APPLICATION OF DMAIC APPROACH FOR REDUCTION OF CUTTING OIL CONSUMPTION

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Abstract

Industries involved in the manufacturing of metal products generate many types of wastes. Wastes tend to increase consumption of resources. Increasing consumption increases the production cost. There is a constantly increasing pressure on the industries to bring down the production cost. This internally gives scope for continual improvements to reduce waste.

The primary purpose of this project was to reduce the amount of cutting oil consumed while manufacturing fuel injection pumps housing in a manufacturing line. DMAIC approach was adopted in this project. It involved Defining project charter, measuring past data about consumption of oil and production quantity, analysing possible causes through co-relating and prioritizing through process FMEA, Improving the prioritized activities and to Control the variation and sustain the improvements observed.

The case shows DMAIC as an effective approach for the machining industries to improve the stability of their processes and increase profitability through driving down manufacturing costs. Result showed significant reduction in cutting oil consumption measured as oil consumed per product manufactured. Cutting oil consumption reduced by 40% thereby saving of 3 lakhs per annum. Modification in the process resulted in to elimination of non value added activities and significant reduction in cycle time.

Key Words: Machining Industry, Waste, Cutting Oil, Profitability

Abbreviations

DMAIC  Define, Measure, Analyse, Improve and Control
GD    Gang drilling machine
KPI   Key process inputs
MS-1  Multi spindle 1st machine
MS-2  Multi spindle 2nd machine
SPM   Special propose machines
VOC   Voice of customer

1. INTRODUCTION

Industries involved in manufacturing of metal products generate many types of wastes. Wastes tend to increase consumption of resources. Increasing consumption increases the production cost. Due to changing the economic conditions companies are striving hard to bring down the production cost. This internally gives scope for continual improvements to reduce waste.

DMAIC is most widely used approach in Six Sigma programs, it has been considered as a powerful manufacturing strategy [1] that employs a well-structured continuous improvement methodology to reduce process variability and drive out waste within the manufacturing processes using effective application of statistical tools and techniques.

The primary purpose of this research is to apply DMAIC approach to reduce the neat cutting oil consumption in a leading manufacturer of fuel injection pump housing. Results achieved are reflected in manufacturing cost savings and process improvements on the shop floor.

1.1 Need for Reducing Cutting Oil Consumption

The current trend in industry is to minimize neat cutting oil used in machining to an optimum consumption level. By reducing cutting oil consumption organizations can reduce production cost, waste disposal costs, increase productivity of cutting oil and to improve work place safety and health.

Reduce manufacturing cost: Neat cutting oils are so called because they do not contain water [2]. It contains 99% of petroleum products. Increasing crude oil price [3] has effect on cutting oil price. The cutting oil consumption must be optimized, as to overcome fluctuating price of petroleum products effecting business. Cost reduced will directly impact in increased profits, there by business can have increased market share by slight reduction in price they offer to customer.

Productivity of neat cutting oil: The effective utilization of resource is amongst the most important management activity in a developing manufacturing scenario. Under utilization resources will result in to increased production costs.

Neat cutting oil does not face problems due to bacterial activities unlike faced by water based or synthetic coolants [2]. Key property of neat cutting oil is heat transferability and rust prevention. It is usable till it has this property. Wasting before this point will reduce its ability to serve the manufacturing thereby reducing its productivity.

Environmental issues: Manufacturing industry is one of the main roots of environmental pollution. Therefore, minimizing the environmental impact of the manufacturing industry has become an important topic [4]. Green manufacturing is a modern manufacturing
strategy, essential for 21st century manufacturing industries, its ultimate goal is to minimize environmental impact and resource consumption.

Nowadays, ever increasing environmental problems are becoming a serious threat to the survival and development of society. After publishing of ISO 9000 quality management standards and ISO 14000 environmental management system standards, one of greatest strategic challenges is to apply this series integrated into a management system in enterprises. [5]

2. DMAIC APPROACH

The research is done to reduce oil consumed in a fuel injection manufacturing line. Many attempts have been done prior to start of this effort. Efforts were done in micro level without major impact on financial performance. Hence need for proper approach towards identifying and attacking right problem was necessary. DMAIC approach was followed because the exact problem is hidden and process of oil consumption is statistical in nature. DMAIC provide a logical platform for identifying and improving process as well as to maintain consistency in observed improvements.

DMAIC is a Six Sigma acronym for the five interconnected phases of a process improvement project: Define, Measure, Analyse, Improve, and Control. At the project level, the DMAIC structure enables project teams to identify the root causes of process variation, design and implement solutions to resolve these problems and to then measure and control the improvements.

Define exists to scope out and communicate the goals, benefits and expectations of the upcoming deployment. The Measure and Analyse phase uses the customer expectations to set business performance targets and then analyses the current business capability of meeting these. To understand what customers expect of the business, they are directly asked during the Voice of the Customer (VOC) collection. The resulting customer requirements enable the setting of business performance standards, from which business-level KPIs are derived. Reliable business measurement systems provide the data that shows business leaders what is really happening in the business and are, therefore, a critical cornerstone of any Six Sigma and Lean initiative. Improve is when the causes of identified business-level issues are understood and a structured roadmap for solving them is put together. The Control phase delivers a continuous improvement program to ensure that the recent achievements are not one-off events, but instead form the basis of a reliable, repeating process [6].

2.1 Define Phase

Define phase is about defining problem or improvement opportunities [6]. Defining problems brings clarity in the scope of project. During this phase following activities were executed

   Project details
   • Problem statement: Increased production cost due to excessive cutting oil consumption as cost of petroleum products are increasing.

   • Goal statement: 25% reduction on cutting oil consumption per component by 31st January 2010 thereby increasing contribution to Rs 1.9 lakh per annum.

   • Assumptions: Cutting oil consumption is proportional to the amount of parts produced and measuring will be done accordingly.

Project team: A cross functional team was framed to address all needs of project. Team comprised of members from top management and middle level management. This enabled commitment and faster execution of the project.

2.2 Measure Phase

The purpose of the measure phase was to establish techniques for collecting data about existing performance that highlights the project opportunities and provide a structure for monitoring subsequent improvements [7]. To measure the extent of the problem and present performance, oil consumed per part scale is selected as provides a process based approach for measuring. During this phase following activities were performed.

Process mapping: A process flow diagram was used as a visual representation of all major steps and decision points in the process [7]. This facilitated in identifying potential problem areas, understanding the process flow.

Figure 1 shows the existing process flow, it involves replenishment and recirculation of cutting oil to the machines.
Cause and effect diagram: A cause and effect diagram is a tool that helps identify, sort, and display possible causes of a specific problem or quality characteristic [8]. It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome.

Figure 3 shows cause and effect diagram representing relation between cause and sub causes with excessive oil consumption. Causes are collected through brainstorming and suggestions. Totally 18 causes were identified.

2.3 Analyse Phase

This phase of the project was intended for identifying major root causes by data and process analysis. It facilitated to identify gaps between existing performance and goal performance. Analysing is carried out to narrow down to get key source of variation. It involved following steps.

Stratification analysis: Oil consumed stratified as to understand key source of consumption. It was clear as shown on Figure 4 MS-1 and MS-2 are machines which were consuming 81% of oil. So causes concerned with SPM and GD machines were ignored from critical causes list.

Distribution analysis: Distribution analysis was carried out to analyse pattern of oil consumption and variation. From Figure 5 it is clear that distribution is normal but there are isolated points on both sides. This increases spread of the process. Spread is increasing because of the strategy of replenishment which is skill based.

After this analysis causes for spread concerned with property of oil are ignored as previous data from test report of each batch showed a consistent value. Lack of interest was also ignored as best use of equipment was done which prevents oil wastage. It gave clear indication that storing of oil in buffers or the strategy of replenishment are possible causes of increasing spread (In fact replenishing decisions were done based on skills not with any indication system).

Correlation analyses: Correlation illustrates significance of factor with the parent cause. In this case oil consumed per part is parent cause, compared with all other factors of production like average temperature, amount of material each machine removes, capacity of tank, operating time and cycle time. The results are tabulated in Table 1. Correlation is calculated using Pearson’s correlation formula.

Process FMEA: Process Failure Modes and Effects Analysis provides a structured, qualitative, analytical framework which taps the multi-disciplined experience of the team to brainstorm and prioritize the execution of actions. Table 2 represents FMEA done for oil consumption process.

2.4 Improvement Phase

The objective of improvement phase is to select and implement best possible solution for causes identified during analysis phase. The two prioritized causes from analysis phases are under consideration for improvement. In the present case improvement phase involved execution of following activities.
Oil consumed per part (ml)

Mean 42.90
StDev 7.760
N 25

Fig. 5 Distribution curve of oil consumed per part

Table 8. Correlation analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Machines</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil consumed per part (ml)</td>
<td>MS 1</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>MS 2</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>SPM</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>GD</td>
<td>2.15</td>
</tr>
<tr>
<td>Average oil temperature (°C)</td>
<td>MS 1</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>MS 2</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>SPM</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>GD</td>
<td>33</td>
</tr>
<tr>
<td>Material removed (grams)</td>
<td>MS 1</td>
<td>288</td>
</tr>
<tr>
<td></td>
<td>MS 2</td>
<td>116</td>
</tr>
<tr>
<td></td>
<td>SPM</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>GD</td>
<td>20</td>
</tr>
<tr>
<td>Oil available in tank (liters)</td>
<td>MS 1</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>MS 2</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>SPM</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>GD</td>
<td>50</td>
</tr>
<tr>
<td>Average operating time per shift (min)</td>
<td>MS 1</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>MS 2</td>
<td>370</td>
</tr>
<tr>
<td></td>
<td>SPM</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>GD</td>
<td>290</td>
</tr>
<tr>
<td>Cycle time (sec)</td>
<td>MS 1</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>MS 2</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>SPM</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>GD</td>
<td>18</td>
</tr>
</tbody>
</table>

Cause validation: Validation is done on narrowed causes from analysis phase, before starting improvement activities. The validation was conducted on experimental setup for both the causes. From the experimental study it was clear that prioritized two causes had contribution of 52% towards consumption of cutting oil as shown in Figure 6.

**Improvement action to reduce escaping oil during final chip disposal**

Metal chips are generated during machining. Chips are nothing but removed material during machining from raw material. Cutting oil is used to flush out the generated chips from cutting zone. Due to this chips absorb certain amount of oil.

To collect oil from damped chips, two alternative solutions were found. They are use of centrifuge and vertical storing methodology. In centrifuge chips are placed in an electrically driven drum which is rotated at higher speed for certain time. Due to centrifugal force cutting oil comes out of the chips. In vertical storing, compartments are created as to allow sufficient amount of time for oil to drain down naturally due to gravity. Figure 7 represents graphical representation of potentials and risk of both methodologies.

Table 9. Process FMEA

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Process/ Function</th>
<th>Potential Mode</th>
<th>Failure Potential Effect(s) of Failure</th>
<th>Severity</th>
<th>Potential Cause(s) of Failure</th>
<th>Occurrence</th>
<th>Current Process Controls</th>
<th>Detection</th>
<th>RPN</th>
<th>Action Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chip disposal</td>
<td>Oil escapes during final chip disposal</td>
<td>Increased oil consumption</td>
<td>7</td>
<td>Deposited one on one</td>
<td>8</td>
<td>Nothing</td>
<td>8</td>
<td>448</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>WIP storage</td>
<td>Temporary buffers</td>
<td>Increased oil consumption</td>
<td>5</td>
<td>Intermediate facilities to collect oil</td>
<td>3</td>
<td>Collection cans</td>
<td>4</td>
<td>60</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Oil replenishment</td>
<td>Oil circulation and filtration process</td>
<td>Increased time to drain and reach tank during recirculation</td>
<td>5</td>
<td>Deposition of chips one over the next, Chips not separated</td>
<td>5</td>
<td>Clean the tray once it is filled</td>
<td>4</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Improper oil lifting mechanism from recycled oil tank</td>
<td>Drop down during lifting from recycled oil tank</td>
<td>7</td>
<td>Lifting mechanism improper</td>
<td>7</td>
<td>Visual and skill based</td>
<td>8</td>
<td>392</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Skill dependent oil replenishment</td>
<td>Increases the spread of the distribution curve</td>
<td>5 No visual indication</td>
<td>3 Skill based</td>
<td>2 30 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cause/Effect Matrix:

- **Cause**:
  - Oil consumption
  - Average oil temperature
  - Material removed
  - Oil available in tank
  - Average operating time per shift
  - Cycle time

**Effect**:

- Increased oil consumption
- Deposition of chips one over the next
- Chips not separated
- Lifting mechanism improper
- No visual indication
Vertical storing methodology was aimed to implement. Basic idea is to create parallel compartments for storing chips. In previous situation when storage area was filled up to desired level, then immediate disposal was done, causing oil in the chips to escape. It was quantified that the oil takes 3 days to drain out by gravity from one meter of height of chips pile up. This necessitated the use of trolleys which can store the chips for 3 days minimum before final disposal to scrap dealers. Figure 8 represents newly added trolleys for parallel storing.

**Fig. 6 Cause validation**

Improvement action to reduce oil spillage during lifting from recycled oil tank

The oil drained down from stored chips, gets collected in an oil tank. From there oil is lifted with the help of rope and bucket mechanism manually. It is natural that lack of skills and fatigue on operator will result in increased oil spillage. Figure 9 shows the oil tank.

**Fig. 7 Risk and potential analysis plot for alternative solutions**

**Fig. 8 Improvement: parallel storage area**

To reduce oil wastage self priming motor was adopted to lift oil from recycled oil tank directly to a can. Figure 10 is schematic diagram of new oil lifting mechanism.

**2.5 Control Phase**

The final step of the DMAIC methodology is to institutionalize process improvement and to monitor ongoing measures to sustain improvement. Accordingly, the key actions taken during the control phase were

Revise format for consumption data collection

Data collection system or data collection approach should facilitate in collecting data easily and efficiently. A new data collection format to be filled up by the operator or supervisor was designed.

**Fig. 9 Oil collecting tank**

**Fig. 10 Improved mechanism for lifting oil from oil tank**

This new recording system improved accuracy of data collection as it allows recording multiple replenishments.

**SOP:** SOP is a written document or instruction detailing all steps and activities of a process or procedure [9]. In present case as process is modified, formulating new SOP was needed. SOP was formulated to instruct operating procedure. A pictorial SOP was formulated for easy understanding.

**3. RESULTS**

After implementation of improvements, measurements are done to analyse gap between expected and achieved results. The data are collected regarding oil consumption per part. By analysing the collected data following results are listed

3.1 Significant Reduction in Oil Consumption

Project execution brought in significant reduction in cutting oil consumption level. After measuring for 7 weeks it was found that average consumption has reduced by 40%. Figure 11 shows the overall changes in the oil consumption per part before and after implementation of improvements.
3.2 Increased Stability in the Oil Consumption Process

Stability is the ability of the process to perform same repeatedly. It is measured by standard deviation or coefficient of standard deviation. It is represented through distribution curve.

![Distribution curve](Image)

**Fig. 12 Distribution curve (Before and after)**

Figure 12 represents distribution curves, continuous line represents status of oil consumption before the start of improvements and dashed line is after implementation of improvement activities. It can be seen that standard deviation is improved and mean value got reduced.

3.3 Savings

Oil consumed per part was 42.90 ml previously, after implementation of proposed activities the oil consumption rate was 25.41 ml per part.

So,

\[
\text{Saving per part} = 42.9 - 25.41
\]

\[
= 17.49 \text{ ml/part}
\]

% of reduction of oil consumption

\[
\text{% of reduction} = \frac{42.9 - 25.41}{42.9} \times 100
\]

\[
= 40
\]

Saving per part = Oil saved/part X Cost of oil per ml

\[
= 17.49 \times 0.049
\]

\[
= 0.857 \text{ Rs/part}
\]

Average monthly production is 30,000 parts

So,

\[
\text{Saving per annum} = 0.857 \times 30,000 \times 12
\]

\[
= 3,08,523 \text{ Rs}
\]

4. CONCLUSION

- Variation in the consumption of oil per part was reduced which is indicated by standard deviation from 7.8 to 1.6.
- 40% reduction in oil consumption was achieved.
- Reduced oil consumption resulted in cost saving of Rs. 3 lakh per annum.

![Distribution of oil consumption per part Before and After](Image)

5. REFERENCES


