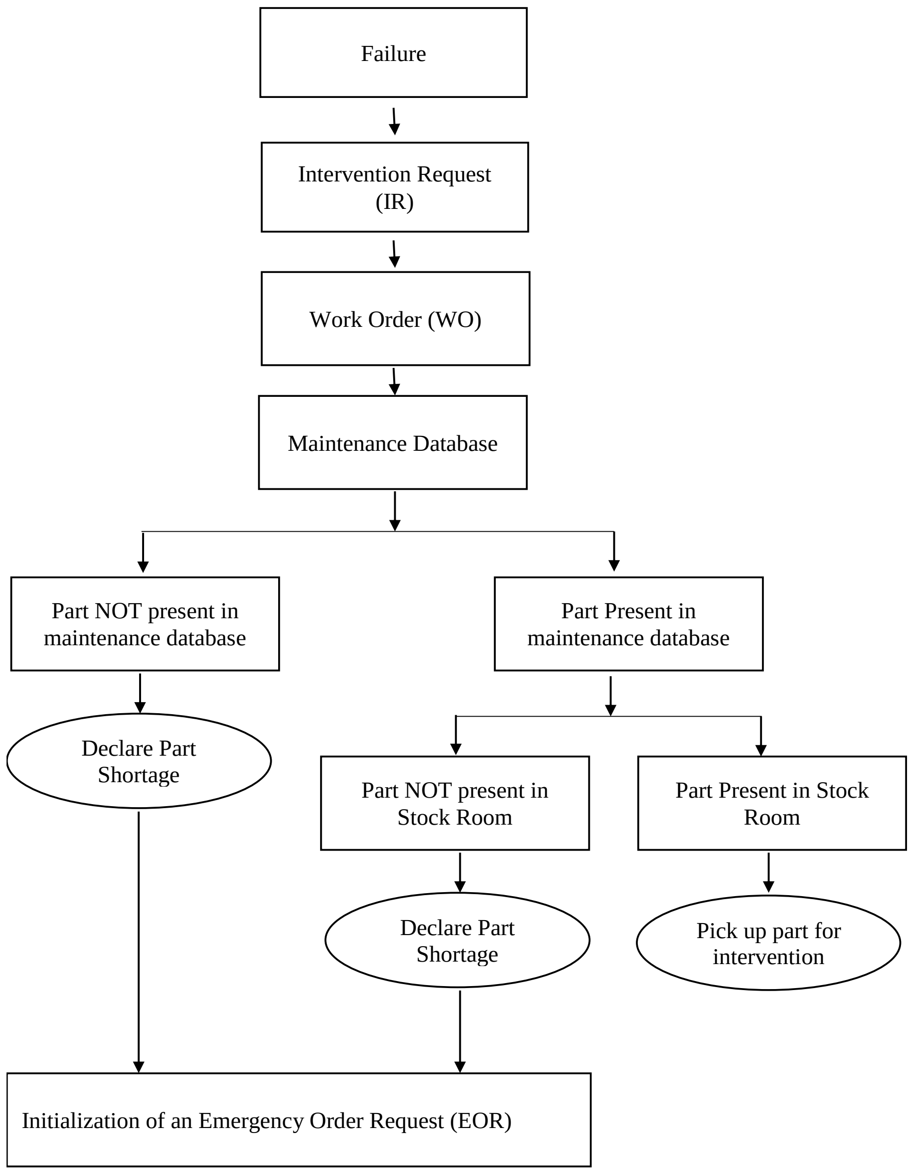

Fig. 3 Flow Chart

3.5. The Critical Customer Requirements (CCR's)

The Critical Customer Requirements (CCR's) is to make spare parts effectively available in stock room at the Agra Plant. The operators required that equipment are available and reliable to run the processes on the floor. In order to provide operators with quality service, technicians require parts to be effectively in stock room when needed. The purchase needs to know the exact quantity to order.

3.6. Benefits of Making the Improvements

Having technicians waiting too long to repair machines, due to spare part unavailability, can be a disaster for the production plan. The readily the part is picked up in stock room, the faster the machine is repaired and well maintained. Therefore, expected benefits of the improvements are:

- Increased uptimes and mean time between failures (MTBF)
- Decreased downtimes and mean time to repair (MTTR)

Phase 2. MEASUREMENT

For data collection, we:

1. Performed a brainstorming to list all possible causes
2. Used 5M of Ishikawa diagram to classify causes
3. Used Pareto Diagram to identifying the principal causes

2.1. 5M of Ishikawa Diagram

In order to identify the roots causes of this problem, we used the 5M approach of Ishikawa which is: Methods, Material, Machine, Manpower, and Environment. The following outputs are the result gained from the data collection and analysis of the Ishikawa diagram. There were 35 causes.

Table -2 Ishikawa 5 M's Diagram

Machinery	1. High machines workload 2. Products line frequent shutdown 3. Intervention requests greater than forecast 4. Poor machine performance 5. Machines not well maintained 6. Poor machine maintenance 7. High corrective than preventive maintenance
Method	8. No clear vision and management strategy 9. Wrong quantity ordered 10. No records for standards procedures 11. Poor customer/ suppliers relationships 12. Weak production capacity 13. No 5S 14. Not meeting customer demand
Materials	15. Inaccuracy in stock level 16. Stock room mess 17. Inaccuracy in purchase database 18. Purchasers order according to fixed lead time 19. Poor storage condition 20. Raw materials late delivery 21. Parts not in reality in stock room 22. Parts not readily available 23. Weak inventory strategy 24. Parts needed higher than stock level
Manpower	25. High level of absenteeism 26. Poor employees performance 27. Lack of manpower to cover critical jobs 28. Weak employees schedule 29. Workers frequent state of fatigue 30. Low employees moral 31. Not enough time to rest and interact with family
Environment	32. Dust and dirt 33. Noise 34. Humidity 35. Area not organized

2.2. Pareto Diagram

The purpose of the Pareto chart is to highlight the most important causes that impact negatively the problem. It allows causes to be sorted by order importance. To do this,

1. A survey questionnaire was proposed to (40) participants (operators and technicians). The question was: 'What causes need great attention to solve the problem of the frequent part shortages?"
2. Using EXCEL, we classified causes by order (Fig. 4):

Table -3 Survey Data

	Causes	Number of Responses	Percentages
1.	Wrong quantity ordered	10	25%
2.	Stock room mess	9	40%
3.	Inaccuracy in stock level	8	55%
4.	Suppliers performance	3	65%
5.	Poorly managed stock room	3	75%
6.	Someone else took it	2	80%
7.	Not in the stock room	2	85%
8.	Weak inventory management	1	90%
9.	lack of material allocation	1	95%
10.	Area not organized	1	100%
	TOTAL	40	

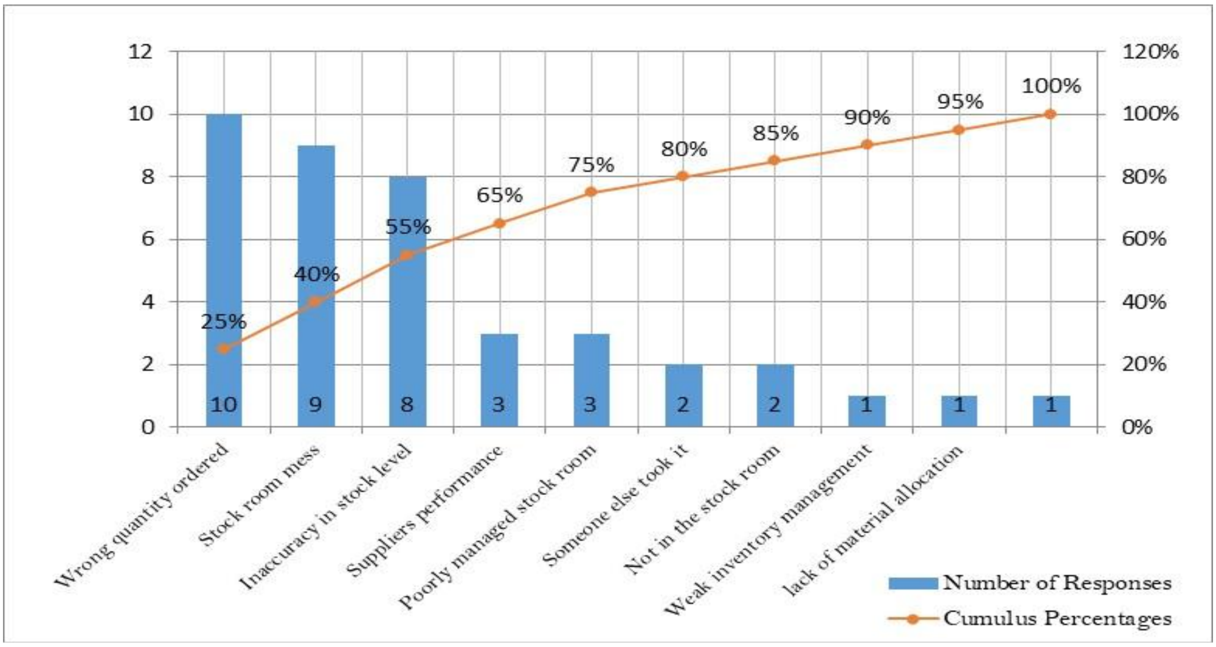

Fig. 4 Pareto Diagram

From Pareto, the following are the principal causes of the part shortages:

1. Wrong quantity ordered
2. Stock room mess
3. Inaccuracy in stock level

By working on these areas, we reduce by 55% the problem of frequent part shortages.

Phase 3. ANALYZE

We analyzed these principal causes using the 5 whys technique to identify the root causes.

Problem: Part shortages					
Why 1	Why 2	Why 3	Why 4	Why 5	Root Causes
Inaccuracy in stock room status	Maintenance database is not reflecting the reality in stock room	Maintenance databas is not updated	Technicians forget to update database after in-out activities on stock room	They lack on stock room management	Stock Room Issues
Stock Room Mess	New technicians turn the place upside down when looking for parts	They lack on awareness on the contents of the room	No time exists for stock room organization training to take place	Intense maintenance activities making them unavailable for training	Stock Room Issues
	Inaccuracy in purchase database	Purchase database not reflecting maintenance database; thus the stock level	Purchasers didn't adjust their database to the returned parts level	Purchasers forget to update database after in-out activities on stock room	Ordering Issues
	Purchase orders according to fixed lead time not to material availability	Purchase objective is to keep inventory low	Incentive system which penalizes purchasers for having too much inventory	Purchasers are responsible for the inventory	Ordering Issues
Wrong quantity ordered	Parts needed are higher than the stock level	Intervention requests turn to be greater than usual forecast	Machines are not well maintained & facing additional wear and tear at the same time	Parts need to fix machines are not readily available in stock room	Ordering Issues

Fig. 5 The 5 Whys Analysis

The 1st Why

1. Why question: Why frequent part shortages?
    a. Because Inaccuracy in stock room status
    b. Because stock room mess
    c. Because wrong quantity ordered

The 2nd Whys

1. Why question: Why inaccuracy in stock room status?
    a. Because maintenance database is not reflecting the reality in stock room
2. Why question: Why stock room mess?
    a. Because new technicians turn the room upside down when looking for parts
3. Why question: Why question: Wrong quantity ordered?
    a. Because inaccuracy in purchase database
    b. Because orders according to a fixed lead time not o material availability
    c. Because parts needed are higher than the stock level

The 3rd Whys

1. Why question: Why maintenance database is not reflecting the reality in stock room?
    a. Because maintenance database is not updated
2. Why question: Why new technicians turn the room upside down when looking for parts?
    a. Because they lack of awareness on the contents of the room
3. Why question: Why inaccuracy in purchase database?
    a. Because purchase database not reflecting the maintenance database; thus the reality in stock room?
4. Why question: Why purchase orders according to a fixed lead time not material availability?
    a. Answer: Because the purchaser objective is to keep inventory
5. Why question: Why parts needed are higher than the stock level?
    a. Because intervention requests turn to be higher than usual forecast

The 4th Whys

1. Why question: Why maintenance database is not updated
    a. Because new technicians forget to update database after in-out activities in stock room
2. Why question: Why new technicians lack of awareness on the contents of the room
    a. Because no time exists for stock room organization training to take place
3. Why question: Why purchase database not reflecting the maintenance database; thus the reality in stock room?
    a. Because purchasers didn't adjust database to the returned parts level
4. Why question: Why purchaser objective is to keep inventory low?
    a. Because incentive system which penalizes purchasers for having too much inventory
5. Why question: Why intervention requests turn to be higher than usual forecast?
    a. Because machines are not well maintained; thus facing additional wear and tear at the same time

The 5th Whys

1. Why question: Why new technicians forget to update database after in-out activities in stock room?
    a. Because they lack on stock room management
2. Why question: Why no time exists for stock room organization training to take place?
    a. Because intense maintenance activities making technicians unavailable for training
3. Why question: Why purchasers didn't adjust database to the returned parts level?
    a. Because purchasers forget to update database after in-out activities on stock room
4. Why question: Why incentive system which penalizes purchasers for having too much inventory?
    a. Because purchasers are responsible for inventory
5. Why question: Why machines are not well maintained; thus facing additional wear and tear at the same time?
    a. Because parts need to fix machines are not readily available in stock room

Summary

Two root causes emerged from the 5whys analysis:

1. Stock Room Issues
2. Ordering Issues

Following the 5Whys analysis, the major causes of part shortages at Agra plant are inaccuracy in stock room status, stock room mess, inaccuracy in purchase database, purchase orders according to a fixed lead time and parts needed are higher than the stock level. These areas of deficiency are categorized into the following root causes: stock room and ordering issues.Stock room is under the leadership of the maintenance department. It is an open room located on back of the maintenance office. The maintenance database contains stock room activities.

Stock Room Issues

The maintenance department is responsible for the management of the stock room.

1. Inaccuracy In Stock Room Status

We found inaccuracy in stock room status. Stock room is supervised by the maintenance department. Sometime, the stock room status on the maintenance database is not updated to reflect the reality in stock room. This is caused by maintenance technicians, especially the newly hired. They forget sometime (or didn't know how) to record their in-out operations on maintenance database. This non-conformity happens because they lack on database management training. This situation causes other technicians to think that parts are available in stock room, when in reality there is no parts. Or, in case the parts are there, the quantity is not exact. The exact status is discovered only when maintenance technicians go inside the stock room to pick up the parts needed for interventions. If that case, technician notify manager who declares part shortages due to parts not effectively in stock room. Then manager notifies the purchase department to initialize an emergency parts order.

2. Mess In Stock Room

We found a big mess in stock room. Many technicians, especially the new ones, lack awareness on the content of the stock room. So when they need a part, they will go to the stock room and try to find it. Because of this lack on stock room management training, they check everywhere, don't know exactly where to look, turning the place upside down. By the time the parts required are found or not, the room is a complete mess. This mess makes it difficult for maintenance technicians to retrieve parts. If parts not found, they report part shortages due to parts not effectively in stock room.

Ordering Issues

The purchase department is the service responsible for the parts ordering and receiving system.

1. Inaccuracy In Purchase Database

We found inaccuracy in purchase database due to due to database not being updated. When an order is received by the purchase department, it send it with the paperwork to the maintenance department. Maintenance technicians pick it up and store it in stock room. At this point, if received wrong parts, they were returned to suppliers and adjusted on maintenance database. Then maintenance department notifies the purchase department for database adjustment. The department adjusts the purchase database based on the actual numbers of returns. However, in several occasions, they were some parts that were received, then returned due to various reasons. We discovered that the purchase department is not adjusting their database, anytime, to the actual level. This making the purchase database not reflecting the reality in stock room since the department didn't takes into account parts that were returned. This wrong stock level causes inaccuracy in parts quantity to order. Since the purchase department is responsible for the parts purchasing system, this inaccuracy is caused by a biased purchase database and results in part shortages.

2. Purchase Orders According To A Fixed Lead Time

We found a poor forecast method. Purchase service schedules orders according to a fixed lead time not according to material availability. They estimate the forecast based on the actual stock level purchase database. The reason we believe purchasers estimate parts forecast is that purchasers are responsible to keep inventory low. An incentive system in place penalizes them for having too much inventory. If the purchasers suspect that the actual demand is going to be less than the forecast, then they will buy less parts. This results in part shortages.

3. Parts Needed Are Higher Than The Stock Level

We found that parts needed for interventions are higher than the stock level. Actual number of parts needed for interventions turn to be more than the quantity ordered and received. This happens because intervention requests (IR) turn to be more than usual due to an increased machine breakdowns rate. This results in machines not being well maintained because parts need to fix machines are not readily available for repair. Sometime, technicians had to improvise solution after a recent breakdown because they didn't have all the necessary spare parts on hand. While technicians were able to get the equipment running, some components were experiencing additional wear and tear at the same time. To avoid severe failures, maintenance manager decided to shutdown machine until those spare parts arrive to resolve the problem. The original date and time scheduled to repair machines get delayed, extending the downtime of the product line.

Phase 4. IMPROVEMENT

The Critical Customer Requirements (CCR's) is to make spare parts effectively available in stock room at the Agra Plant. Operators required that equipment are available and reliable to run the processes on the floor.In order to provide operators with quality service, technicians require parts to be effectively in stock room when needed. Parts needed to repair machines are not effectively available in stock room when needed because of the stock room and ordering issues. Since an emergency part orders takes at least 3 days for delivery, this results in long waiting time to get spare parts and fix machines. The long waiting times causes long machine downtimes; and thus long product line shutdowns. To reach the CCR's, corrective actions were implemented to:

1. Improve the stock room organization and management;
2. Improve the stock room ordering system;
3. Order the right quantity required.

4.1. Stock Room Improvement

4.1.1. Create a stock room service

We created a new entity called stock room service, appointed two supervisors (as one per shift). The oldest hired between the technicians were appointed. Function, mission and responsibilities were notified and with the given resources. They also serve also as technician time to time. Training classes for stock room management was established.

Supervisor's responsibilities, mission, objectives

- Assign responsibility for stock control and the stock room and develop written procedures.
- Keep the stock room well organized. An organized stock room saves time when ordering or locating items and prevents stock from getting lost.
- Make sure stock room records are completed regularly.
- Keep stock cards in the stock room. This enables the person responsible for stock control to update the cards after every transaction (ordering, receiving and issuing stock). Write each transaction on a separate line, even if there is more than one transaction on the same day.
- Record any stock-outs on stock cards and on stock room database.
- Keep each card with the stock in the correct place on the shelves.
- Keep and file old cards.
- Carry out random checks to ensure that record cards are being updated regularly and accurately.

4.1.2. Stock Room Re-Organization

We implemented corrective actions to make sure that parts "checked in" in database are effectively in stock room. Stock room was re-organized in a simple and logical way so that items can be found quickly and easily. Parts were classified by section representing each machine group number. Clearly we labelled each section of the stock room, allocated each item to a specific place and labelled the position of the item on the shelf so that it is easy to read. We divided parts into regular use and reserve stock, placing the reserve stock on the same shelves behind the regular use stock. On room shelves, each section contains the following: part name, parts numbers, quantity in stock and quantity out of stock. Remove damaged or obsolete items from the shelves and dispose them according to approved procedures. For accuracy of stock level, all in-out parts activities were noted on shelves and in the stock room records. Then reported on computer database. We kept the stock room secure, clean, free from pests, dry, not too hot or cold, well ventilated and not exposed to direct sunlight. We put up curtains at windows to keep out direct sunlight. We installed a thermometer in the stock room to monitor the temperature daily.

4.1.3. Stock Room Status

To improve the stock level accuracy on stock room database, we implemented the following corrective actions rules:

1. Organize and enforce rules for the stock room computer database.
2. Computer database of the stock room is now updated immediately by supervisors or assistants after every in-out parts activities.
3. For accuracy, all in-out parts activities were noted on shelves and in the stock room records. Then reported on computer database by the stock supervisor for update. With date and time.
4. On stock room computer database, spare parts were classified by order of importance (criticality). It contains part name, parts numbers, and machine group number, number of parts in stock, number of parts out of stock, total parts in stock, date and time.
5. Training classes for computer database management was established.

At end of each shift, results are passed to the next stock room supervisor.

4.1.4. Stock Room Control

Stock room management is about the control of the stock. Stock control includes keeping accurate and reliable records of stock received and issued, stock taking (checking stocks on a regular basis), and carrying out an inventory of stock at least once a year. A stock control system uses tools such as stock record cards and a stock control ledger. Effective stock control is important to order the right quantities of spare parts.

- *Stock room records* - Reliable record keeping is very important, because errors caused by poor record keeping affect service delivery. If the stock room records used for the ordering system are not accurate, the quantity ordered may be too much or too little. Accurate record keeping methods and forms used are stock cards (stock record cards) and stock control ledgers.
- *Stock cards*are kept for each type of item in stock. While are time consuming to keep up to date, stock cards have many advantages. They provide information about quantities received, issued and in stock at any time. They can be used to calculate orders, and are a useful tool for preventing shortages. Stock cards help supervisors to monitor overall consumption and to check stock levels, assess wastage and identify theft.
- *Stock control ledger* - Once a month the information on the stock room cards is transferred to the stock control ledger. It is simpler to make an order using the summary in the stock control ledger than using all the individual stock cards. The stock control ledger is also a useful tool for analyzing stock management and reviewing the accuracy of stock levels.

4.1.5. Issuing Parts

Stock room used the Stock Voucher as the system for recording issue of parts. The following information were recorded every time an item is issued: date of issue, item and quantities issued, name of receiving service or individual, and the signature of the technicians or recipient. Give a copy of the issue voucher to the recipient for their records. After issue, the receiving service or individual is responsible for the care of the item and accountable for loss or breakage. Parts that have low cost (bolts, nuts, etc.) normally stored in open, accessible bins near the stock room entrance and on floor, so it would have easy access.

4.1.6. Stock Counting

Regular stock counting is an important control portion of stock room management. It involves physically counting what is in stock and comparing the counted figures with the balance figures on the stock cards and on database. If there is a difference between the counted figures and the balance figures on the stock cards or on database, supervisors are responsible to find out why. A stock may have been received or issued without being recorded or may have been stolen. Supervisors are responsible to carry out a stock count before ordering more parts.

4.2. Ordering Improvement

The purchase method in place is based now on parts availability. No more on fixed lead time. Also, the ordering system of spare parts is based now on stock room database, not on purchase database as it was before. For an effective coordination, the purchase department is still controlling the ordering process, but according now to the stock room database. This means the accuracy of the stock room database is a requirement and supervisors are now responsible for the ordering database.

4.2.1. Placing an Order or Re-Ordering

When placing an order or re-ordering, we established the following procedures:

- Check the stock records to find out the stock balance and decide what items and how much of each item you need to order.
- List the parts to be ordered alphabetically and in sections. Only include one item and one item size on each line. If you are ordering from a catalogue, write down the catalogue code number for each item.
- Provide a full and clear description of each item.
- Specify the quantity of each item. Place orders for complete packs. For example, if the need is 32 seals and a pack contains 12 seals, order 3 packs. Making 36 seals.
- Check that all copies of the order are easy to read and signed by an authorized person.
- Make at least two copies of the order. Keep one copy in the stock room service and send one copy to the supplier.

4.2.2. Receiving Ordered Spare Parts

When receiving ordered spare parts, make sure at least two people receive and check supplies. It is important to check orders received before putting them away in the stock room. This check includes quality control and inspection to insure the spare parts quality, parts numbers, serial numbers, application, modifications, expire date, and physical conditions are correct. It helps to report problems to the supplier immediately and explaining the nature of the problem. When unpacking orders, enter the details on the stock card and in database. It is also important to keep a goods received record (items, supplier, date, invoice number and the serial number). Register the warranty and keep all packaging materials in case a need to transport it again in the future.

4.2.3. Ordering the Right Quantity

It is important to order the right quantities needed. General rule, ordering too little (understocking) will result in shortages, making the plant not being able to provide effective output. Ordering too much (overstocking) results in a buildup of unused stock. Ordering the right quantity depends on the annual requirement which is the quantity of spare parts required in a 12 month time period.

- **Finding Annual Requirement**

Twelve months was chosen by the company as the most practical time period to use for calculation, because it allows for seasonal variations in requirements. To calculate the annual requirement, data collection was made for the opening stock balance, the stock received, the closing stock balance, the wastage and the stock out.

Table -4 Data Collection

Parts	Opening stock balance (Jan 1, 2017)	Stock received	Closing stock balance (Dec 31, 2017)	Waste	Stock out (months)
Pump Process Fatty Acid	100	1000	22	0	2
Pump Process Soda Pump	22	1000	19	0	2
Mixing Heat Exchanger (PKO + Stearin)	88	1000	39	0	2
Mixing Heat Exchanger (water + soda)	120	1000	67	0	2
Dosing Pump Brine	45	1000	51	0	2
Dosing Pump EDTA	56	1000	45	0	2
Dosing Pump Titanium	23	1000	90	0	2
Recycling Pump soaps	12	1000	67	0	2
Group Empty Pump	55	1000	58	0	2
Extruding	9	1000	79	0	2
Process Water Pump	100	1000	15	0	2
Reactor Tabular	17	1000	57	0	2
Conveyors 45	68	1000	22	0	2
Switchboard	29	1000	39	0	2
Hopper Bagging	98	1000	45	0	2
Sewing Machine	78	1000	32	0	2
Exchanger Tabular	63	1000	49	0	2

With the collected data, calculation for recorded consumption, real consumption, and adjusted real consumption was made to find the annual requirement. Annual requirement is the same as the adjusted real consumption.

Recorded consumption =	Opening stock balance (+) Stock received (–) Closing stock balance
Real consumption (RC) =	Recorded consumption (–) Wastage (avoidable losses)
Adjusted Real Consumption =	Real consumption (x) Period in calculation (/) Period in stock
Annual Requirement =	Adjusted Real Consumption

Table -5 Annual Requirement

Parts	Recorded consumption	Real consumption	Adjusted Real Consumption	Annual Requirement
Pump Process Fatty Acid	1078.0	1078.0	1293.6	1293.6
Pump Process Soda Pump	1003.0	1003.0	1203.6	1203.6
Mixing Heat Exchanger (PKO + Stearin)	1049.0	1049.0	1258.8	1258.8
Mixing Heat Exchanger (water + soda)	1053.0	1053.0	1263.6	1263.6
Dosing Pump Brine	994.0	994.0	1192.8	1192.8
Dosing Pump EDTA	1011.0	1011.0	1213.2	1213.2
Dosing Pump Titanium	933.0	933.0	1119.6	1119.6
Recycling Pump soaps	945.0	945.0	1134.0	1134.0
Group Empty Pump	997.0	997.0	1196.4	1196.4
Extruding	930.0	930.0	1116.0	1116.0
Process Water Pump	1085.0	1085.0	1302.0	1302.0

Reactor Tabular	960.0	960.0	1152.0	1152.0
Conveyors 45	1046.0	1046.0	1255.2	1255.2
Switchboard	990.0	990.0	1188.0	1188.0
Hopper Bagging	1053.0	1053.0	1263.6	1263.6
Sewing Machine	1046.0	1046.0	1255.2	1255.2
Exchanger Tabular	1014.0	1014.0	1216.8	1216.8

- **Finding the Right Quantity to be Ordered**

To calculate quantity to be ordered, the order quantity, minimum level and the stock balance are needed. The formula to calculate how much extra or less stock should be ordered is:*Quantity to be ordered = Order quantity + Minimum order level – Stock balance*

Time between orders (Month)		6 Months			
Stock balance (Parts)		120 Parts			
Lead time	1 month	2 months	3 months	6 months	12 months
Reserve stock	2 weeks usage	1 month usage	1.5 months usage	2 months usage	3 months usage

- ***Lead time and frequency of orders -*** The length of time between placing an order and receiving the items is called the lead time (or the delivery time). The lead time and the frequency of ordering affect the order quantities. The less frequent an order, the larger the quantities of each item to be ordered to maintain stocks until the next delivery. On the other hand, if orders are placed frequently, order less to maintain stock levels between deliveries.
- ***Stock levels -*** The stock level is the quantity of an item that is available for use in a given period of time. The reserve stock is the lowest level of stock for each item, and quantities should not be allowed to fall below this level. Reserve stocks are essentially extra parts to ensure that there are no stock out if there is an unexpected increase in demand or a delay in receiving parts. The quantity of reserve stock depends on the average monthly consumption and the lead time.
- ***Average monthly consumption*** **(AMC)** is the average quantity of an item that is issued each month over a period of months. It takes account of seasonal variations in demand and is calculated using the following formula: *Average monthly consumption = Total quantities issued in the time period / Number of months in the time period*
- ***The minimum stock level*** (sometimes called the re-order level) is the stock level that indicates you need to place an order to avoid running short of supplies. The minimum stock level can change over time, so check it regularly and make any necessary adjustments to the stock card and your orders. To calculate the minimum level, use the formula: *Minimum stock level = Reserve stock + Stock used during lead time*
- ***Stock used during lead time*** is the quantity of items that is used during lead time. *Stock used during lead time = Lead time x AMC*
- ***The order quantity***is the quantity of items that is ordered to be used in one supply period, and it depends on the length of time between orders (i.e. frequency of ordering) and average monthly consumption. If, for example, you place an order every 6 months, the quantity ordered should maintain stocks above the reserve stock level until the next supplies are received i.e. last for 6 months. To calculate the order quantity, in other words how much you need for the supply period, use the formula: *Order quantity = Time between orders x Average monthly consumption.*
- ***The maximum stock*** level is the maximum amount of any item you should have in stock at any time. You will usually only have the maximum level in stock just after receiving a delivery. The maximum level helps to prevent you from over ordering. This level can change over time, so check it regularly and make any necessary adjustments to the stock card and your orders. To calculate the maximum stock level, use the formula: *Maximum level = Reserve stock level + Order quantity for one supply period*
- ***Quantity to be ordered -*** To calculate changes in the quantity of an item to order, you need to know the order quantity, minimum level and the stock balance. The formula to calculate how much extra or less stock should be ordered is: *Quantity to be ordered = Order quantity + Minimum order level – Stock balance*

AMC =	Total quantities issued in the time period (/) No. of months in the time period
Reserve stock =	1 month if lead time is 2 months stock
Stock used during lead time =	Lead time (x) AMC
Minimum stock level =	Reserve stock (+) Stock used during lead time
Order quantity =	Time between orders (x) AMC
Maximum stock level =	Reserve stock (+) Order quantity
Quantity to be ordered =	Order quantity (+) Minimum order level (–) Stock balance

Table -6 Quantity to Order

Parts	Requirement	AMC	Reserve stock	Stock used during lead time	Min stock level	Order quantity	Max stock level	Quantity to be ordered
Pump Process Fatty Acid	1293.6	107.8	107.8	215.6	323.4	646.8	754.6	850.2
Pump Process Soda Pump	1203.6	100.3	100.3	200.6	300.9	601.8	702.1	782.7
Mixing Heat Exchanger (PKO + Stearin)	1258.8	104.9	104.9	209.8	314.7	629.4	734.3	824.1
Mixing Heat Exchanger (water + soda)	1263.6	105.3	105.3	210.6	315.9	631.8	737.1	827.7
Dosing Pump Brine	1192.8	99.4	99.4	198.8	298.2	596.4	695.8	774.6
Dosing Pump EDTA	1213.2	101.1	101.1	202.2	303.3	606.6	707.7	789.9
Dosing Pump Titanium	1119.6	93.3	93.3	186.6	279.9	559.8	653.1	719.7
Recycling Pump soaps	1134.0	94.5	94.5	189.0	283.5	567.0	661.5	730.5
Group Empty Pump	1196.4	99.7	99.7	199.4	299.1	598.2	697.9	777.3
Extruding	1116.0	93.0	93.0	186.0	279.0	558.0	651.0	717.0
Process Water Pump	1302.0	108.5	108.5	217.0	325.5	651.0	759.5	856.5
Reactor Tabular	1152.0	96.0	96.0	192.0	288.0	576.0	672.0	744.0
Conveyors 45	1255.2	104.6	104.6	209.2	313.8	627.6	732.2	821.4
Switchboard	1188.0	99.0	99.0	198.0	297.0	594.0	693.0	771.0
Hopper Bagging	1263.6	105.3	105.3	210.6	315.9	631.8	737.1	827.7
Sewing Machine	1255.2	104.6	104.6	209.2	313.8	627.6	732.2	821.4
Exchanger Tabular	1216.8	101.4	101.4	202.8	304.2	608.4	709.8	792.6

Phase 5. CONTROL

5.1. Stock Room Issues

The stock room Supervisor is now the sole responsible for all stock related issues, compared to the maintenance department before. The results show an improvement in stock room issues. The room is now well organized and managed. Supervisors and assistants are responsible for all in-out activities. The stock room database is well managed, with updating procedures well enforced. Stock control procedures were implemented and enforced. Stock room management and database management training classes were established.

5.2. Ordering Issues

The purchase department is still the service responsible for the parts ordering system. However, the ordering system is now based on stock room database, comparing to the purchase database before. The results show an improvement in ordering issues. This results from the implementation and enforcement of new ordering and receiving procedures.

Table -7 Past and Actual Performance

Equipment	Past Performance				Actual Performance			
	Downtime	Frequency	MTBF	MTTR	Downtime	Frequency	MTBF	MTTR
Pump Process Fatty Acid	20.83	8.00	397.69	2.60	3.15	2.00	1198.95	1.58
Pump Process Soda Pump	17.56	5.00	597.07	3.51	1.93	1.00	1799.03	1.93
Mixing Heat Exchanger (PKO + Stearin)	23.75	3.00	894.06	7.92	4.51	1.00	1797.74	4.51
Mixing Heat Exchanger (water + soda)	18.75	3.00	895.31	6.25	2.06	1.00	1798.97	2.06
Dosing Pump Brine	65.50	6.00	504.93	10.92	1.97	2.00	1199.35	0.98
Dosing Pump EDTA	29.08	11.00	297.58	2.64	1.45	2.00	1199.52	0.73
Dosing Pump Titanium	2.83	1.00	1798.58	2.83	0.31	1.00	1799.84	0.31
Recycling Pump soaps	2.67	1.00	1798.67	2.67	0.16	1.00	1799.92	0.16
Group Empty Pump	54.75	6.00	506.46	9.13	2.19	2.00	1199.27	1.10
Extruding	1.50	2.00	1199.50	0.75	0.17	1.00	1799.92	0.17
Process Water Pump	8.67	3.00	897.83	2.89	0.09	2.00	1199.97	0.04
Reactor Tabular	15.75	8.00	398.25	1.97	1.26	2.00	1199.58	0.63
Conveyors 45	3.42	2.00	1198.86	1.71	0.17	1.00	1799.91	0.17
Switchboard	12.17	1.00	1793.92	12.17	0.24	1.00	1799.88	0.24
Hopper Bagging	21.00	2.00	1193.00	10.50	0.21	1.00	1799.90	0.21
Sewing Machine	2.83	1.00	1798.58	2.83	0.31	1.00	1799.84	0.31
Exchanger Tabular	18.75	3.00	895.31	6.25	2.06	1.00	1798.97	2.06
Average	18.81	3.88	1003.86	5.15	1.31	1.35	1587.68	1.01

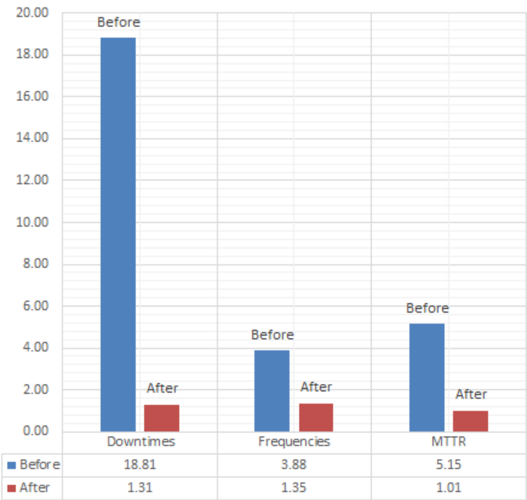

Fig. 6 Past and Actual Downtimes, Frequencies and MTTR

Fig. 7 Past and Actual MTBF

The result of this study (Fig 6) shows a significant decrease in mean time to repair (MTTR), in average downtimes and in frequencies. Therefore, and addressing in Fig 2, the total repair related down time decreased due to a decrease in spare part time. This means technicians are not waiting too long now to change parts needed to repair machines, because spare parts are readily available in stock room. Availability is a portion of the time equipment is actually available to perform work out of the time it should be available. This reduce the time wasted while waiting for spare parts shortages, and thus reduce machine downtimes. The readily the part was picked up in stock room, the faster machine was repaired and well maintained. The result also shows that average mean time between failures (MTBF) increased (Fig 7). This means machines are running under a steady uptimes to run the processes on the floor. MTBF increased because parts needed by technicians to repair are effectively in stock room. Reliability is the probability that an equipment will perform properly under normal operating circumstances. MTBF value is a direct measure of reliability. More the MTBF more is the reliability. Therefore, the results of this study served the CCR's which is making spare parts effectively available in stock room at the Agra Plant.

4. CONCLUSION

The plant is experiencing frequent product line downtimes due to part shortages. The objective of this study was to Define, Measure, Analyze, Improve and Control (DMAIC) a process that makes spare parts effectively available in stock room at the Agra Plant. To reach this objective, we defined the problem, collected data using the diagram of Ishikawa to find the causes of the problem, and selected principal causes using the diagram of Pareto. Stock room mess, stock room inaccuracy status and wrong quantity ordered emerged as the principal cause of the frequent part shortages. We then analyzed these causes using the 5 Whys technique. Two root causes emerged: stock room issues and ordering issues. For the improvement phase, we implemented corrective actions to close the gaps observed. To address the stock room issues, we focused on stock room organization and management improvement. To address the ordering issues, we focused actions on improving the process for ordering the right quantity. Running out of supplies is a serious problem, and having an oversupply is a waste of money and space. The Maximum and Minimum (Max/Min) system is a common system for keeping the right amount of supplies and to make sure that you never run out of stock. There are several variations of the Max/Min system and there are also different ways of calculating the maximum, minimum, and order quantity. In some systems, you have to make orders according to a regular schedule, for example once a year or periodically. In others, you are able to order supplies as and when you need to. The results show a decreased averages equipment downtimes, frequencies and MTTR. However, the average equipment MTBF increased significantly. MTBF value is a direct measure of reliability. More the MTBF more is the reliability. Therefore, this paper Defined, Measured, Analyzed, Improved and Controlled (DMAIC) corrective actions that made spare parts effectively available in stock room at the Agra Plant.

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