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Application of Six-Sigma for Process Improvement in Manufacturing Industries: A Case Study

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Abstract: This is an era of quality management and quality is a parameter for the selection of a product or service because the customer wants a defects free product or service. Six-Sigma is a quality improvement approach that aims to reduce the number of defects up to 3.4 parts per million. In the last three decades, it helped several companies to enhance the capability of their processes and to increase the level of quality of their product or service. This case study based research deals with application of DMAIC (Define, Measure, Analyze, Improve and Control) methodology of Six-Sigma to reduce the machine downtime for process improvement. The tools and techniques used during the analysis are Process Mapping (SIPOC Diagram), Process Flow Chart, Process Capability Analysis, Histogram, Pareto Chart, Pie Chart, Cause and Effect Diagram, Brainstorming, Affinity Diagram and ANOVA. The results of this study show that sigma value has improved from 2.79-2.85 Sigma. This study also highlighted the five critical problems (reasons) of downtime which are, i.e., electricity problem, shortage of material, quality issues, machine fault and reactive maintenance. The valuable principles and practices of Six-Sigma will do well by continuously refining the organizational culture. Time and commitment both are required and compulsory to bring change in cultural before they are strongly implanted into the organization. I do assure that this research study will provide opportunities to the organizations for the better implementation of Six-Sigma projects.

Key words: Six-Sigma, project management, organizational culture, quality, process improvement

INTRODUCTION

Six-Sigma is a big breakthrough in the field of quality which is equally applicable in manufacturing and service sectors. The philosophy of Six-Sigma is to satisfy the customer by offering the defect free product or service delivering on time at lower cost. The methodology of Six-Sigma does not only improve the quality of a product or service but it also focuses upon the cost of goods sold and the return on investment. A number of quality programs have practiced over the last 25 years starting from Quality Circles (QC), "Statistical Process Control (SPC)", "Total Quality Management (TQM)", "ISO", etc. Some few reengineering concepts brought in practice along with the above said programs like kaizen and lean manufacturing. With the proper implementation of these quality programs, many manufacturing companies got financial benefits through lowering the cost of poor quality, reduced their cycle time and decreased the ratio of their customers' complaints. After that, a breakthrough approach was required in business to fulfill the high expectations of the stakeholders for low price, the demand for defect free product or service and to meet the competitive pressure. So, according to my point of view the Six-Sigma is the most latest and successful method to describe, evaluates, examine, develop and manage the quality and efficiency of the any process, product or service. This part explains the interest why we selected the topic of Six-Sigma for my research project and what aim, objectives and outcomes are set to achieve from this research moreover what research methodology and Six-Sigma tools are used for analysis and improvement.

Purpose of the study: The aim of this research study is the application of Six-Sigma to reduce the machine downtime for process improvement.

Planned objectives of the research study: The creation, invention and research of everything have some definite objectives behind that concept. Nothing is superfluous, waste and useless in this world. With the application of Six-Sigma, the following objectives will achieve:

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- Decrease the downtime
- Establish performance measures
- Increase/enhance productivity and utilization
- Increase quality of product
- Decrease/minimize operating expenses

Planned outcomes of the research study: The effectiveness (how well it is going on) of any method or technique is measured through its outcomes. This research study has the following main outcomes:

- Improvement in operational efficiencies
- Cost reduction through process improvement

Research methodology: In this research study, DMAIC "(Define, Measure, Analyze, Improve and Control)" methodology of Six-Sigma used to meet the planned objectives and outcomes. This research project divided into four main phases:

- Phase 0: problem statement
- Phase 1: data collection and measurement
- Phase 2: analysis and measurement
- Phase 3: improve and verify analyzed data
- Phase 4: control and maintain

The data of machine downtime of 3 months collected for analysis and improvement and the following tools and techniques used to perform various analysis:

- Process mapping (SIPOC diagram)
- Process flow chart
- Process capability analysis
- Histogram
- Pareto chart
- Pie chart
- Cause and effect diagram
- Brainstorming
- Affinity diagram

Literature review: Sigma is a letter of Greek alphabet and now it has become a statistical symbol and measurement of the process variation. Generally, Six-Sigma denoted in different ways, mostly we write it like this 6σ. "The Six-Sigma quality is to reduce process output variation so that on a long term basis, this will result in no >3.4 defects per million opportunities" (statistical definition). Therefore, Six-Sigma is a statistical concept which represents the amount of variation in any current process comparative to the customer requirements and quality requirements. Motorola is the originator of Six-Sigma which brought this new concept of quality in 1980s after being consistently, beat in the competitive marketplace by foreign firms. When the process operates at the Six-Sigma level, the amount of variation is so small or minimum that the resultant products and services are 99.9997% defect free (Leathers, 2006). The approach of Six-Sigma differs from conventional quality improvement programs as it focuses on input variables. While conventional process improvement methods and techniques depend upon measuring the outputs and establishing the control plans to protect customers requirements from organizational defects (Kwak and Anbari, 2006). Six-Sigma based on the concept of customer centered, systematic and the data driven technique for doing the things better. It is a disciplined and the data driven approach to eliminate or remove the defects in any process from manufacturing to transactional and from product to service who is end user of product. Six-Sigma is a detailed and lithe system to achieve, sustain and maximize the business success. Six-Sigma is not a theory of management or even a single business methodology. Six-Sigma is a method of providing defects free product of service to the customers. Six-Sigma gives us different tools to improve systematically the entire business (Fig. 1).

The two perspectives of Six-Sigma processes

Statistical perspective: According to the statistical perspective, the term Six-Sigma is defined as having <3.4 defects per million opportunities or has a "99.9997%" success rate. So, sigma is used to represent the average process variation of a system.

Business perspective: Six-Sigma is a business strategy that is used to increase the profitability of business to enhance the efficiency and effectiveness of all processes to meet or go beyond the customer's needs and expectations. Firstly, it applied in manufacturing operations and then quickly expanded to different functional areas like engineering, manufacturing and marketing, purchasing and servicing (Kwak and Anbari, 2006).

The main characteristics of Six-Sigma are managing decisions with data, leadership commitment, training and cultural change that brings Six-Sigma performance. Six-Sigma performance brings high profits, value add-in and reduce variation (Fig. 2).

Six-Sigma methodologies, applications and benefits: Six-Sigma has two approaches "DMAIC" (Define, Measure, Analyze, Improve and Control) and "DMADV" (Define, Measure, Analyze, Design, Verify) which used for process improvement.

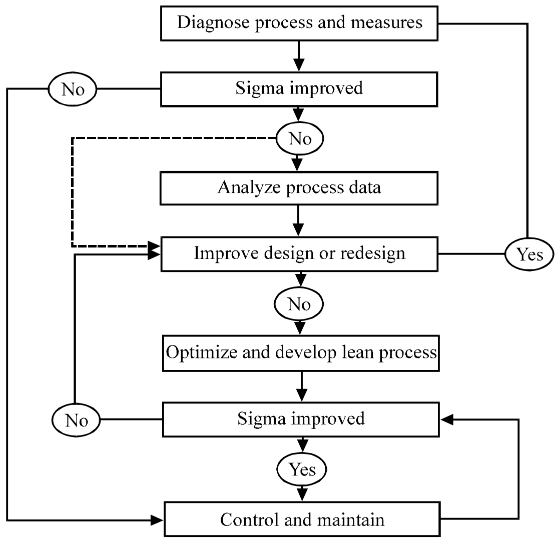


Fig. 1: Essentials of lean Six-Sigma by Taghizadegan

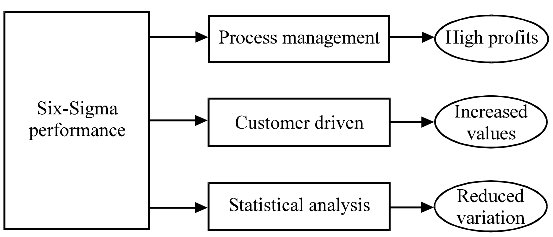


Fig. 2: Essentials of lean Six-Sigma

DMAIC: When a product or a process is in existence in our company but that is not meeting customer specification or not performing adequately in this situation DMAIC methodology is used.

DMADV: When a product or a process is not in existence in our company and one need to be developed (if we want to produce a new product) then in this situation “DMADV” methodology is used.

Benefits of Six-Sigma on organizational level: It builds the company reputation in market, it creates the new customer opportunities for the company, it fosters the vision and mission of the company, it improves the market position comparative to competitors and it improves the ability to serve customers and fulfill the customer requirements.

Benefits of Six-Sigma on operational level: It decreases the employee workloads for undesirable work, it eliminates the non-value added activities of a process, it improves the employee morale, it increases the employee and process productivity, it reduces the cycle time, it reduces the external inputs to processes, reduces process steps, simplifies processes and workflow steps. Six-Sigma challenges: the lack of management support, lack of data support, no interest from the employees, no long term or strategic thinking.

Six-Sigma tools and techniques: The main Six-Sigma tools and techniques which are used within Six-Sigma process improvement or development projects:

Check sheet: This tool is used in data collection of desired characteristics of any process which has to be improved. If the collected data is false then the most suitable methods will be resulting in failure. Check sheet is used in the measuring phase of Six-Sigma. The check sheet is typified in tabular form. Check sheet has to be simple, easy and associated with the characteristics to be measure.

Histogram: This is the 2nd Six-Sigma tool which is used in the analyzing phase. Histogram is used to know about the distribution of data and information collected in measuring phase. Collected data is to be divided in different classes by using the histogram. Area of each rectangle in histogram is proportional to a number of calculation and observation within every class. So, if we add the areas of all the rectangles it will equal to the total number of the observation. The suitable number of classes in a histogram should be in between 6-12.

Cause and effect diagram: It is also called the fishbone or the Ishikawa diagram. Dr. Kaoru Ishikawa introduced this Six-Sigma tool in 1943. This tool facilitates us to find out all the possible causes of the problem. It is used as a first step in solving any problem by listing all the possible causes. It is applied in defining and analysis phases of Six-Sigma.

Pareto chart: The Pareto chart introduced by the Joseph M. Juran in 1940. It is also known as 80/20 rule; it means that 80% of the problems are due to the 20% of causes.

Control chart: Shewhart introduced the control chart in 1924 and is using in industry since Second World War. Control chart is also known as Statistical Process Control (SPC). This tool is used in analysis, improvement and control phase of Six-Sigma project. In the analysis phase this tool is very helpful for identifying whether or not the process is predictable, in the improvement phase it identifies a special cause of variation and in the control phase it verifies that there is improved process performance.

Pie chart: Pie chart is the most suitable for illustrating percentage distributions of qualitative variables, e.g., the breakdown of the annual hospital or education budget into categories of expenditure such as teacher salaries, staff salaries, school construction and maintenance.

SIPOC diagram: SIPOC diagram identifies all elements of a process improvement project before work begins. It provides a deep understanding of the current process "it helps to define and refine a complex project that might not be well scoped" "it also helps to answer the questions such as". "Where does the process start and end?" "What are the major steps in the process?" "What are the primary process inputs and outputs?" "Who are the key customers of the process (both internal and external)?" "Who are the key suppliers of the process (both internal and external)?" "What are the requirements of the customers?"

The main dynamics for employing a successful Six-Sigma program: Top management dedication and participation, comprehend the Six-Sigma methodologies, tools and techniques, connecting the Six-Sigma with business strategy, connecting Six-Sigma with customers, The selection, evaluations and tracking of project, the suitable infrastructure of the organization, change in organizational cultural, project management expertise's, connecting Six-Sigma with suppliers, training and education, connecting Six-Sigma with human resources (Wang, 2008). Why do we implement Six-Sigma? The few reasons for implementing the Six-Sigma are following: to become responsive and customer focus, to improve the performance of the product and the service, to improve the business's financial performance and the profitability, having the competency to measure the quality programs, to be considered as a supplier for a business. Six-Sigma is giving results in addition to quality improvements or continuous improvement and variability reduction. DMAIC is used to achieve operational excellence or DMAIC problem-solving approach (Montgomery, 2010). Six-Sigma methodologies alone can not do miracles and must be integrated with the organization and Six-Sigma projects or initiatives positively affects the vision and enables employees across the organizational hierarchy to work in the direction of achieving and maintaining the standard of quality and requirement of process (Al-Sagheer, 2011). The most important objective of the Toyota system has been to increase production efficiency by consistently and thoroughly eliminating waste." The reduction on the order-to-cash cycle is an important goal of production and SCM. Through, Six- Sigma can increase customer value, improve sales processes, increase efficiency of human resources, reduce purchasing costs, reduce operational losses and improve business decision-making (Lokkerbol *et al*., 2012) (Table 1-4 and Fig. 3).

After extensive literature review is done by keeping in view the requirement of the topic and comments are given by researchers which is used in analysis. Six-Sigma is a method of providing defect free product or service, top management dedication and distribution of resources and effort are required for Six-Sigma system and top

Table 1: Comparison of old and new (Lean Six-Sigma) Methods

Problem	Old methods	New methods
Design	Product performance	Product productivity
Analysis	Experience based	Data based
Issue	Fixing problems	Preventing problems
Manufacturing/Molding	Test and error process	Strong design process
Inventory level	High production quantity	Low production quantity as needed
People	Cost to company	Asset to company
Management	Cost and time	Quality and time
Employee goal	Company	Customer
Product engineering	Little input from customer	High input from customer
Quality focus	Product	Process
Dominant process factors selection	Apply one factor at a time	Apply design of experiment
Process improvement	Robotic technique	Optimization technique
Proving	Experience based	Statistically based
Company outlook	Short-term plan	Long-term plan
Customer satisfaction	Production at statistical acceptance quality level	Fewer defects, when and what quantity customer wants
External relationship	Value based relationship	Long-term relationship
Production schedules	Forecast	Customer order
Manufacturing cost	Continuously rising	Stable and decreasing

Table 2: Process capability

Amount of variation	Effects	Sigma value
Too much	Difficult to produce output within customer requirements or specifications	Low (0-2)
Moderate	Most output meets customer requirements	Middle(2-4.5)
Very little	Almost all output meets customer requirements	High (4.5-6)

Table 3: Sigma performance and yield

Sigma levels	Defects per million opportunities	Yield (%)
1σ	697,700	30.23
2σ	308,537	69.20
3σ	66,807	93.32
4σ	6,210	99.38
5σ	233	99.98
6σ	3.4	99.99

Table 4: Sigma calculations (Devadasan and Goya, 2005)

Sigma calculation	Description
DPU	Defects per unit DPU = Number of defects/number of units
DPO	Defects per opportunities DPO = Number of defects/number of units× number of opportunities
DPMO	Defects per million opportunities DPMO = DPO×10^6s
Sigma	Consult the sigma table

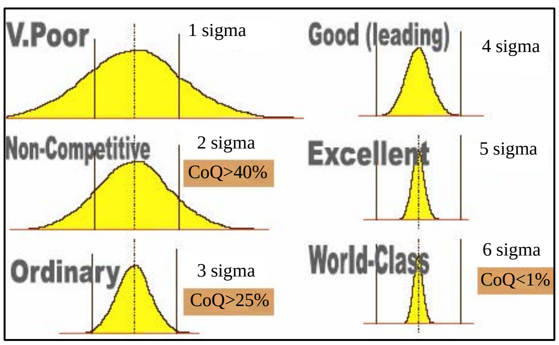


Fig. 3: Sigma value and process rating

management plays a vital role in the successful implementation of the Six-Sigma (Kwak and Anbari, 2006), the Six-Sigma project must be carefully planned, selected and reviewed to maximize the benefits of its implementation (Kwak and Anbari, 2006). SMART approach should be adopted by the management so that they will work for the effective goals and targets to track the project constraints like cost, schedule and scope it must be well documented, Six-Sigma methodologies is equally applicable in manufacturing and service sectors, for the application of Six-Sigma process approach should be adopted by the management, Six-Sigma forms a strong basis for total quality management, by encouraging and accepting the cultural change the Six-Sigma project can be made successful and beneficial for the organization, Six-Sigma approach requires change and sustainability in each activity within the organization, Six-Sigma approach is perceived as a tool and technique to enhance the efficiency of a process or increase the quality of a product or service, lack of resources is one of the major constraints for the application of Six-Sigma in industry, the effectiveness of Six-Sigma could be achieved by managing the internal processes of the organization, strategy is a course of action and it is directly linked with the internal processes, every process of the organization should be strategy focused and action oriented, Six-Sigma approach gives an opportunity to the organization to provide 99.9997% defect free product or service to customers, SWOT analysis plays a vital role in describing a business in terms of those factors that have the maximum impact on business, SWOT analsis should perform in every organization in order to understand the current position while predicting its future threats and opportunities, the continuous education and training of managers and employees is very compulsory to make sure that the complex Six-Sigma techniques are effectively applying and implementing.

Six-Sigma in industries: This part of research study explains the reported benefits of implementing Six-Sigma in different sectors like manufacturing, financial, healthcare, engineering and construction, research and development.

Manufacturing sector: The term Six-Sigma was firstly used by Motorola in the 1980s taking it as part of its quality performance measurement and improvement program. Now Six-Sigma has applied successfully in various other manufacturing organizations such as "General Electric", "DuPont", "Boeing," "Toshiba", "Seagate", "Allied Signal", "Kodak", "Honeywell", "Texas Instruments", "Sony", etc. (Kwak and Anbari, 2006).

Financial sector: In this modern era, it is demanded from the finance and credit institutions to reduce the cash collection cycle time and variation in collection performance to stay competitive (Kwak and Anbari, 2006). According to the nature of financial institutions functions the most distinctive Six-Sigma projects include increase the accuracy of distribution of cash to reduce bank charges, automatic payments, improving accuracy of reporting, reducing the defects of check collection, etc. So, in the banking sector the Bank of America "(BOA)" comes in the pioneers in adopting and implementing Six-Sigma concepts to modernize operations, attract and retain customers and create competitiveness over credit unions (Kwak and Anbari, 2006).

BOA is applying different Six-Sigma projects in different areas. By successfully implementing the Six-Sigma concept, the BOA reported that there is 10.4% increase in customer satisfaction and 24% decrease in customer problems (Uprety, 2009). Six-Sigma principles also applied in American Express to improve external vendor processes and eliminate non-received renewal credit cards. Through this approach, there is an increase in sigma level of 0.3 in each case (Kwak and Anbari, 2006). Few other financial institutions like “GE Capital Corp”, “JP Morgan Chase” and “SunTrust Banks” are applying the Six-Sigma technique to focus on and improve customer requirements and customer satisfaction (Kwak and Anbari, 2006).

Healthcare sector: Due to the healthcare nature of zero tolerance for mistakes and potential for reducing medical errors, the healthcare sector and the Six-Sigma principles are very well harmonized and effective. Six-Sigma projects include improving timely and accurate claims settlement, streamlining the process of healthcare delivery and reducing the inventory of surgical equipment and related costs. Six-Sigma is also adopted in the ‘University of Texas MD Anderson Cancer Center” at the radiology film library and improved service activities greatly. The same concept was also applied in the same institution’s “OPD CT exam lab”, the preparation time of patient was reduced from 45 min to <5 min in many cases and it was reported by the institution that there was a 45% increase in examinations with no additional machines or shifts (Kwak and Anbari, 2006).

Engineering and construction sector: In the year 2002, “Bechtel Corporation” was one of the largest engineering and construction companies in the world, it got the great saving of $200 million and done an investment of $30 million in Six-Sigma program for the identification and prevention of rework and defects in everything from design to construction to on-time delivery of employee payroll (Kwak and Anbari, 2006).

Research and development sector: In R&D organizations, the main objectives for the implementation of Six-Sigma projects are to reduce cost, increase speed to market and improve “R&D” processes. To gain the fruitful results and to measure the effectiveness of Six-Sigma project the organizations need to focus on data driven reviews, improved project success rate and integration of R&D into regular work processes. It is reported that through the implementing of “DFSS” process the development and manufacturing of the new prototype at “W.R. Grace (Refining Industry)” was cut to 8-9 months from 11-12 months (Kwak and Anbari, 2006).

MATERIALS AND METHODS

This is an analytical and case study based research which describes the study of Six-Sigma application in a manufacturing organization. So, according to the nature of this research study we used the 1st methodology of Six-Sigma DMAIC:

Define: At the 1st stage, we defined my study goals/objectives, e.g., reduce the machine downtime, increase the quality.

Measure: At the 2nd stage, we measured the existing system and developed a valid and reliable “metrics” that helped to monitor the progress towards achieving those goals and objectives.

Analyze: At the 3rd stage, we analyzed the whole system or process to identify the ways to eliminate the gap/flaws between the current performance of the system or the process and to achieve the desired goals/objectives and applied the statistical tools for analysis.

Improve: At the 4th stage, we proposed the possible improved the system, found the new ways to do the things better, cheaper, efficiently and faster. We used Six-Sigma tools and techniques to implement new approach and to validate the improvement in processes.

Control: At the 5th stage, we developed the control plan and gave recommendations to control the proposed modified system.

Research scope: The scope of this research study is to apply the main concept of Six-Sigma to reduce the machine downtime but the application is being limited to DMAIC methodology.

Research design and methodology: Generally, there are three methods of research design which are surveys, experiments and case study mostly used during the research. For this study we used “Case-Study” to collect the objective evidences and to conduct this case study. Personal visits were made to collect the required data and information with the purpose to get the true picture of the problem and not just to record what they say about themselves. According to the nature of the study, the DMAIC “(Define, Measure, Analyze, Improve and Control)” methodology of Six-Sigma is used.

Manufacturing structure: Before starting it there is a complete process flow chart of manufacturing 12.7×108 mm Ammo (Aircraft and Anti-Aircraft Ammunition floor) structure for the clear understanding about the current process (Fig. 4 and 5). Summary of 12.7×108 mm Ammo Manufacturing Floor Structure (Air Craft and Anti-Aircraft Ammunition).

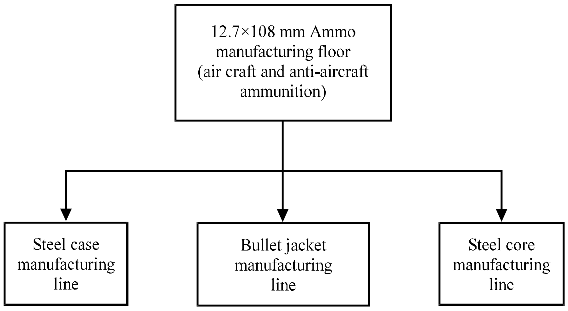


Fig. 4: Process flowchart of manufacturing 12.7×108 mm ammunition (aircraft and anti-aircraft ammunition floor)

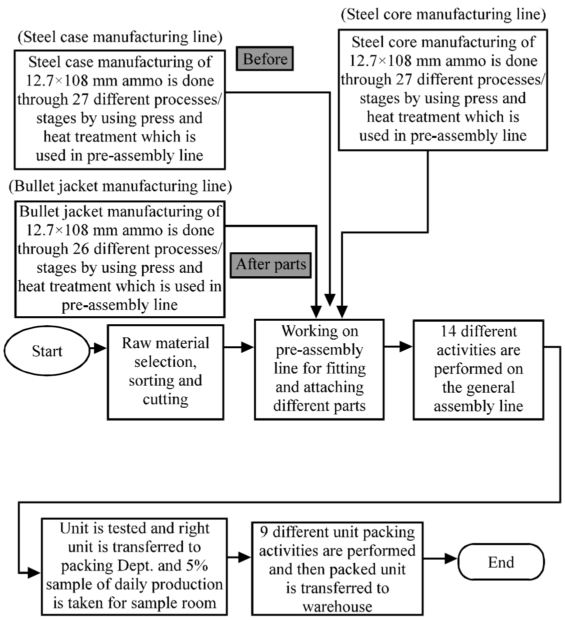


Fig. 5: Summary of 12.7×108 mm ammo manufacturing floor structure (air craft and anti-aircraft ammunition)

RESULTS AND DISCUSSION

Define phase

Problem statement: A conventional arms and ammunitions company had an average downtime 21% during the first quarter 2012, resulting in an additional labor and overhead cost of Rs. 10.95 million. This cost could be exceeded up to Rs. 40.0 million if the current trend continuous within a year. The main objective of this research project is to reduce the total machine downtime by at least half to the maximum of 10.5% and not to increase that afterward and through this way the company will be in a better position to meet the market demand and its own daily production target without the requirement of overtime.

SIPOC diagram: For the clear understanding of the process itself a "Process map SIPOC" and "Flow-Chart" is developed (Data Collection and Measurement). The outputs relevant to the machine downtime of all process are attributing in nature and recorded in the form of network database. Some of the major issues that cause the machine downtime are as in Fig. 6. Process flow chart is given in Fig. 7.

Measure phase

Histogram: Histogram is showing the distribution of downtime in minutes. Downtime of machine is positively skewed according to following histogram (Fig. 8 and 9).

Descriptive analysis (min., max., mean and SD): Table 5 and 6 show that the mean of downtime is 100.44. The median of downtime is 80. The range of a set is the difference between the highest and lowest values. The range of machine of downtime is 300. Graph shows that 95% of data will lie between 82.36-118.52 for mean confidence interval and 95% of data will lie 60-110 for median confidence interval.

Multiple bar chart: According to this multi bar chart, it is cleared that in these 3 months which are (April, May, June), the electricity problem, shortage of material, quality issues, machine fault and reactive maintenance are the five critical problems (reasons) of downtime which are ultimately affecting the daily production target and overall performance. Based on 3 months data the researchers found the following reasons (problems) of machine downtime and their respective frequency of their occurrence in 8 h shift (Fig. 10)

Pareto analysis: According to this Pareto chart, it is cleared that the electricity problem, shortage of material, quality issues, machine fault and reactive maintenance are the five critical problems (reasons) of downtime (based on 80-20 rule) which are ultimately affecting the daily production target and overall performance (Fig. 11).

Pie chart: Pie chart is showing the percentage of each downtime reason, according to this 29.9% area is covered by the EP, 20.9% area is covered by SM, 16.4% area is covered by QI, 7.5% is covered by RM and 7.5% area is covered by MF and the rest of reasons (factors) have lesser percentage. Therefore, the company should focus on the first five major areas which are most significant for its performance and production target (Fig. 12).

Suppliers	Inputs	Process (Downtime)	Output	Customers
Part vendors	Part quality machine jams	Step1: "Machine fault occurs"	Defective parts	Final assembly
Inventory control system	People reaction time part availability	Step 2: "Operator investigates fault"	Additional labor and overhead cost	
Production planning	Switch over another part (change-over)	Step 3: "Operator makes decision to clear fault or ask for mechanics"	Part yield Machine efficiency Labor	

Fig. 6: Process mapping SIPOC diagram

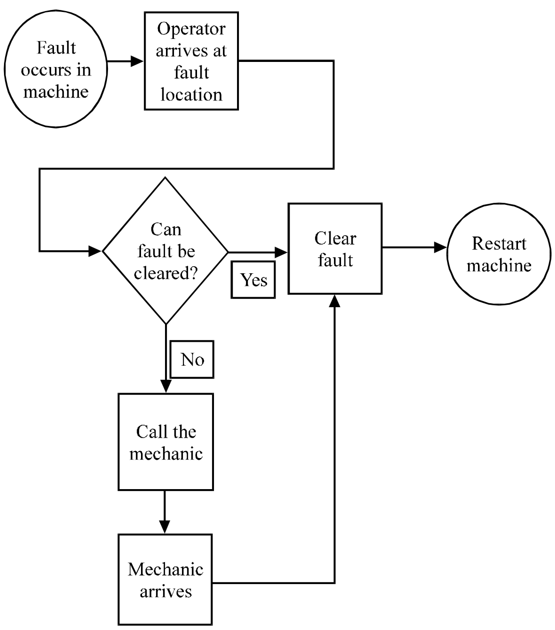


Fig. 7: Process flowchart

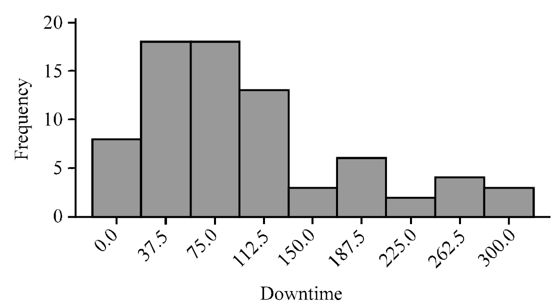


Fig. 8: Histrogram of downtime

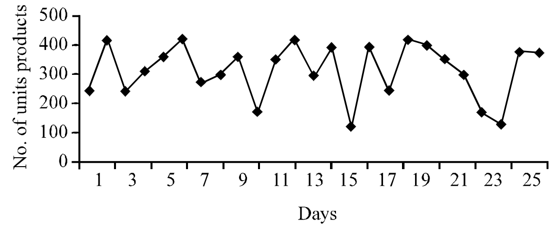


Fig. 9: Production chart

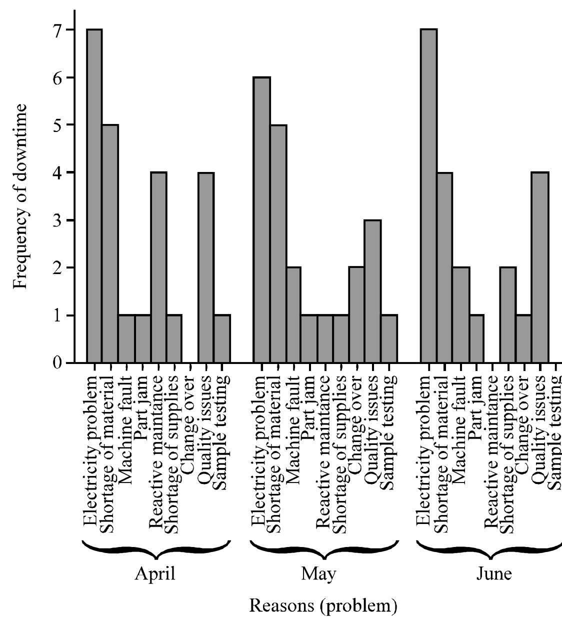


Fig. 10: Downtime reasons and frequency

Table 5: Downtime reasons vs frequency

Variable	Sum	Mean	Median	Min.	Max.	Range	SD
Down time	7533	100.44	80	0	300	300	78.58

Sigma calculation

Maximum working hours

(8 h/day×6 (No. of working in a week)) = 48 h/week

Allowable down-time = 6 h/week

Total allowable working hours = (Max working h-allowable downtime)
= 48-6 h
= 42 h/week (2520 mint/week)

Additional down-time = 4.1 h/week (246 mint/week)

Time required to produce one unit = 1 mint

Maximum production capacity = (Total allowable working time×Time consumed to produced one unit)
= (2520 mint×1)
= 2520 units/week

Total units produced (according to given information) = 2274 units/week

Production loss due to extra down-time = 246 units/week

Defect Per Opportunity (DPO) = (Production loss/Max production capacity)
= (246/2520)
= 0.0976

Defect Per Million Opportunity (DPMO) = (DPO×1000000)
= (0.0976×1000000)
= 97600

Sigma value = 2.79 Sigma

Table 6: Downtime reasons vs. frequency

Reasons (problem)	April	May	June	Total
Electricity problem	7	6	7	20
Shortage of material	5	5	4	14
Machine fault	1	2	2	5
Part jam	1	1	1	3
Reactive maintenance	4	1	0	5
Shortage of supplies	1	1	2	4
Change over	0	2	1	3
Quality issues	4	3	4	11
Sample testing	1	1	0	2

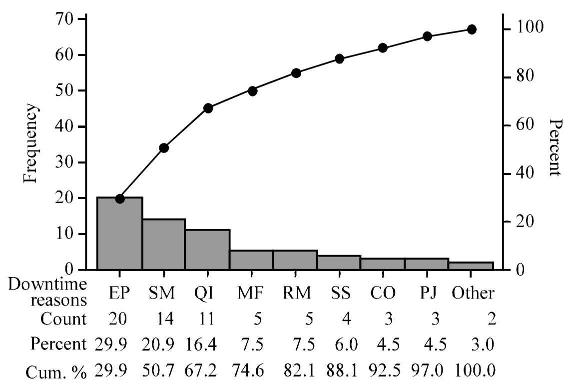


Fig. 11: Pareto chart of downtime reasons

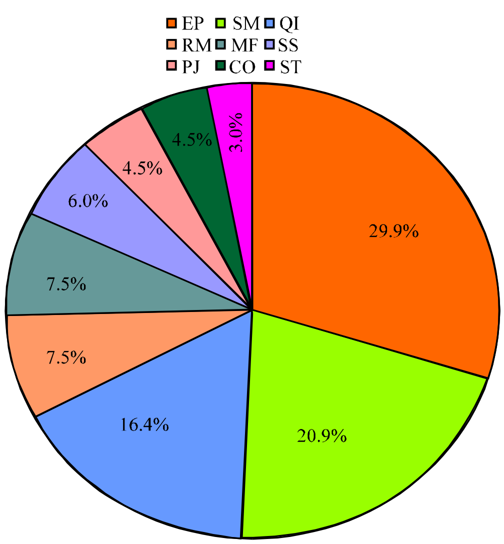


Fig. 12: Pie chart of downtime reasons

Table 7: One-way ANOVA (down-time versus reasons)

Sources	df	SS	MS	F-values	p-values
Reason	8	129841	16230	3.98	0.001
Error	58	236701	4081		
Total	66	366542			

$S = 63.88$, $R^2 = 35.42\%$, R^2 (adj) = 26.52%

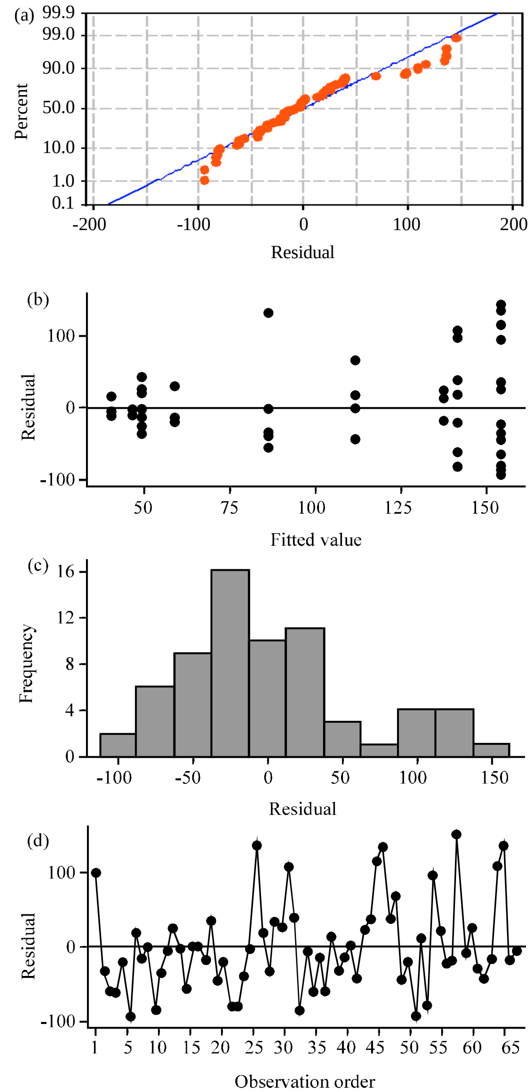


Fig. 13: One-way ANOVA: a) normal probability; b) versus fits; c) histogram and d) versus order

Analyze phase: The one-way ANOVA shows that on average all critical reasons are not equally inputting machine downtime (Fig. 13 and Table 7). As the $p<0.05$.

Cause and effect diagrams: According to 4-M (man, machine, method and material), the researcher did a comprehensive study to find out all the possible causes of downtime to develop the cause and effect diagram. It is cleared in Fig. 13 that the two factors (material and method) have the high percentage of possible process variation rather than the other two factors (man and machine) (Fig. 14).

The analysis was done on the top five downtime reasons (factors) which were demonstrated in the pareto chart. According to pareto chart, it is cleared that the electricity problem, shortage of material, quality issues, machine fault and reactive maintenance are the five critical

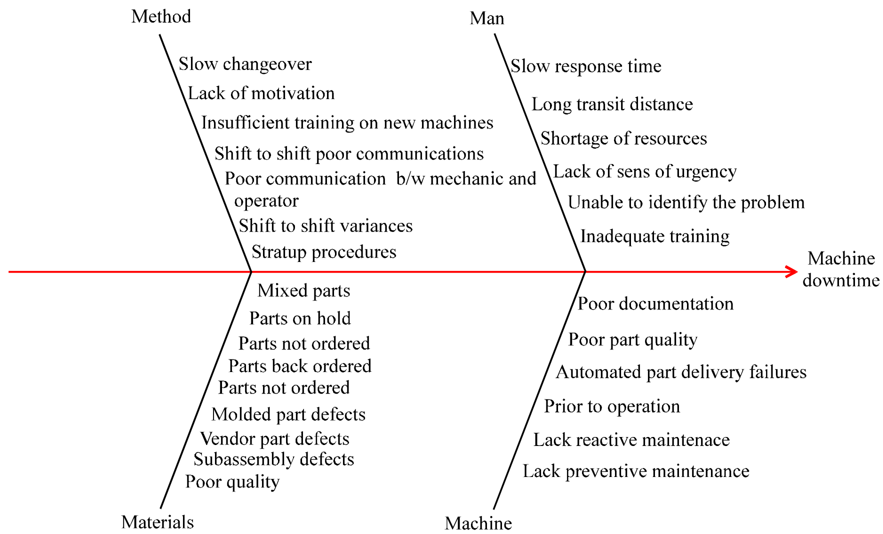


Fig. 14: Cause and effect diagram of possible process variation

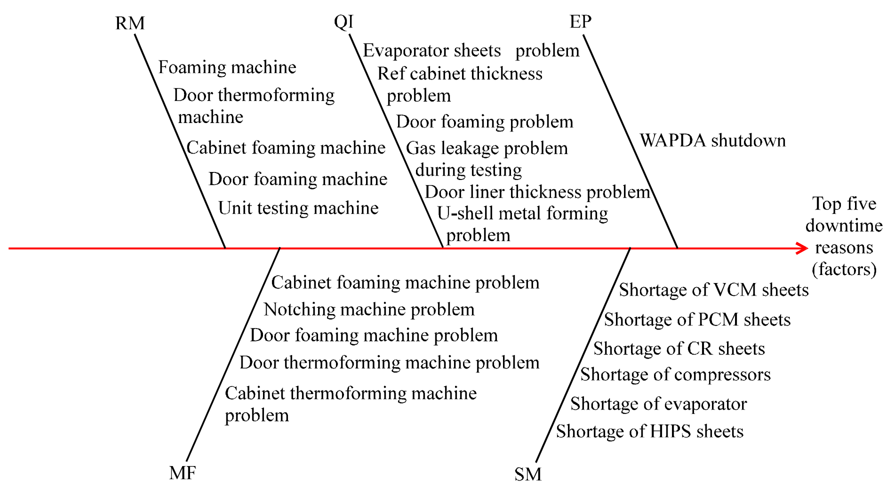


Fig. 15: Cause and effect diagram of downrime reasons

problems (reasons) of downtime (based on 80-20 rule) which are ultimately affecting the daily production target and overall performance. All these factors have the maximum percentage (Fig. 15).

Improve phase

Process capability analysis: In order to complete the improve phase, the procedures for carrying out the following activities in sequence shall be developed:

- Identify the potential techniques to achieve the improvements (tools: total productive maintenance, 5S, standardized work, setup reduction, kaizen)
- Improve the data collection methods and techniques
- Work Instructions (WI)
- Control plans
- 5S methodology
- Total productive maintenance
- Spare parts inventory
- Training of new employees "(rotation system)"
- Process flow diagram/charts

On the initial stage, it is assumed that if the company addresses the 1st major problem (electricity shutdown) of downtime which has the maximum frequency and percentage (41%) then the process capability analysis will be as in Fig. 16.

The analysis shows that the data is positively skewed and by putting the LSL (0) and USL (60) only the 51.91% of the data falls within these limits and the 49.09% data falls outside the USL (Fig. 17).

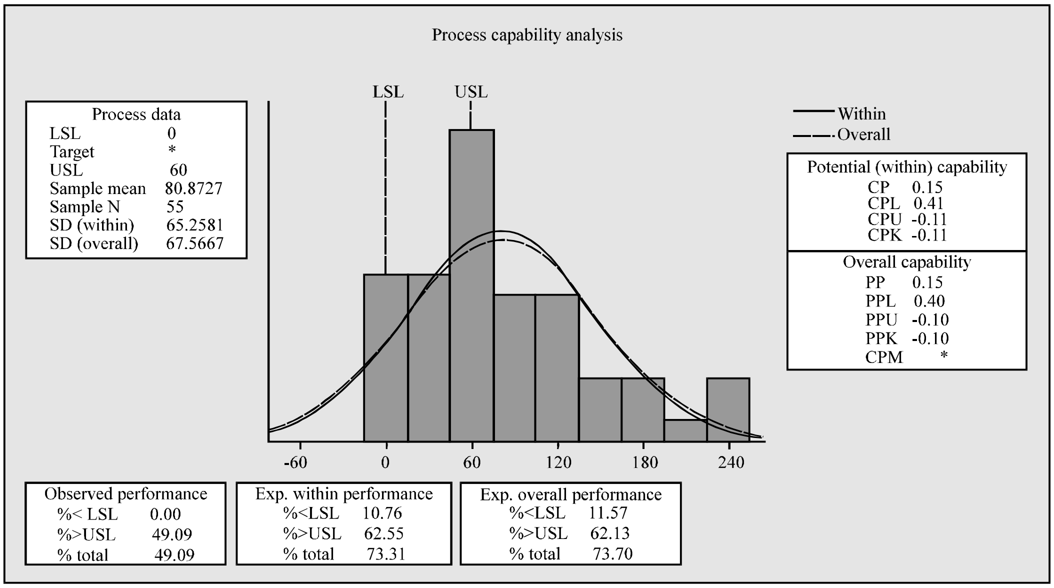


Fig. 16: Electricity shutdown

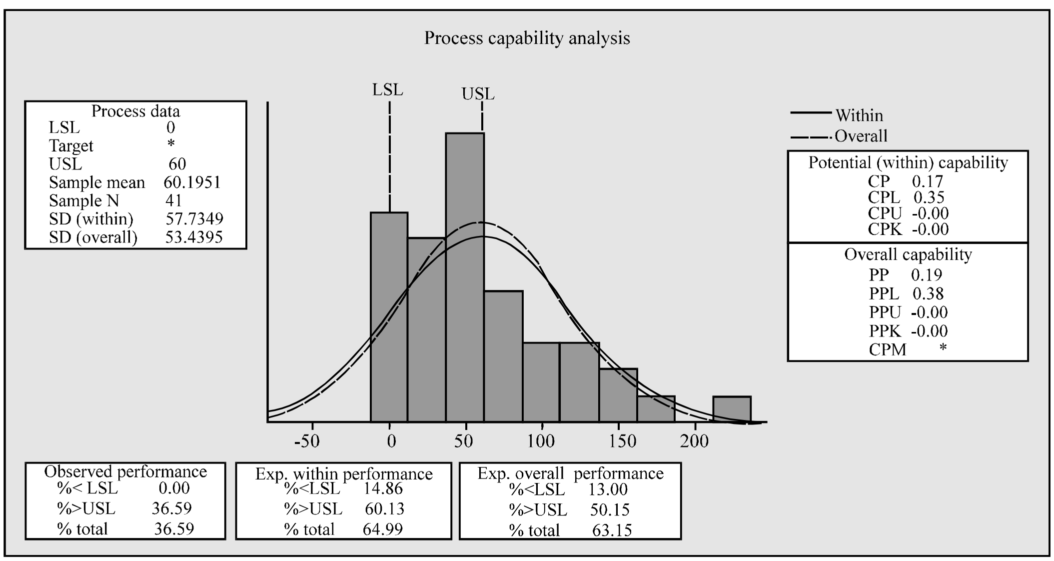


Fig. 17: Shortage of material

On the 2nd stage, if the company addresses the 2nd major problem (shortage of material) of downtime which has the 2nd maximum frequency and percentage (27%) then the process capability analysis will be as in Fig. 18.

The analysis shows that the data is positively skewed and by putting the LSL (0) and USL (60) only the 63.41% of the data falls within these limits and the 36.59% data falls outside the USL.

On the 3rd stage, if the company addresses the 3rd major problem (quality issues) of downtime which has the 3rd maximum frequency and percentage (7.16%) then the process capability analysis will be as in Fig. 18.

The analysis shows that the data is normally distributed and by putting the LSL (0) and USL (60) only the 60% of the data falls within these limits and the 40% data falls outside the USL.

On the 4th stage, if the company addresses the 4th major problem (machine fault) of downtime which has the 4th maximum frequency and percentage (7.40%) then the process capability analysis will be as in Fig. 19.

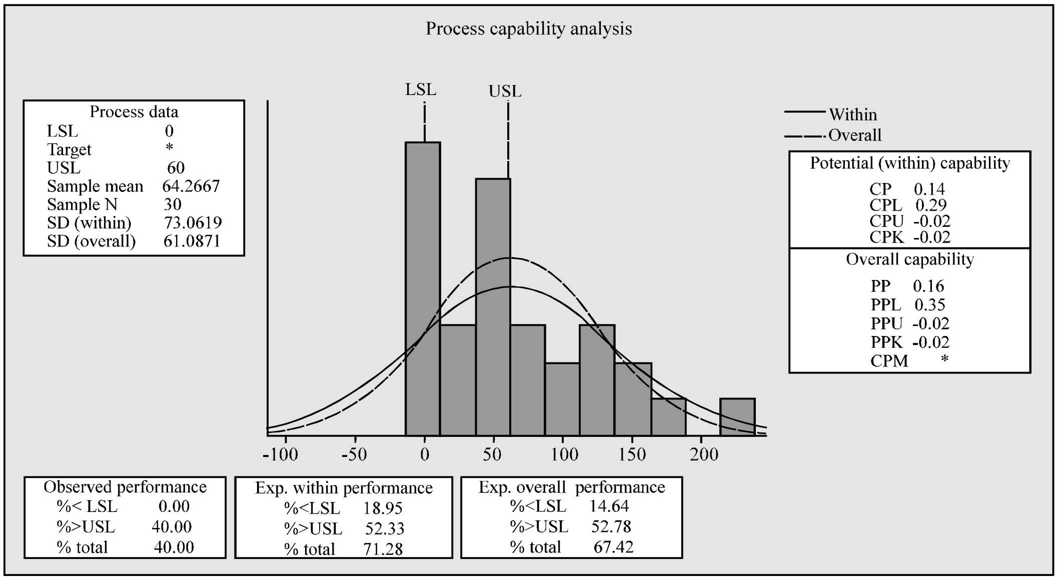


Fig. 18: Quality issues

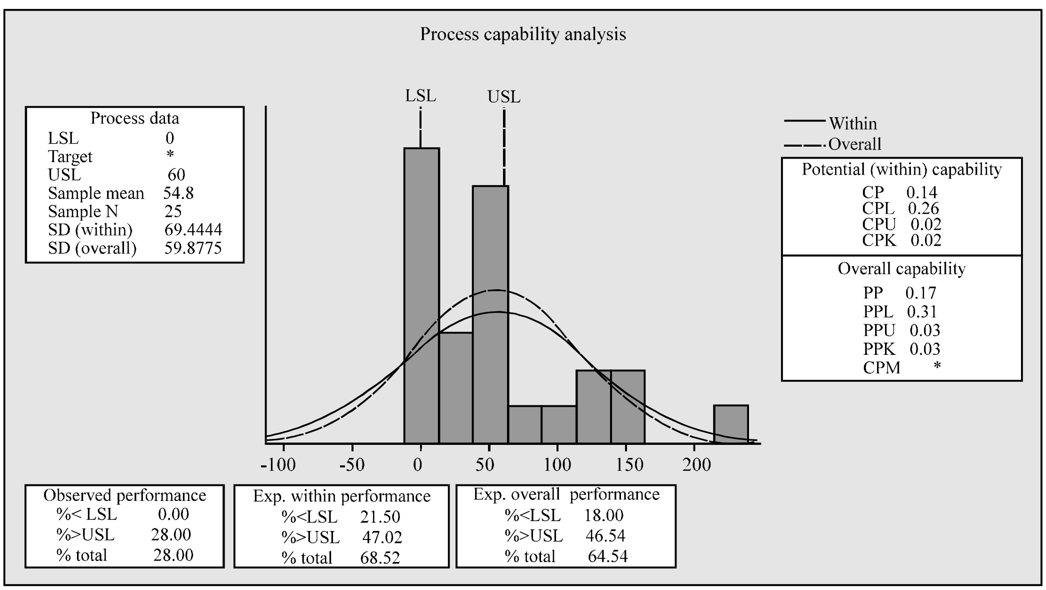


Fig. 19: Machine fault

The analysis shows that the data is normally distributed and by putting the LSL (0) and USL (60) only the 72% of the data falls within these limits and the 28% data falls outside the USL.

On the 5th stage, if the company addresses the 5th major problem (reactive maintenance) of downtime which has the 5th maximum frequency and percentage (5.71%) then the process capability analysis will be as in Fig. 20.

The analysis shows that the data is normally distributed and by putting the LSL (0) and USL (60) only the 75% of the data falls within these limits and the 25% data falls outside the USL. On the 6th stage, if the company also addresses the 6th problem (shortage of supplies) of downtime which has the 6th maximum frequency and percentage (7.30%) then the process capability analysis will be as in Fig. 21.

The analysis shows that the data is positively skewed and by putting the LSL (0) and USL (60) only the 93.75% of the data falls within these limits and the 6.25% data falls outside the USL. This is a big breakthrough in the process improvement and optimization.

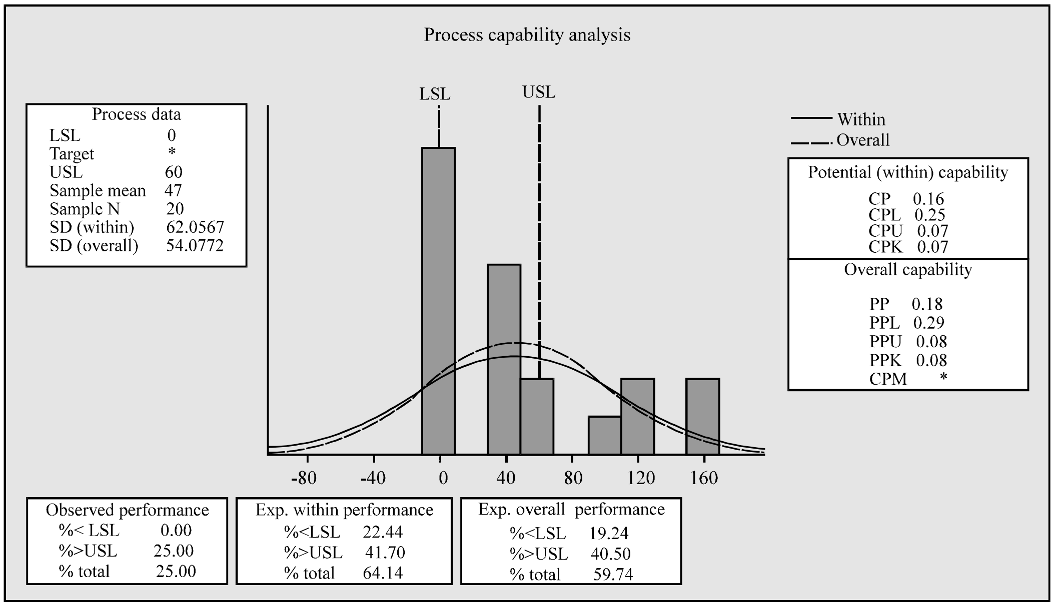


Fig. 20: Reactive maintenance

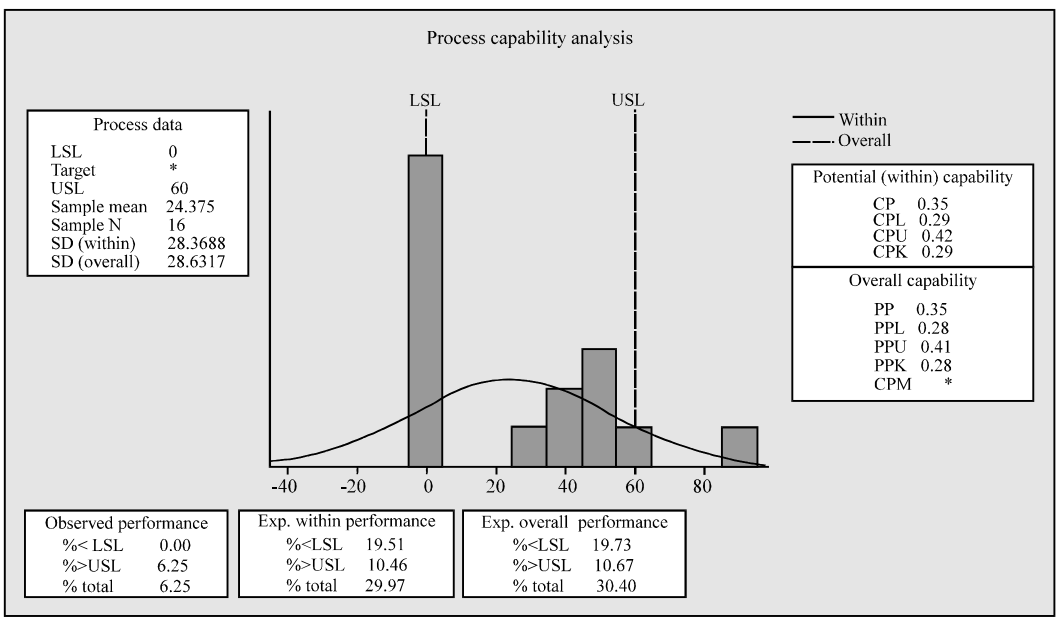


Fig. 21: Shortage of supplies

Improved sigma level

Maximum working hours
(8 h/day×6 (No. of working in a week)) = 48 h/week
Allowable down-time = 6 h/week
Total allowable working hours = (Max working hours-Allowable downtime)
= 48-6 h
= 42 h/week (2520 mint/week)
Additional down-time = 3.75 h/week (225 mint/week)
Time required to produce one unit = 1 min
Maximum production capacity = (Total allowable working time×Time consumed to produced one unit)
= (2520 mint×1)
= 2520 units/week
Total units produced (according to given information) = 2295 units/week
Production loss due to extra down-time = 225 units/week
Defect Per Opportunity (DPO) = (Production loss/Max production capacity)
= (225/2520)
= 0.0893
Defect Per Million Opportunity (DPMO) = (DPO×1000000)
= (0.0976×1000000)
= 89285
Sigma value = 2.85 Sigma

Control phase: Lean Six-Sigma activities must be adopted to continuous improve, control and maintain the established process or system like improve the data collection methods and techniques, Work Instructions (WI), control plans, 5S methodology, total productive maintenance, spare parts inventory, training of new employees "(rotation system)", process flow diagram/ charts. The additional monitoring plans should also take up like review the statistical data of machine downtime at weekly team meetings, create the real-time monitoring of machine faults occurrences using control charts and analysis, develop and implement the monitoring chart for individual machine downtime, observe the given preventive maintenance schedule to enhance the efficiency of machines.

Control charts (X Bar and R Chart): Figure 22 is showing that process is statistical in control. Improved process flow chart improved process flow chart is show in Fig. 23.

Preventive maintenance schedule: The maintenance department is responsible to conduct the corrective and preventive maintenance. Preventive maintenance has to be done in two ways. Periodic (e.g., 15, 30 and 45 days) whenever, preventive maintenance is due depending on the type of the machine and preventive maintenance should be done when the machine is free from the line flow by keeping the machine in the line. The following maintenance formats for different machines have been designed and the maintenance manager is responsible to get it done accordingly (Table 8 and 9).

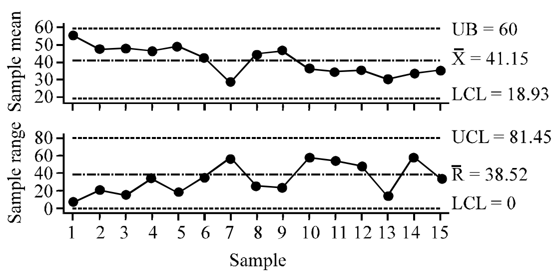


Fig. 22: Control charts (X bar and R chart)

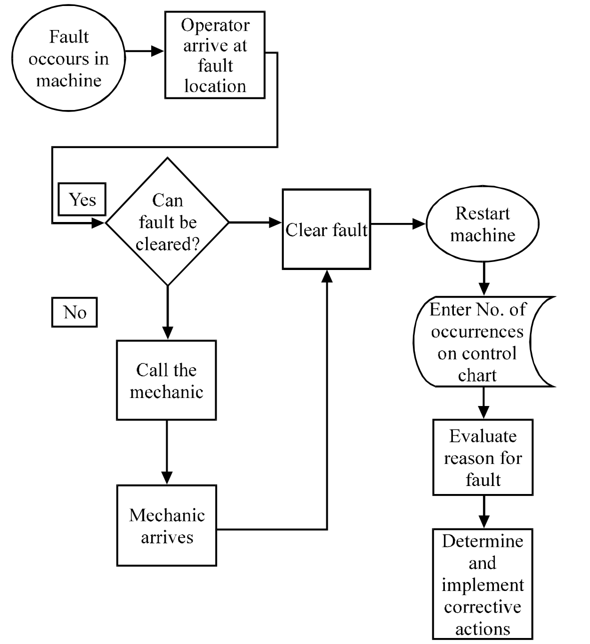


Fig. 23: Improved process flow chart (monitoring chart for individual machine downtime)

Table 8: Preventive maintenance schedule

M/C No.	Main. date	Due date	Main. date	Due date	Main. date	Due date	Main. date	Due date
1	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
2	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
3	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
4	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
5	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
6	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
7	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx
8	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx	xx-xx-xxxx

Table 9: Preventive maintenance log sheet

					Things to be checked					
M/C No.	M/C type	Line	Main. on	Next due	1	2	3	Remarks	Mech. sign	Sup. sign
1	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
2	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
3	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
4	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
5	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
6	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX

CONCLUSION

After conducting a detail and comprehensive analysis, we may conclude that the process capability analysis of the current process shows that the data is positively skewed and by putting the LSL (0) and USL (60) only the 40% of the data falls within these limits and the 60% data falls outside the USL. The values of Cp and Cpk are also giving this information that the process is out of control. The pareto chart (based on 80-20 rule) clears that the electricity problem, shortage of material, quality issues, machine fault and reactive maintenance are the five major problems (reasons) having the maximum percentage of downtime which are ultimately affecting the overall performance of process and also the daily production target; electricity problem (40.94%), shortage of material (26.28%), quality issues (7.16%), machine fault (7.40%), reactive maintenance (5.71%). In addition, if the company resolves all these issues (problems) regarding the downtime then it will be in a better position to reduce cost, improve the current process, reduce the overtime and the percentage of scrape and rework. The company can also achieve the Six-Sigma by addressing these major problems.

LIMITATIONS

The research study was carried out under some limitations like only the manufacturing of 12.7×108 mm Ammo (aircraft and anti-aircraft ammunition) floor is selected to do this case-study. Though, the researchers tried to get the maximum data but as the maximum. Companies do not allow to go in depth to take proper accurate data. So, such limitations were also faced here to collect the data. The support of trained people of concerned department was available but they were less informed about the quality tools. The researchers tried their level best to synchronize the sequence and data as much as possible.

RECOMMENDATIONS

In the light of results, we may suggest future recommendations to improve the current process and system: the proposed improvement analysis (which is performed in the improve phase of the study) shows that the company should address those five major downtime problems (which are highlighted in pareto chart) one by one or simultaneously which will bring a big breakthrough in the process improvement and will ultimately improve the sigma value. Company need to be develop and practically apply the Production Planning and Control (PPC) System to address the relevant downtime problems (e.g., shortage of material, shortage of supplies and change over). There is also need to incorporate the Total Productive Maintenance (TPM) (an important Lean Six-Sigma activity) to reduce the machines faults and to reduce allowable downtime to enlarge the production rate and to improve the overall performance of the system. To increase the efficiency and accuracy of work, company should install or modify the existing machines with sensors to avoid accidents/tool breakage and install the multi station presses line system for both steel case and bullet jacket lines to increase the productivity, accuracy and quality of work. Selection of materials, process and tooling used for the manufacturing of 12.7×108 mm ammo should be according the required specification to increase the efficiency and accuracy of work. Brass material should be used instead of low carbon high grade steel for the manufacturing of 12.7×108 mm ammo. Because Brass is a softer, metal and easy to process as compared to steel and the other advantage of Brass material is in less consumption of tooling. Preventive maintenance should be assured and implement in the shop floor. Establish a Training and Development Department for individual unit to groom, train and specialized the current workforce and the new induction.

APPENDIX

Appendix A: Training form

Section A: Trainee data

Date: --

Department: -----------------------------------

Employee name: -------------------------------

Designation: -----------------------------------

Suggested by: ----------------------------------

Section B: Reasons for training (mark reason)

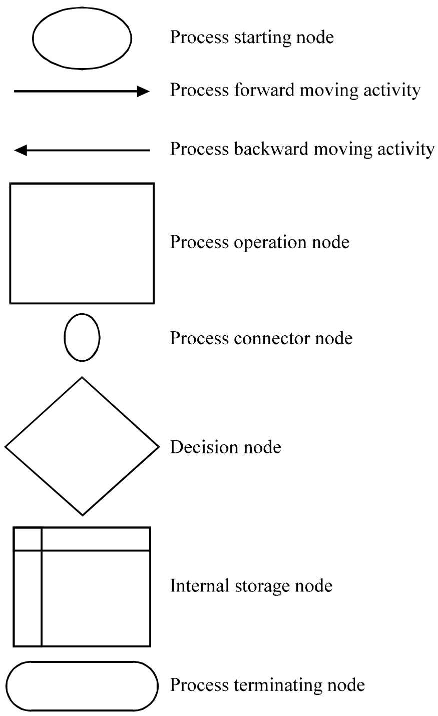
Changes in services or operations	xxx
New or revised procedures or changes in the quality policy	xxx
Inadequate performance of individuals or groups of personnel	xxx
Corrective/preventive actions	xxx
To enhance the competence level	xxx

Section C: Training required/suggested

T. No.	Course title	Course code	Training details	Internal/ external	Proposed trainer
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx	xxx

Department Head   HR Department   Chairman/V.C/Director

Appendix B: Process flow chart symbols



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