ROOT CAUSE ANALYSIS FOR REDUCTION OF WASTE ON BOTTLE FILLING AND CROWNING OPERATIONS

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ABSTRACT

The global market place has become increasingly competitive and volatile, thus resulting in the need for the players in the beverage industry to continuously improve their processes, especially on bottle filling and crowning operations. Waste reduction becomes an increasingly dominant force in the modern manufacturing world. The paper aims to apply Pareto analysis to identify the key area which results in waste at a case study company. The process is first mapped to outline the key inputs, outputs and all the possible wastes. Historical and current data for the filling and crowning operations is gathered so that the facts about the problem are accurately described. Ishikawa diagrams are then used to present the key problems and recommended solutions are implemented. SPSS software is used for statistical analysis to compare the before- and-after scenarios with the view to verify and validate the improvements made.
1 INTRODUCTION

In an increasingly competitive market place amongst the beverage industries, bottle filling industries in particular, show a clear and distinct need to improve their operations [1]. A typical bottle filling production line generally includes arranging the bottle, cleaning the bottles, filling, crowning, labelling, detection of the foreign bodies, and packing as shown in Fig 1. Waste during these operations has become problematic since it increases the production costs. With this in mind it became imperative to conduct a study on 1 such line to establish the root causes of waste during the bottle filling and packaging operations and thereafter put in place the right cost-effective measures to eliminate these losses.

Losses are defined as loss of product from the stated liquid tank agreed volume and the volume of product exiting the filler less all rejects. The only way to control liquid product loss is to identify the main problem areas in order to effectively work towards minimising the losses. Liquid tank to filler loss is product lost prior to the filler valve monitor (FVM) on the actual filler machine. These losses include incorrect declared and agreed volumes of the liquid tank. In the event of the valve system failing, the liquid is pushed away from the liquid tank through the flush system.

Figure 1: Flow diagram for bottle packaging operations

The aim of the paper is to identify and address the root causes of waste that arise during the bottling process of a case study company. Possible intervention measures are thereafter suggested as part of the study.

2 LITERATURE REVIEW

Enormous strides have been made in the last twenty years in the size, speed, quality of performance and complexity of bottle filling equipment. One of the key requirements of a filling machine is that the containers must be filled as quickly as possible with a commercially accurate quantity of product. The quality of the product must be maintained during the filling operation and there must be no mutually inflicted damage between the container and the filling mechanism [2]. When filling a bottle, the concern is to avoid the introduction of certain elements such as dissolved oxygen in some processes, which could invariably affect the accurate fill level of the product [3].
In general, filling machines are designed around a carousel of valves, allowing many bottles to be filled in a continuous system. The valves are based on mechanical and pressure actuation; pressure to open, mechanical springs to close. The filling level is determined by an open-ended pressure balance tube that projects into the bottle from the valve. As liquid enters the bottle, the pressure is balanced until the end of the tube is covered, which releases the valve to close by spring return [4].

Ridgway (1999) investigated the use of ultrasound monitoring and controller design methodologies as a means of on-line measurement of fluid levels in a bottling process. The bottling process was modelled using MATLAB and SIMULINK packages and controller designs were implemented to improve the response characteristics of the process [5].

When it comes to online detection of moving beer bottle, Zhang (2008) used a fusion algorithm based on segmentation of optical flow field and Susan’s operator under the condition of camera being fixed [6]. Yepeng (2007) asserts that the defect on bottle mouth is one of the most important defects of beer bottle and developed a set of defects-inspected system based on digital image process technology to eliminate unqualified bottles [7].

Hypothesis testing is a method used by researchers to determine how likely it is that observed differences between different sample estimates are entirely due to sampling error rather than underlying population differences. An important factor in hypothesis testing is to determine whether or not the difference between two observed means is due to stochastic variation and whether or not the difference is large enough to allow the conclusion that the two samples come from populations with different means [8]. Generally, real life problems are characterised by unknown values for the population variances. Under such circumstances, the independent t-test can be used to compare the means between two unrelated groups on the same continuous, dependent variable.

Significance tests can be grouped into parametric and non-parametric when analyzing data for hypothesis testing. Parametric tests are generally considered more powerful because their data are typically derived from interval and ratio measurements when the distribution is known, except for some parameters. Non-parametric tests are also used with nominal and ordinal data. Parametric tests place different emphasis on the importance of assumptions while nonparametric tests have fewer and less stringent assumptions. They do not specify normally distributed populations or homogeneity of variance [9]. Conclusions can then be drawn from the data that is subject to random variation, observational errors or sampling variation through statistical inference [10].

3 METHODOLOGY

3.1 Defining the problem

At this case study company it was revealed that product losses through wastage on the filling operations adversely impact the company with losses amounting to hundreds of thousands of rands per year being incurred.

Product losses arising during the filling processes have its own broad scope because within it there are different contributors to it and areas which can be focused on.

There are losses that could occur between the product tank and the filler/crowner discharge operation due to incorrect measurement in the being taken at either side. Further losses could be made up through: overfills, no crowns, distorted crowns, under fills, brand change, bottle defects, start-up, shut down and incorrect jetting. Figure 2 depicts typical product losses incurred per shift.

This paper focuses on an in depth study on the losses at the filler operation due to the fact that this was the operation highlighted as being the contributing factor within the overall process. The loss is measured as a ratio of loss incurred at the respective area against the withdrawn volume of product.
3.2 Process mapping

Process mapping is a powerful way of visualising the relationships between a sequence of actions required to execute a task, outlining the inputs to the process, the outputs and all the possible wastes. In the diagram below, the filling process is visualised, clearly outlining both the filling and crowning which are both performed by the filler. Although the illustration shows as if the overfills and underfills leave before crowning, in reality, these are only detected after passing through the fill inspection device which is placed after the filler/crowner.

Fig 3: Mapping of filling and crowning operations

3.3 Gathering historical data

The aim is to gather all the facts so that the problem is accurately described. We also wanted to identify where in the filling process the most product is lost, whether it is the actual filling or the crowning process that is contributing to the losses.

For the selected production line, data is collected manually using the appropriate form and fed into computer. Key parameters to be entered into the system include the bottle count, underfills and missing crowns for the shift. It must be noted that total product loss will not be calculated without the labeller counts having being inserted as well. “Good bottle” counts are obtained from the filler valve monitor and entered into data warehouse. There are two fill inspection points, one is after the filler and another is just before the labeller. The system computes the liquid loss using the simple formulae shown below.

\[
\text{Total liquid loss} = \text{Volume withdrawn} - \text{Volume produced} \quad (1)
\]

\[
\text{Liquid loss after filler} = \text{Volume produced} - \text{Filler good production} \quad (2)
\]

\[
\text{Labeller liquid loss} = \text{Filler good production} - \text{Labeller production} \quad (3)
\]
Liquid loss after labeller = Labeller production – Labeller good production

Figure 4 shows the extent by which the product loss deviates from the KPI target of 0.9 from early April to mid August.

\[
L = \frac{P - g}{P} \tag{4}
\]

It is clear from the graph that corrective measures were imperative since the product loss was negatively deviating from the target for the period from week 9 to about end of week 17.

Figure 5 shows the percent loss of product as a function of total volume produced per month. There is no significant difference between the underfills and the missing crowns but the underfills are still higher than the missing crowns. We also investigated the shifts to see if there were any significant differences in the waste ratio per shift and noted that there is no significant difference between the three shifts.

Figure 5: Data on waste from filling and crowning operations

3.4 Problem solving using basic tools

The recommended problem solving tools include the Cause-effect (Ishikawa), Scatter diagrams, Failure mode effect and criticality analysis (FMECA). The Scatter diagram captures all possible causes of a problem and shows how these causes are interrelated [11]. For this project, we decided to use the cause-effect (fishbone) to identify the root causes for beer loss.
According to Bilsel (2012), Ishikawa or Cause and Effect diagrams are popular tools to investigate and identify numerous different causes of a problem and used as a guideline to allocate resources and make necessary investments to fix the problem [12]. This is a casual diagram that shows the causes of a specific event. The causes are grouped in categories to identify the sources of variation. Figure 6 illustrates an Ishikawa diagram for bottle filling and crowning operations.

![Ishikawa diagram for bottle filling and crowning](image)

**Fig 6: Ishikawa diagram for bottle filling and crowning**

Fillers experience problems through gushing of product out of filling valves. Over filling also contributes towards product losses. This is, however, minimal. Poor filling control caused by filling problems can cause liquid to gush during the snift process. Poor bottle handling at the filler to crowner transfer will cause the liquid to be agitated, resulting in the product gushing out of the bottles. Poor or incorrect jetting will cause excessive liquid loss from the bottle resulting in underfilling of a bottle. Damaged filling valve components will also result in under filling and/or overfilling. Then there are rejects caused by incorrect crowning and missing crowns. Uncrowned bottles will be rejected at the filler discharge.

The environmental conditions such as time, temperature, and culture in which the process operates, in this case are not applicable since no noticeable effect was realised.

### 3.5 Verification of standard operation

Each of the causes were then followed up to check if the standards were taken into consideration during the filling process and also to identify if procedures are being followed. Table 1 shows a summary of the actually operating procedures when compared to the standard operating procedures.
Table 1: Comparison of observations and standard operations

<table>
<thead>
<tr>
<th>Description</th>
<th>Verification notes</th>
<th>Standard Operation</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator accepting incorrect volume from filtration</td>
<td>Operator to check for correct volume before confirming the volume of product from tank</td>
<td>Operator to check correct volume on computer monitor before confirming product from tank</td>
<td>Operators checking tanks before confirming</td>
</tr>
<tr>
<td>Operator accepting sub-standard quality product from filtration</td>
<td>Operator to check all quality parameters before confirming liquid from tank.</td>
<td>Check quality parameters before confirming product from tank.</td>
<td>Liquid from tank checked against specifications before confirmation.</td>
</tr>
<tr>
<td>Operator failing to respond quickly to deviations</td>
<td>Process input/output monitoring sheets have triggers to guide operators monitor the process and take corrective action where necessary.</td>
<td>&lt;40 underfills/hour 15 missing crowns/hr.</td>
<td>Quick fix routines applied in case of deviations.</td>
</tr>
<tr>
<td>Defective crowns.</td>
<td>Suspect crowns to be checked or isolated and a new batch should be withdrawn.</td>
<td>Defective crowns should be quarantined, samples kept for the lab and on-line rejection completed.</td>
<td>Procedure is always complied with.</td>
</tr>
<tr>
<td>Inputs not set correctly.</td>
<td>Input settings are all marked to avoid mistakes.</td>
<td>Set inputs according to work instructions and monitor</td>
<td>All inputs set correctly.</td>
</tr>
<tr>
<td>Worn valve gas seals causing excessive underfills</td>
<td>Physically check gas seals for wear</td>
<td>Gas seals replaced during annual shut down</td>
<td>Seal worn</td>
</tr>
<tr>
<td>Wear and tear</td>
<td>physically check bottle pads, key and key way for wear</td>
<td>Monthly schedule in place</td>
<td>Worn bottle pads, worn crowning pistons, worn key way on the hub</td>
</tr>
</tbody>
</table>
3.6 Identification and implementation the proposed solutions

These solutions included entrenching foundational practices for reacting promptly to deviation by taking corrective actions since this would effectively reduce the underfills and missing crowns. We also identified that valve overhaul and replacement of gas valve seals would result in better control of CO₂ during filing process. Replacement of crowning pistons would alleviate the problem of having worn pistons from falling and damaging machine. It was also critical to replace crowner bearings so as to reduce of skewing of crowns.

We used Deming’s PDCA cycle to implement the possible solutions. It was critical to ensure that the spares for the filler/crowner were always available. The crowner was overhauled and all worn components were replaced. We also detected and corrected root causes of underfills and missing crowns at source. It was then imperative to check the bottles for improved sealability during start up as well as for improved filling. Lastly, we conducted a 200 bottle volume check and sealability of the crowns. The maintenance schedules were revised to ensure preventive maintenance on valve gas seals and crowner components performed by the engineering planner for the line. The operators were then trained on foundational practices.

3.7 Verification of improvements

After the loops are closed, the targets and actual values were then tracked to check for improvement. The target for waste reduction was 0.9% of withdrawn volume for the packaging hall. Figure 7 shows the extent by which the product loss deviates from the KPI target of 0.9 from mid August to end of February the following year.

![Figure 7: Deviation of liquid loss from target](image)

Comparing Figure 7 with Figure 4 shows a marked improvement in plant performance. There is a significant difference in the product loss figures after the changes have been effected.

3.8 Statistical validation

We used the data collected for deviation of percent liquid loss from a target of 0.9 to conduct some statistical analysis using SPSS Statistics 17.0 software. Table 2 shows data on extent to which the product losses were deviating from the target 0.9 percent. It was crucial to verify and validate whether the changes made were responsible for the positive results shown in Figure 7 or whether it was due to chance.
Table 2: Data on percentage of liquid losses

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.14</td>
<td>1.7</td>
<td>1.73</td>
<td>1.88</td>
<td>1.19</td>
<td>1.28</td>
<td>1.49</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>1.98</td>
<td>1.4</td>
<td>1.85</td>
<td>1.33</td>
<td>0.85</td>
<td>1.62</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>2.09</td>
<td>1.82</td>
<td>1.43</td>
<td>1.87</td>
<td>1.23</td>
<td>1.58</td>
<td>2.04</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>1.87</td>
<td>1.62</td>
<td>1.28</td>
<td>1.85</td>
<td>2.2</td>
<td>0.87</td>
<td>1.52</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>1.88</td>
<td>1.61</td>
<td>1.61</td>
<td>1.94</td>
<td>1.52</td>
<td>1.28</td>
<td>1.53</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>1.78</td>
<td>1.59</td>
<td>1.89</td>
<td>2.14</td>
<td>1.58</td>
<td>1.36</td>
<td>1.62</td>
<td>0.69</td>
</tr>
</tbody>
</table>

We assessed normality of our data through the Kolmogorov-Smirnov and the Shapiro-Wilk Test. Shapiro-Wilk Test is more appropriate for small sample sizes (< 50 samples), but can also handle sample sizes as large as 2000. At 95% confidence interval, if the sigma value of the Shapiro-Wilk Test is below 0.05, the data significantly deviate from a normal distribution.

Table 3: Test of normality

<table>
<thead>
<tr>
<th></th>
<th>Kolmogorov-Smirnov</th>
<th></th>
<th>Shapiro-Wilk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistic</td>
<td>df</td>
<td>Sig.</td>
<td>Statistic</td>
</tr>
<tr>
<td>Before</td>
<td>0.138</td>
<td>24</td>
<td>0.200*</td>
<td>0.954</td>
</tr>
<tr>
<td>After</td>
<td>0.157</td>
<td>24</td>
<td>0.128</td>
<td>0.959</td>
</tr>
</tbody>
</table>

The results from Table 3 show that the sigma value of both the Kolmogorov-Smirnov and Shapiro-Wilk Test is greater than 0.05, thus we reject the null hypothesis and accept the alternative hypothesis, which implies that the data is normal.

Alternatively, we used the descriptive statistics to check whether the samples resembled normal distribution. Using $\alpha = 0.05$, both samples passed the normality assumption for kurtosis and skewness since the standard error (z-score) values were not falling between -1.96 and +1.96 as shown by the descriptive statics in Table 4.

That means we could then perform a parametric statistical test. We then performed an Independent samples T-test (also called a between-subjects t-test). The aim of a T-test was to check if there will be a significant difference or improvements. We state the null hypothesis as population means for the two samples as equal. An arbitrary level of significance ($\alpha$) to reject the null hypothesis was selected at $p = 0.05$, implying that we would reject the null hypothesis when the p-value is less than or equal to 0.05, implying that the two means are significantly different. On the contrary, when the p-value is greater than 0.05, we cannot reject the null hypothesis.
Table 4: Descriptive statistics of liquid loss data

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Parameter</th>
<th>Statistic</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>Mean</td>
<td>1.7938</td>
<td>0.04708</td>
</tr>
<tr>
<td></td>
<td>Variance</td>
<td>0.053</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>0.23067</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skewness</td>
<td>-0.468</td>
<td>0.472</td>
</tr>
<tr>
<td></td>
<td>Kurtosis</td>
<td>-0.176</td>
<td>0.918</td>
</tr>
<tr>
<td>After</td>
<td>Mean</td>
<td>1.3146</td>
<td>0.10831</td>
</tr>
<tr>
<td></td>
<td>Variance</td>
<td>0.282</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>0.53063</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skewness</td>
<td>0.172</td>
<td>0.472</td>
</tr>
<tr>
<td></td>
<td>Kurtosis</td>
<td>0.095</td>
<td>0.918</td>
</tr>
</tbody>
</table>

Table 5 shows the results for the independent samples T-test for the prior situation before the improvements were effected as well as after process modification.

Table 5: Independent samples test for the before-and-after scenarios

<table>
<thead>
<tr>
<th>t-test for Equality of Means</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal variances assumed</td>
<td>4.05</td>
<td>46</td>
<td>0.000</td>
<td>0.479</td>
<td>0.1181</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td>4.05</td>
<td>31.39</td>
<td>0.000</td>
<td>0.479</td>
<td>0.1181</td>
</tr>
</tbody>
</table>

Since sigma (2-tailed) is 0.000 which is less than 0.05, assuming unequal variances, thus we reject the null hypothesis and conclude that there has been a significant difference or improvement from the previous scenario to the later situation.

4 CONCLUSION

The packaging process of the product has faced many challenges which could be alleviated through focused process improvement. Pareto analysis can be used as tool to identify key areas in the process that could benefit from a focus improvement initiative, thereby benefiting the overall company. The analysis of the filling and crowning process through Ishikawa diagrams revealed the critical process inputs and parameters which influenced excessive waste. Recommended solutions were identified and implemented to reduce the negative influence of these critical process inputs. It is crucial to always ensure that the workers comply with the standard operating procedures in order for waste to be reduced. After effecting any changes, statistical analysis can be used as a tool for verification of whether there were improvements made or if the results were due to chance.
5 REFERENCES


