DMAIC 6 Sigma of fill height optimisation of line 8 at SAB Alrode

by

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Executive Summary

This project was executed at SAB's Alrode brewery which is currently the largest brewery in the Southern hemisphere. The main concern of the project is production line 8, which focuses on the production of main stream brand in the quart. As the goal of this project is fill height optimisation, it is required that the filling process is stable and that the process conforms to the packaged quantity of its brands (in accordance with the legal prescriptions of the Trade Metrology Act, SABS 1841). The target fill volume is equal to 750ml with a standard deviation of less than 2mm on a fill height of 72mm. The deliverables of this project follows the structure of the DMAIC methodology. The necessary tools and techniques required to achieve the desired outcome of this project such as DMAIC Six Sigma, were researched and summarised in the literature review which also includes SAB's relevant policies and procedures regarding fill heights. A filler capability study was done in order to understand the overall performance of the filler as well as the performance of individual filling valves. It was identified that fill heights are not on target and has a very high standard deviation. The capability study also indicated that the fill operators are capturing inaccurate data during the current routine fill height performance, which is measured on a daily basis. Though analysis of the problem, the critical process inputs with the greatest influence on fill heights were identified. Based on the Failure Mode and Effect analysis that was conducted for these critical inputs, certain changes were recommended. The improvements, as a result of these recommendations, were estimated in terms of fill heights and financial benefits. Further improvements were also suggested in order to address individual valve performance, as well as the accuracy of the current routine fill height procedure conducted by the fill operators. Should these further suggestions be implemented along with the improvement of the critical process inputs, the fill heights and financial benefits will show an even further improvement, which justifies the means of this project.

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Glossary

Abbreviation	Description
BBT	Bright Beer Tank
C&E	Cause and Effect
DMAIC	Define Measure Analyse Improve and Control
DoE	Design of Experiment
EBI	Empty Bottle Inspector
EWO	Emergency Work Order
eQMS	Electronic Quality Management System
FMEA	Failure Mode and Effect Analysis
FVM	Filler Valve Monitor
HMI	Human Machine Interface
MSA	Measurement System Analysis
OOC	Out of Control
OOS	Out of Specification
PFBI	Preliminary Full Bottle Inspector
PIMS	Process Input Monitoring Sheet
PM schedule	Preventative Maintenance Schedule
POMS	Process Output Monitoring Sheet
QC	Quick Changeover
QFR	Quick Fix Routine
r and R	Repeatability and Reproducibility
SCONS	Shape Canter Outliers Normality and Spread
SIC	Short interval control
Sigma (σ)	Standard Deviation
SPC	Statistical process Control
WI	Work Instruction

1 Introduction and Background

1.1 Introduction and Background to the Company

The South African Breweries Limited (SAB) was founded in 1895 and is the historical birthplace and the South African subsidiary of SABMiller plc, which is currently one of the world's major brewers by volume. More than 200 brands are distributed over 75 countries. The South African Breweries Ltd is the leading brewer and –distributor ofsoft drinks and beer in South Africa with a sales revenue of R32 billion.The collection of beer brands includes five of the country's most popular brands, namely Hansa Pilsener, Castle Milk Stout, Carling Black Label, Castle Lite and Castle Lager.

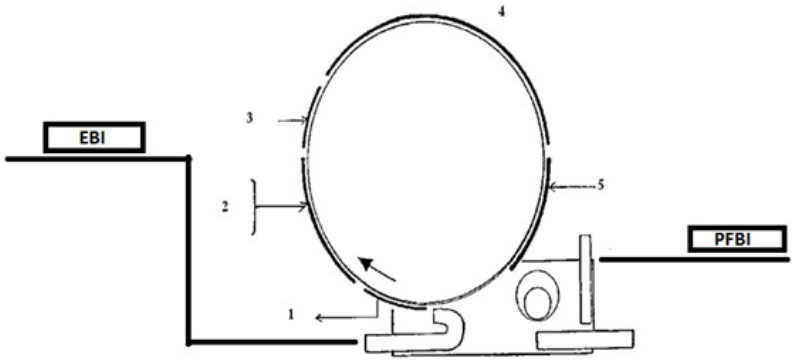
Seven breweries are operated by the company, along with over 40 depots within South Africa, with the brewing capacity reaching up to 3.1 billion litres per year.Amalgamated Beverage Industries (ABI) is SAB's soft drink division, which is one of the largest suppliers of Coca-Cola brands in SA. SAB also owns the South African Breweries Hop Farms (Pty) Ltd, The South African Breweries Barley Farms(Pty) Ltd, The SouthAfrican Breweries Maltings (Pty) Ltd and a 60%share of ColeusPackaging (Pty) Ltd.

This project will be executed at SAB's Alrode Brewery which was established in 1965 and is currently the largest brewery in the Southern hemisphere with a daily production of over 1.9 million litres.This project concerns a particular production line at SAB's Alrode Brewery, namely line 8 which focuses on the production of main stream brand in the quart[1]. The quarts produced on line 8 include Carling Black Label and Hansa Pilsener. Each quart goes through a certain number of processes for bottle filling on this line, which includes sterilisation, start-up, beer supply, container supply and the bottle filling process.

1.2 The Process Description

The bottle filling process which can be seen in Figure 1 will be the main focus of this project, with the goal of fill height optimisation. The loss of beer must be avoided and the nominal fill of every bottle must be ensured which will result in high output, high efficiency and low product losses of the filler. This is done with the intent of reducing the fill height standard deviation. The quantity of content in pre-packed packages must also comply with the legal prescriptions of the Trade Act and Regulations (SABS 1841).

[1] 750ml Glass Bottle



1. Bottle positioning.
2. **Triple** Pre-evacuation
   - 1st Pre-evacuation.
   - Flushing.
   - 2nd Pre-evacuation.
3. Counter-pressure.
4. Filling.
5. Snifting or Decompression (Purging)

O Fobbing or Jetting.

Figure 1 - Bottle Filling Process
Pieters (2004)[8]

2 Problem Statement

Fill Heights are very important to SAB as fill heights indicating an under fill will possibly be in violation of the Trade Metrology Act and over fills will result in unnecessary profit loss.

During a brief the following problems, which need to be resolved by this project, were identified:

- The standard deviation of fill heights[2] from the target value needs to be minimised. The target fill volume is equal to 750ml with a standard deviation of less than 2mm on a fill height of 72mm.
- The fill height process must conform to the packaged quantity of its brands, in accordance with the legal prescriptions of the Trade Metrology Act, SABS 1841. (See literature study Section 5.1.1 for specifications).
- The fill height process should behave consistently over time, in other words the fill height process should be stable and in control.
- Based on the need to improve the ability of the line to manage and optimise fill height performance, a simplified fill height sampling and analysis methodology is required. This includes statistically monitoring the moving averages and the process capabilities of the filling operations, as well as the performance of individual filling valves.The introduction of the proposed methodology will highlight fill height performance issues quicker and response time to correct under-performing valves will be reduced.
- Best practices should be identified for electronic fillers.

[2] The fill height is measured from the top of the bottle to the fill level.

3 Project Aim

The aim of this project is to improve the ability of the production line to manage and optimise fill height performance, thus minimise the standard deviation of the fill heights from the nominal value. The objectives acting as a basis for the aim are as follows:

- Establish a performance baseline for fill heights through conducting a capability study
- Make suggestions regarding a control system that will:
    - Minimise standard deviation of filler around nominal fill level (less than 2mm standard deviation on fill height)
    - Highlight fill height performance issues quicker
    - Reduce response time to correct underperforming valves
- Ensure conformance to the packaged quantity of brands (in accordance with the legal prescriptions of the Trade Metrology Act).

4 Project Scope and Boundaries

This project focuses on the study of the filler process of quarts at Alrode line 8. The process boundary is from postempty bottle inspection(ebi) to pre-pasteuriser (See Figure 1, Section 1.2).

The following aspects are included in the scope of the project:

- The filling process
- Filling performance measurement of the filler
- The valve monitoring system and the fill height measurement equipment, namely FT100 – PFBI (Preliminary full bottle inspection)
- Quick changeover (QC) equipment used to do fill height measurements such as a scale or a measurement instrument called Akitek
- Quick fix routines for filling

The following aspects are not included in the scope of this project:

- All processes post pasteuriser
- All processes pre ebi (empty bottle inspection)
- All raw materials supply (crowns/bottles)
- Warehousing
- Any information regarding breakdowns which may occur

4.1 Process Maps

4.1.1 High Level Process Map

1. Bottle positioning

The infeedstar wheel transfers the bottles to the bottle lift plates while the bottle lifts raise the bottles towards the filling valve.The bottle lifts keep the bottle pressed against the seals of the centring cups. Therefore, the bottle's present proxy is activated.

2. Triple Evacuation

Triple evacuation is seen as one step which is repeated three times. One step includes the vacuuming of air out of the container (pre-evacuation) and the flushing of $CO_2$to further purge air out of the container (CO_2flushing).The CO_2 used in the third flush is reused in the next occurrence of the first flush.

3. Counter pressure

As in flushing, the pneumatic valve solenoid opens the gas valve(vacuum valve closed). Another electronic control rotates the filling valve control solenoid and this raises both the pressure and the concentration of CO_2 in the bottle.

4. Filling

Filling is considered the main focus of this project even though the other process components may also be taken into account. Filling consists of both fast and slow filling.

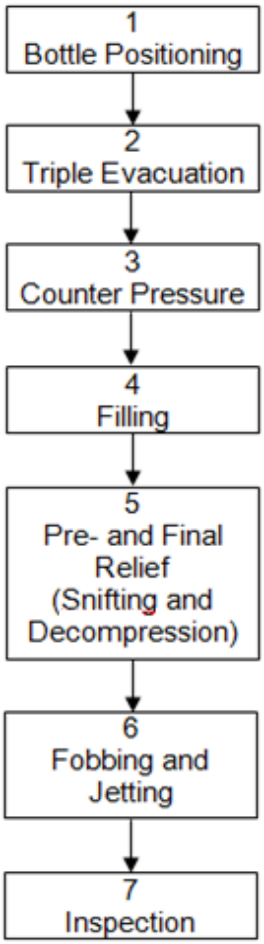


Figure 2 - High Level Process Map

Fast Filling - When the pressure in the bottle equalises with the filler bowl pressure, the filling valve control lever mechanism opens the liquid valve seal via the outer spring and Isobarometric (gravity) filling commences.The beer can now flow downwards and is deflected by the return gas tube against the bottle wall and flows down the wall in a thin film.CO_2 displaced, flows back into the bowl through the return gas tube.

Slow Filling - After fast filling, the filler now looks for the filler probe level indication. As soon as the level reaches the set probe height, filling will stop.

5. Pre-and Final Relief (Snifting and Decompression)

Pre-and final relief are controlled via electronic solenoid valves. The excess pressure in the bottle is released through a small orifice until it slowly equalises with the atmospheric pressure.

6. Jetting and Fobbing

Under high pressure a thin jet of water is injected into filled bottles and the air contained within the neck of the bottle will be displaced.

4.1.2 Low Level Process Map

The following low level process map is an extension of the high level process map, as it is discussed in more detail with regards to inputs and outputs. The inputs and outputs are later used as input into the Cause and Effect Matrix.

Table 1 - Low Level Process Map

Nr.	Input	Process	Output
1	Bottle	**Bottle Positioning**	Good positioned bottle
	Star wheels		Bad positioned bottle
	In feed worm		Burst/broken bottles
	Platforms		
	In feed guides		
	Conveyors		
	Lift cylinders		
	Ride tracks		
	Tulip rubber		
	Hanger bracket		
	Lift cylinder pressure		
2	Good Positioned Bottle	**Triple Evacuation**	Air free Good positioned bottle
	Bad positioned bottle		Air free Bad positioned bottle
	Vacuum cylinder		
	CO2 return channel		
	Solenoids		
	Tulips		
	Sensor (timing)		
	Lift cylinder pressure		
	Valve		
3	Air free good positioned bottle	**Pressurisation**	Pressurised good positioned bottle
	Air free bad positioned bottle		Pressurised bad positioned bottle
	Tulip		Burst bottles & cullet
	CO2 channel		
	Solenoids		

	CO2 Pressure		
	Valve		
	Pressure on solenoids		
	Lift cylinder pressure		
	Lift cylinder pressure		
	Hanger Brackets		
	Platform		
4	Pressurised good positioned bottles	**Filling**	Filled bottle
	Pressurised bad positioned bottles		
	Beer		
	Beer temperature		
	Counter pressure CO2		
	Filling probe		
	Solenoids		
	Correction factor		
	Bowl level		
	Bowl level control (4 capacitive probes)		
	CO2 (gas channel)		
	Lift cylinder		
	Hanger brackets		
	Platform		
	Valve		
5	Filled bottle	**Pre-and Final Relief**	Filled bottle open to atmosphere
	Atmosphere		
	Relief chamber		
	Valve		
	Solenoid		
6	Filled bottle open to atmosphere	**Jetting and Fobbing**	Filled jetted bottle
	Jetter nozzle size		Beer loss (over bottles)
	Jetter pressure		
	Jetter temperature		
	Jetter position		
	Star wheels		
	Bottle guides		
7	Filled jetted bottles	**Crowning**	Crowned filled bottle
	Crown		Wasted crowns
	Crown platforms		Uncrowned filled bottles
	Crown thraights		
	Crown shoe's		
	Crown piston heights		
8	Crowned filled bottle	**Inspection**	Overfilled
	Uncrowned filled bottle		Under filled
	Conveyors		Correct filled bottles
	PFBI (Preliminary Full Bottle Inspector)		Cullet
	Rejecter		Beer loss
			False rejects

4.2 Deliverables

The deliverables of this project are stated in terms of the DMAIC methodology. The DMAIC methodology as described in the literature study in Section 5.3 is a data-driven tool used for optimising, improving and stabilising processes or designs. DMAIC is an abbreviation for five phases, namely define, measure, analyse, improve and control. The deliverables are as follows:

Phase one of the project included the completion of the define phase of the DMAIC methodology.

Define – Develop a fully defined project which will incorporate the voice of the customer, define the project objectives and scope the project properly. The define phase includes the following:

- Problem statement
- Process boundaries
- Project resources
- Task and activities to be performed (deliverables)
- Initial project proposal/charter

Phase two of the project included the completion of the measure an analysis phase of the DMAIC methodology.

Measure – Define the current process and establish metrics by documenting the process and identifying output- and input variables. The measurement phase includes the following:

- Literature study
    - Analyse existing literature
    - Select appropriate method
    - Document method
- High level process map
- Low level process Map
- Initial data
- Measurement system analysis(MSA)
- Basic Stats
- Baseline process capability (continuous)
- Revised proposal/charter

Analyse – Understand relationship between process input- and output variables and identify potential sources of process variability. The analyse phase includes the following:

- Cause and effects matrix
- Determine high-risk inputs from Failure Mode and Effects Analysis(FMEA)
- Determine suspected critical inputs
- Plan improvement activities
- Identify relationship between inputs and outputs
- Revised proposal/charter and literature study

The final phase included making suggestions for the improvement phase and control phase of the DMAIC methodology. The extent to which these phase are executed is dependent on what SAB is prepared to implement.

Improve – Quantify relationship between inputs and outputs by determining the effects of the inputs on the outputs by the use of experiments. The improvement phase includes the following:

- Critical inputs identified and verified (experiments if required)
- Improvement plan for process
- Process 'should' map
- New process baseline to be defined

Control – To establish a control plan and maintain the gains achieved through the project. The control phase includes the following:

- In-control and capable process
- Control plan including measurement plan
- Shared best practices
- Final capability
- Final report

4.3 Resources

The resources identified were needed to successfully achieve the defined deliverables and complete the project. Certain resources were critical in completing tasks such as defining the problem, gathering data, analysing the problem and identifying an improvement plan.

4.3.1 Infrastructural resources

- Transportation to and from SAB Alrode
- Laptop (Microsoft Office)
- Internet (Data required from books, journals and newspaper articles)
- Dropbox
- Stationary

4.3.2 People resources

Supporting and coaching resources:

- Line Manager and Project Sponsor at SAB Alrode – Elsabe Pieters
- Manufacturing development specialist at SAB Alrode – Marianca De Winnaar
- Project leader at the University of Pretoria – Wynand P. Breytenbach

Functional Resources at SAB Alrode Line 8:

- Filler Specialist – Russel Langa
- Line Maintenance – Garson
- Planner – Willem Verwey
- Four QC/Filler operators (four shifts)
- Four team leaders (four shifts)

4.3.3 Financial resources

SAB will provide funding for the implementation of any improvements suggested, given that the improvements are financially justifiable.

4.3.4 Physical resources

- QC equipment in lab (Akitek and Scale)
- Fill height measurement equipment (FT100 – PFBI) (Preliminary full bottle inspection)

5 Literature Review

The literature study is a detailed investigation which assists in identifying the appropriate tools, methods and techniques used for design and problem solving. The study also includes information regarding the various aspects of this project.

5.1 Trade Metrology Act and Regulations (SABS 1841)

According to Pieters (2004:75) [8] the trade metrology act controls the quantity of content in pre-packed packages. This legislation covers only volume and mass, referring to the South African Bureau of Standards Specification 1841. This standard specifies the requirements for pre-packed packages with a quantity of 5ml or 5g or greater. A company has the moral responsibility to show diligence with respect to the consumer and the product within the packages supplied to the consumer.

Benefits of conforming to the standards of the Trade Metrology act:

- e-Mark certification which will guarantee conformance to standards
- Acceptability to export markets
- Consumer confidence
- Demonstrates the company's commitment to quality

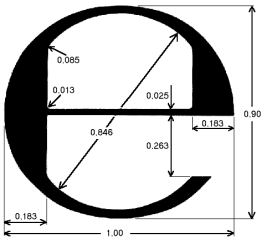


Figure 3 - e-Mark
Pieters (2004:98) [8]

The e-Mark (not related to fill heights, only weight or volume)

- It is the responsibility of the packer to ensure package meets specifications
- Checks and measurements are carried out with suitable and legal measurement instruments
- Ensures that the actual volume or weight of the pre-packages conform to standard

Negative error (NE) refers to the quantity by which the nominal quantity is greater than the actual quantity of the package. The nominal quantity is indicated on the pre-package while the actual quantity is the quantity in the package. Should a package have a negative error which is greater than twice the specified tolerable error it is considered an inadequate package (NE>2*TNE). It is considered to be a non-standard package when the negative error is less than twice the specified tolerable error but greater than the specified tolerable error (TNE<NE<2TNE).

1	2	3
Nominal quantity of the contents Qn 'ml or g	Tolerable Negative Error (TNE)	
	Percentage of Qn	Ml or g
>= 5-50	9	-
>50-100	-	4.5
>100-200	4.5	-
>200-300	-	9
>300-500	3	-
>500 -1 000	-	15
>1 000 - 10 000	1.5	-
>10 000 - 15 000	-	150
>15 000	1	-

Figure 4 - Tolerable Negative Error (TNE)
Pieters (2004:80) [8]

May (1999:6) [5] states the three rules that apply to pre-packages:

- Rule 1 – The average of the actual content of a pre-package must not be less than the nominal quantity stated on the package
- Rule 2 – The proportion of non-standard pre-packages must not be greater than 2,5%
- Rule 3 – No inadequate packages may be offered for sale

5.1.1 Fill Height Specifications Relative to the Trade Metrology Act

The specification relevant to the project is that of a quart (calabash) which is 750ml in volume. It is assumed that the volume is a function of the bottles fill height, thus a 750ml bottle should have a fill height of 72mm. The volume is also influenced by the shape and composition of the bottle itself, but that is not taken into consideration for this project, as the scope of this project includes fill heights and not reference volumes. The lower- and upper specification limit will be 735ml and 765ml respectively, seeing as the tolerable negative error is 15ml for a volume between 500ml and a 1000ml. A 3σ limitfor fill heights, with σ equal to 2mm, will ensure that the volume doesn't go beyond the lower specification limit of 735ml. Volume and fill height can be seen relative to one another in Figure5 (it is important to remember that fill height is measured from the top of the bottle downwards, thus a smaller fill height indicates a larger volume).

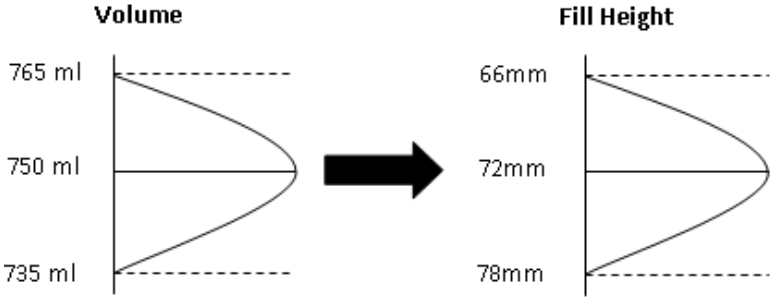


Figure 5 - Trade Metrology Act Fill Height Specification Limits

It is critical to the outcome of this project that results fall within the following specifications:

- Target value (nominal) = 72mm
- Standard deviation (σ) = 2mm
- Upper specification warning limit (USWL) = Target value + 2σ = 76mm
- Lower specification warning limit (LSWL) = Target value -2σ = 68mm
- Upper specification limit (USL) = Target value + 3σ = 78mm
- Lower specification limit (LSL) = Target value - 3σ = 66mm

Should the fill height be greater than the USL of 78mm, the volume will be less than 735ml and possibly in violation of the Trade Metrology Act.

5.2 SAB Policies and Procedures

The investigation and study of SAB's policies and procedures are used to identify where improvements must be made, by making use of the results during the measurement and analysis phase of the project.

5.2.1 Mechanical Filler Best Practices

The filler best practices currently in place at SAB Alrode are only focussed on mechanical fillers. Since line 8 at Alrode makes use of electronic fillers, a need for electronic filler best practices was identified. The relevant mechanical filler best practices, as discussed below, was summarised from SAB's filler best practices document [11].

5.2.1.1 Machine Cleaning

- Daily Hygiene cleaning – Daily cleaning is required for the filler to ensure that the machines condition and hygiene standards are maintained.
- Opportunity cleaning –Whenever a situation arises that allows for cleaning the opportunity should be used. Avoid contact of any raw materials with the cleaning agents.
- Maintenance day cleaning – The filler must be stopped 3.7 hours before maintenance commences. This time allows for the completion of machine cleaning. Once maintenance is completed, touch-up cleaning is required.
- Cleaning effectiveness – Micro swabs should be taken from the filler in order to evaluate if proper cleaning was executed.

5.2.1.2 Filler Maintenance

Filler maintenance has been developed into packages that include the minimum that should be in place for each machine.

5.2.1.3 Audits

- Running audits – Auditors can conduct an audit at any given time, this will provide a snapshot view on the condition and the quality of the filler. These audits will include subjects such as quality performance, spare and change part management, machine set-up, machine timing, etc.
- Technical audits –Auditors conduct this type of audit based on machine performance, this will provide a detailed view on the fillers condition and the infeed-to-discharge condition. A technical audit includes a review on filler capability, a non-running technical audit during maintenance and a running audit before and after maintenance.

5.2.1.4 WCM Practices

WCM practices refers to work instructions, methods and procedures which ensure that the fillers performance is consistent and of good quality. These instructions, methods and procedures include documents that cover process capability, manning requirements, safety, start-up, shutdown, etc.

5.2.1.5 Current Routine Performance Methodology- Fill Height Management

The mechanical filler best practice document [11] was used as reference for the current routine performance methodology. There are two possible procedures used to sample fill heights, the one requires 12 samples and the other 20 samples. Currently the 12 bottle sampling method is used only on Alrode line 8, all other lines and facilities use the 20 bottle sampling method. This is because the 12 bottle sampling method is new and SAB is using line 8 to test the method. There is thus no data currently available for the 20 bottle sampling procedure for line 8.

The differences between the two methods can be seen in the table below:

Table 2- Current Routine Performance Methodology

Differences	**20 bottle sampling methodology -previous method-**	**12 bottle sampling methodology -current method-**
Bottles Sampled per shift[3]	20	12
Valves Sampled per Shift	20	4
Bottles Sampled per Valve	1	3
Valves Sampled Daily[4]	60	12
Calculate Average	Per shift	Per valve

The two fill height sampling procedures (namely the 12 bottle sampling- and 20 bottle sampling methodology) are identical to one another except for only these few minor differences which can result in major differences regarding the outcome of the fill height studies.

The 12 bottle sampling methodology has many advantages over the 20 bottle sampling methodology:

- Sampling is significantly easier to manage
- The average, standard deviation and range of the fill height can be calculated per valve
- Problematic valves will be easier to identify and problem solving can be done earlier
- Reduces the randomising of samples

[3]One shift consists of 8 hours
[4]A day consists of 3 shifts

The procedure which remains the same for both methods are as follows:

- The required valves are selected on the filler valve monitor (FVM) and collected once they are rejected. The samples are marked according to the number of the valve sampled.
- Samples must then stand for 45 to 60 minutes to allow foam to collapse
- The measurement equipment namely the Akitek must be properly calibrated
- Verify the calibration
- Once the foam collapses, the sampled bottles can be analysed
- Before results can be recorded the fill operator must verify that samples were analysed under the correct conditions. See Figure 6 below.
- All results recorded by the filler operator must be recorded in the eQMS system. eQMS is a program used by SAB to capture data and to calculate the daily statistics.

See Appendix C for additional detail on the procedure followed when measuring fill heights.

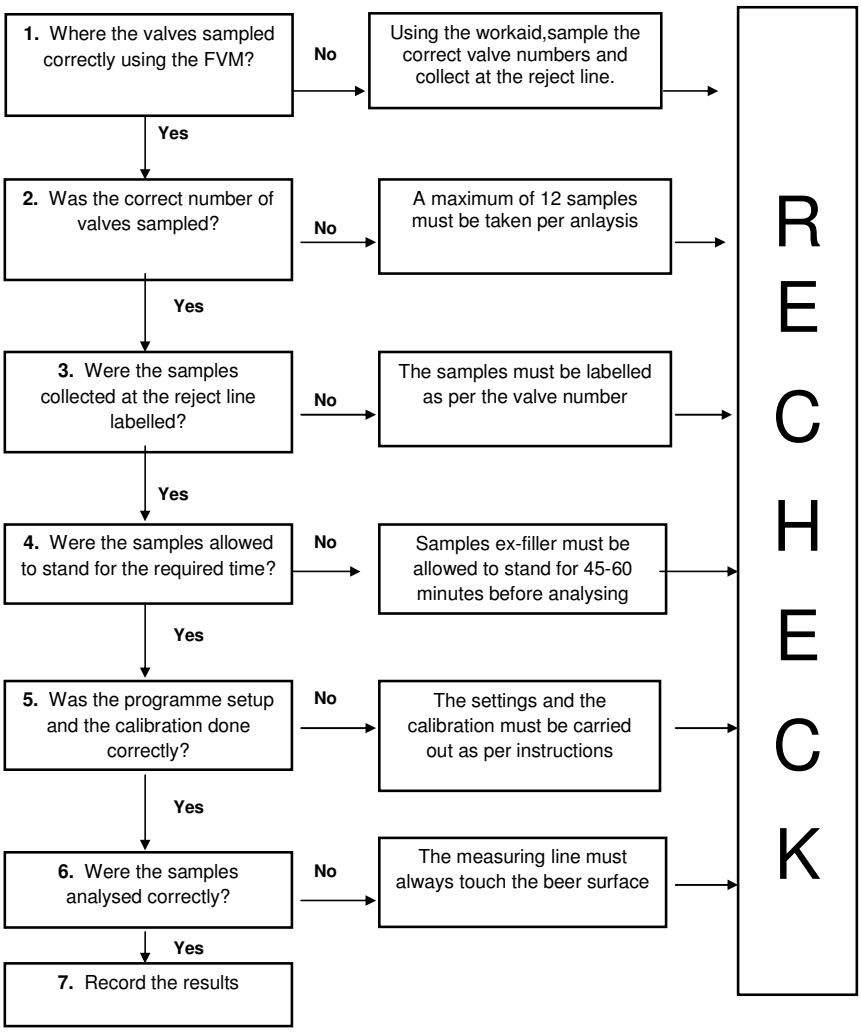


Figure 6 - Verify Sampling Conditions

Decision process flow for fill heights:

This decision process flow seen in the figure below is based on the 12 bottle sampling methodology. It states that SAB's operators uses eQMS to calculate an average for each valve and they then check to see if the average falls within the specification limits. Re-sampling takes place if the results do not meet specification. Should the updated results still deviate from the specification, the operator should:

- Apply quick fix routines(QFR)
- If the results are still out of control, the process artisan should address the problem.

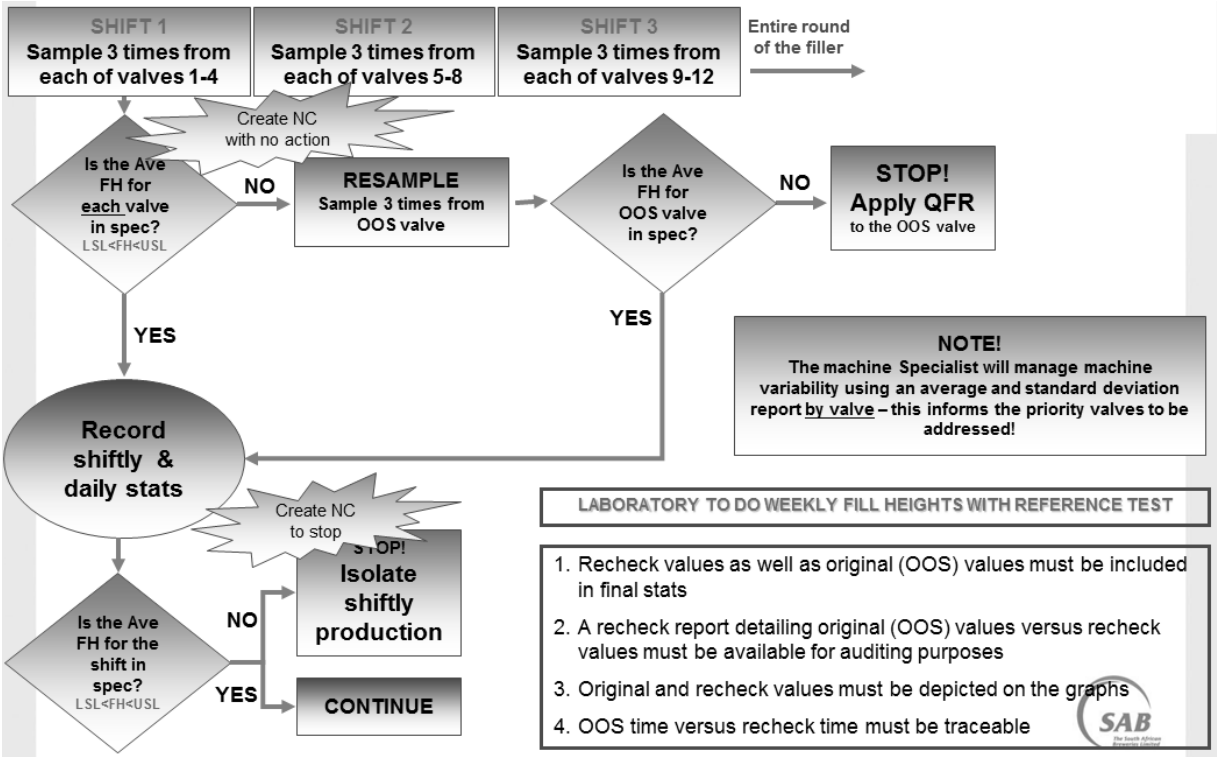


Figure 7 - Decision Process Flow for Fill Heights (12 bottle sampling methodology)
Unknown (2011) [11]

During the decision process flow, the sample data is captured in eQMS. This is done in order to demonstrate conformance to the Trade Metrology Act, thus the program plots the results against the specification limits. However, SAB also needs a system which displays the results using control limits, which will indicate the filler performance and capability.

5.2.2 Fill Height Capability Studies Methodology

Filler capability studies illustrate the individual valve performance and thus the overall filler performance. It is necessary that these studies are done:

- When the filler shows out of control results.
- Before a technical audit is conducted.
- At least once a quarter.

5.2.2.1 Preparation

- Set a date and time for the capability study with the relevant unit manager
- Collect and mark the crates required to store the samples (marking the crates by sticking masking tape on the outside wall of the crate, write the valve number corresponding to the crate pocket)

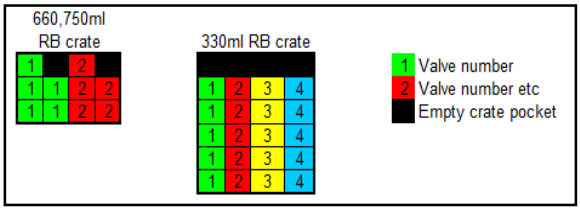


Figure 8 - Marking the crates

BBT data		
Brand		
CO_2 Content		
Volume remaining		
Filler		
Process input	Line specific standard	Actual result
Filler speed		
Beer temperature		
Beer pump pressure		
Bowl level		
CO_2 low pressure		
CO_2 high pressure		
Lifting cylinder pressure		
Vacuum		
PFBI Verification	Syncronisation checked as correct	
Jetter		
- Position and Alignment	Left/middle/ right, centre of the bottle	
- Pressure		
- Temperature		
- Profile	Solid line	
* Line specific standard as per line Filler specific PIMS sheet		

Figure 9 - PIMS and BBT Data Template

5.2.2.2 Procedure

The following procedure should be followed when conducting a capability study:

<u>Capability study preparation</u>

- Check BBT volume, ensure that there is sufficient volume in the tank to complete the study
- Ensure all resources are available and clarify roles (+- 3 people - i.e. 1 person to select sampling, 1 person to collect sampled rejects, 1 person to manage full and empty crates)
- Move all prepared crates to the line and store close to sampling point in valve sequence
- Complete filler process input monitoring sheet (PIMS) and the BBT data sheet and correct any out of controls

PFBI verification on valve synchronisation

- Stop the filler and remove a filling tube or de-activate a filling probe from a specific valve
- Start-up filler and when in normal running speed (Line rating) verify that the bottle identified on the PFBI screen corresponds to the valve where the vent tube/probe was removed/de-activated
- Should the synchronisation be fine, replace/activate the vent tube/fill probe and start with the study, should the synchronisation be out, get hold of the relevant person and correct the synchronisation of the PFBI

Execute the sampling

- Set up the PFBI to reject 5 samples per valve on consecutive revolutions
- Ensure that the filler is running at line rating, start sampling from valve 1 and 2, once rejected place the samples in the prepared crate ensuring that the samples are placed in the pocket for the corresponding valve, once 5 samples per valve have been taken move on to the next two valves
- Ensure to agree the next sample number with the person operating the PFBI - this will ensure that there is no mix up or incorrect samples being taken.
- Should the Filler stop or ramp down in between a sample set, discard the specific sample and re-sample only once the filler is running at line rating, if a defect is picked up with a sample bottle (i.e. chipped neck/missing crown) discard this sample and re-sample
- Once a crate is full pass it on to the person managing the crates and receive an empty crate from them before starting to sample the next valves
- Continue the above process until 5 samples per filling valve have been taken
- Take two additional random samples, this will be used to check beer temperature before stating analysis
- Allow time to production during the sampling process so that relevant machine counters and information can be recorded

Storage of samples

- Once all samples have been taken, move the full crates to the dedicated storage area
- Mark the crates clearly i.e. LINE 2 CAPABILITY STUDY SAMPLES DO NOT REMOVE, include your name and date on the sheet and allow the samples to temperate overnight.

Analysis of samples

- Take one of the additional bottles that was sampled the previous day, open the bottle, using a thermometer measure the actual beer temperature in the bottle
- The beer temperature in the bottle should be at 20℃ in order to start the analysis, if below 20℃ leave the samples to temperate further, using the second random bottle sampled the previous day re-check the temperature
- Should the beer temperature be at 20℃, prepare the Akitek for the analysis
- Ask one of the senior lab technicians to calibrate the Akitek unit for your specific bottle type.
- Once calibration has been completed, start the analysis, working from valve one until complete.

- Once samples have been analysed place them back into the specific crate and move the crate out of the way
- Ensure to either record or save each result (brewery specific), at the end of the analysis print out the results, take care to do the analysis in valve sequence (as per the markings on the crate)

Sample Return

- Once analysis have been completed take the samples back to the respective line and place back onto the line - given that the line is still running the same brand
- If the line has done a brand change store the samples in a safe area so that the samples can be placed back onto the line during the next production run, ensure to mark these samples clearly so that it does not get removed

Capture and analyse results

- Capture the valve specific results by making use of the filler capability study template
- Analyse the data and identify problematic valves by either looking at all results in red on the filler capability study spread sheet or outliers on the valve graphs
- Individual valves with a standard deviation of > 2mm is classified as problematic and would require corrective action

  Discuss results with relevant parties (Maintenance controller, Unit manager, Engineering controller etc.) and develop detailed action plan

5.2.3 Current Routine Fill Height Performance methodology vs. Initial Fill Height Capability Study Methodology

It is very important in this project to understand the difference between the current routine performance and the initial capability study. The routine performance is derived from the data collected on a daily basis by the fill operators. The fill operators use the 12 bottle sampling method. The initial capability study is conducted by an independent party only when needed and when conducted, it is usually completed over a period of one to three days. The main differences are summarised in the table below:

Table 3 - Current Routine Performance vs. Capability Studies

Differences	Current Routine Performance Methodology	Capability Study Methodology
Bottles sampled per valve	3	5
Valves per shift	4	176
Time to Sample all 176 Valves	± 2 Weeks	One to Three days
Sampling Conducted by	fill operator on shift	independent party

5.3 DMAIC Six Sigma

According to Antony et al (2006:4) [1] Six Sigma is a collective quality system of activities, events and plans designed to guarantee that the processes, services and products satisfy the needs of the customer. It is used to pursue continuous quality improvement by reducing system variability. Six Sigma identifies the process if it has a high variability or if it is off-target and then corrects the problem. It does this by defining goals and performance metrics and by the use of statistical and quality tools. Six Sigma makes use of the DMAIC (Define, Measure, Analyse, Improve and Control) or DFSS (Design for Six Sigma) methodologies, breaking away from the use of traditional methodologies. DFSS is used when a new process or product is designed, whereas DMAIC is ideal for existing processes and products.

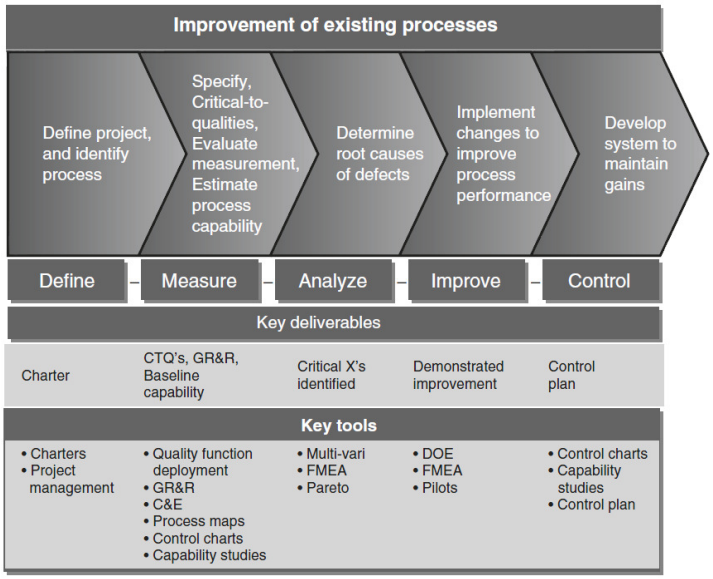


Figure 10 - the DMAIC Methodology and Key Tools
Antony et al (2006:212) [1]

Six Sigma is not considered to only be a quality program, but a strategic tool used to improve performance of all the strategic priorities namely cost, flexibility, quality and delivery. Pyzdek (2003:3) [10] states that Six Sigma is a highly effective, focused and rigorous implementation of verified quality techniques and principles. Sigma is the measure of variability in a process and the sigma level of a process measures the company's performance. Six sigma has a standard of 3.4 problem/million opportunities. In Summary, Six sigma is a business philosophy meaning it is fact driven, statistically structured, measurement based and it focuses on customer needs.

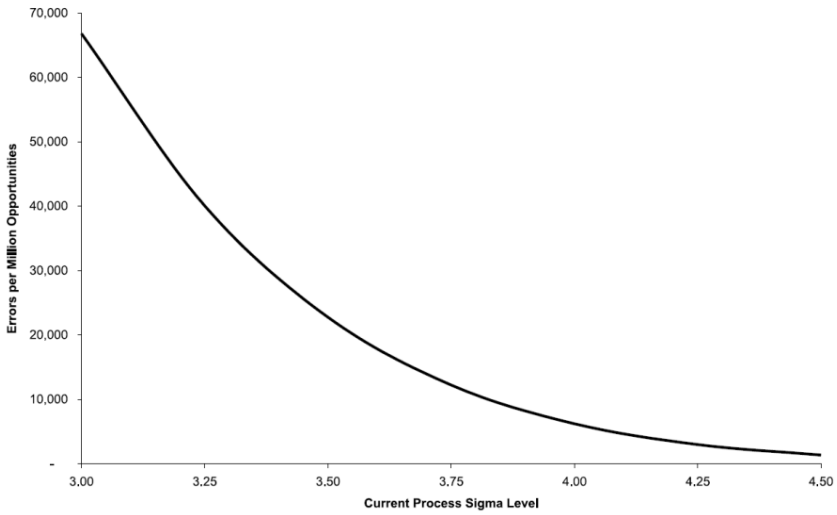


Figure 11 - Error Rate versus Sigma Level
Pyzdek (2003:7) [10]

The Six Sigma tools, according to Pyzdek (2003:237) [10], are applied within the performance improvement model, DMAIC. The DMAIC methodology is used when the goal of a project can be achieved by improving existing products, services or processes. It is utilised as a framework for executing and controlling a Six Sigma project.

The different phases of DMAIC:

- Define – Define the improvement goals and scope of a project which can be obtained from the voice of the customer. Its outcomes include process boundaries, a projects charter and the identification of the process owner and stakeholders.
- Measure – Measure the system by stating/establishing metrics used to assess the goals obtained. The measurement phase includes process maps, process capability and a cause and effect matrix.
- Analyse – The analysis phase is used to see how the current system performance should be changed in order to meet the goals defined. Thus, identifying the causes of the process variability through the use of a failure mode and effects analysis (FMEA) and Multi-Vari studies.
- Improve – Identify and implement ways which will improve the system. This phase identifies the critical relationships by use of Design of Experiments (DEO).
- Control – Monitor and control the system by implementation of a control plan.

The tools and techniques used in the five phases of the DMAIC methodology are further discussed in detail below.

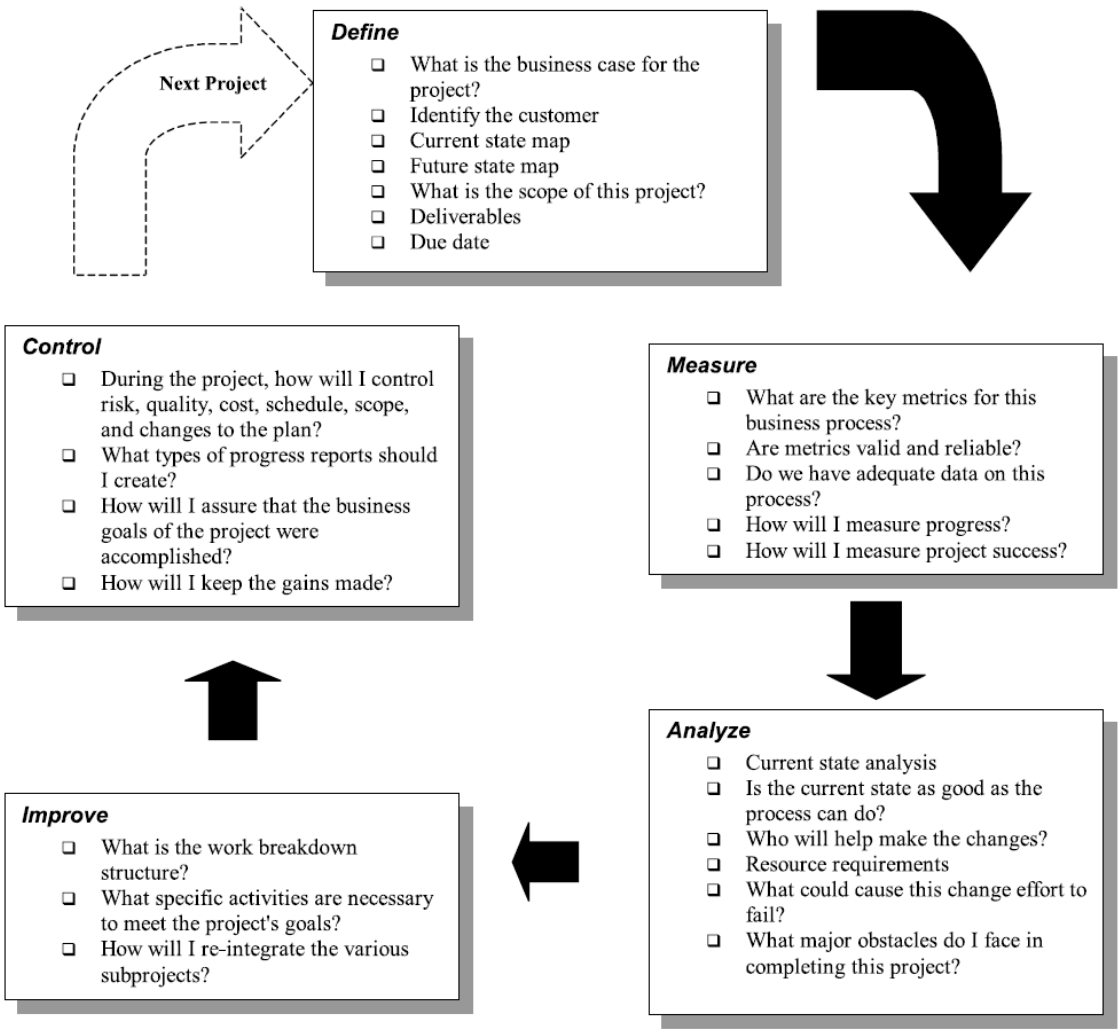


Figure 12 - DMAIC Used in Six Sigma Projects

Pyzdek(2003:239) [10]

5.3.1 Process Maps

As stated by Pyzdek (2003:252) [10] a process map provides a graphic representation of the work flows of the company, showing the tasks in sequence by use of flowchart symbols. This gives a picture of how employees conduct their daily activities. Alternative routes are provided by a process map which facilitates planning. The following steps are followed to develop a process map:

1. Process selection
2. Process definition
3. Primary process map
4. Map the identified alternative paths
5. Map the identified inspection points
6. Use the process map to identify process improvements

Beard et al (2011) [2] defines a process map as the tool used for the documentation of key process inputs and –outputs, sub-processes and major activities. He gives the following reasons for the use of a process map:

- Helps gain an understanding of the system before making any changes to the system
- Enables you to measure and manage the system, enabling you to improve the system.
- Helps identify delays, waste, bottlenecks and capacity issues.

Inputs are provided by the process map to the FMEA, multi-vari studies, capability studies, the control plan and to the cause and effect matrix.

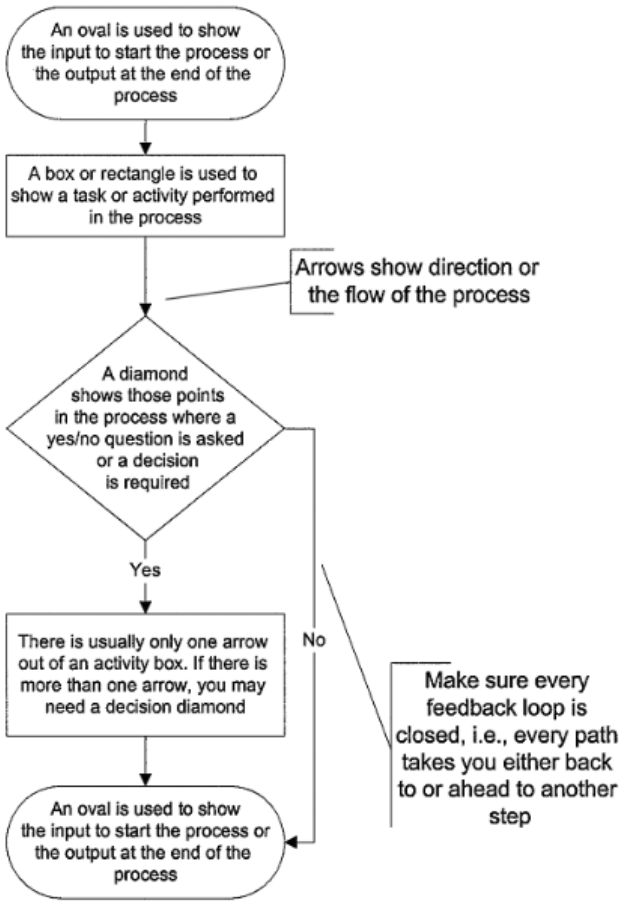


Figure 13 - Process Map Using Flow Chart Symbols Beardet al (2011) [2]

5.3.2 Capability Studies

In short, a capability study establishes how customer specification compares to the process performance. This was defined by Deleryd (1997: 320) [3]. These studies are often used to monitor a process' capability, thus it is based on a collection of process data. The process is required to be stable in order to collect viable data for the study. Figure 14 illustrates the four most important steps in completing a capability study.

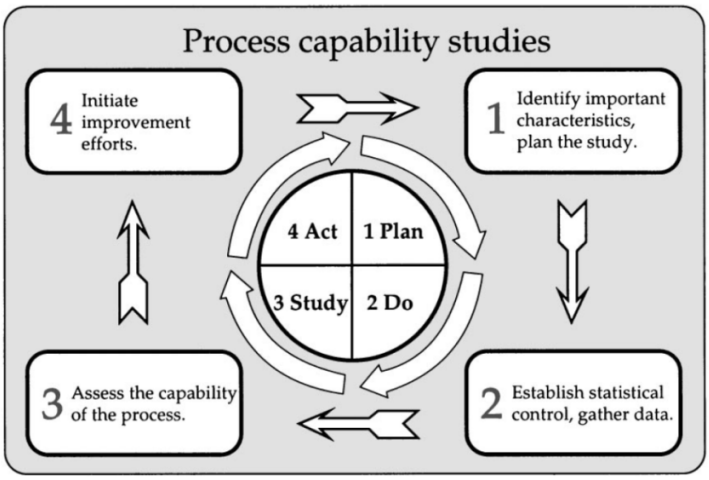


Figure 14 - Basic Steps for Capability Studies
Deleryd (1997: 320) [3]

According to Pyzdek (2003:467)[10] the two most important stages involved in process capability studies are:

1. Achieving statistical control of the process over a certain period of time.
2. Comparison of engineering requirements and the measured process performance (capability ratio).

It is useful to conduct an initial as well as a final capability study for the goal of comparison, to see whether improvements implemented have succeeded in reaching the established goals. The capability studies will vary depending on the data types namely attribute data and continuous data. Continuous capability studies will be the focus of this project.

5.3.2.1 Capability Study Definitions and Concepts

Continuous capability studies refer to studies on unstable processes. There is thus a need to differentiate between performance and capability.

Process Stability-Refers to the consistency of the process with respect to important process characteristics such as the average value of a key dimension or the variation in that key dimension. If the process behaves consistently over time, then we say that the process is stable or in control.

Process Capability-Is a measure of the ability of the process to meet specifications. It tells us what the best potential performance of the process is.

Performance Indices

P_{pk} is called performance indices because they show the actual performance of the process relative to customer requirements over the long term.

P_{pk} - Index of the expected number of times the actual process variation can fit into the tolerance, taking the off-centeredness into account.

$$P_{pk} = \text{Min}\left[\frac{\bar{X}-LSL}{3S_{LT}}, \frac{USL-\bar{X}}{3S_{LT}}\right]$$

If the process is stable over time the capability indices and the performance indices calculations will be close.Whilst there is no direct relationship between process stability and process capability, there is an important connection: process capability assessment should only be performed after first demonstrating process stability.

Capability Indices

P_p , C_p and C_{pk} are called the capability indices because they show what the process is capable of in a short period of time. They express the process best case performance.

P_p- Index of the expected number of times the potential process variation can fit into the tolerance, assuming that the process is centered on target, but excessive variation is not addressed.

$$P_p = \text{Min}\left[\frac{\bar{X}_0-LSL}{3S_{LT}}, \frac{USL-\bar{\bar{X}}_0}{3S_{LT}}\right]$$

C_p - Index of the expected number of times the potential process variation can fit into the tolerance, assuming that the process is centered on target and the inherent variation has been achieved.

$$C_p = \frac{USL-LSL}{6\hat{\sigma}}$$

C_{pk}- Index of the expected number of times the potential process variation can fit into the tolerance, assuming that the process variation is minimized, but process is NOT on target.

$$C_{pk} = \text{Min}\left[\frac{\bar{X}-LSL}{3\hat{\sigma}}, \frac{USL-\bar{X}}{3\hat{\sigma}}\right]$$

The following relates C_{pk} (on target but excessive variation not addresses) to other quality indicators.

Table 4 -Cpk Capability Index

C_{pk}	Sigma	Area under Distribution	Process Yield	DPMO
0,33	1	0.6826894921	68.27%	31 7311
0.67	2	0.9544997361	95.45%	45 500
1.00	3	0.9973002039	99.73%	2 700
1.33	4	0.9999366575	99.99%	63
1.67	5	0.9999994267	99.9999%	1
2.00	6	0.9999999980	99.9999998%	0.002

Interpretation of Indices

Table 5 - Ppk Interpretation

Ppk	**Interpretation:**
Less than 1,0	Process is not performing/ conforming: High probability that some output are outside specification limits.
Between 1,0 & 1,33	Process is performing marginally well: Output is barely inside spec limits.
Larger than 1,33	Process is performing well: All output is comfortably inside the specification limits.
Larger than 2,0	Process is producing exceptionally well (world class): All output is very close to the target value.

Table 6 - Cp, Pp and Cpk Interpretation

Cp, Pp, Cpk	**Interpretation:**
Less than 1,0	Process is not capable: Even at its best, high probability that some output will be outside specification limits.
Between 1,0 & 1,33	Process is marginally capable: At its best, very small probability to get output outside spec limits.
Larger than 1,33	Process is capable: At its best all output will be comfortably inside the specification limits.
Larger than 2,0	Process is extremely capable: has potential to be world class

5.3.3 Measurement System Analysis (MSA)

According to Pyzdek (2003:325)[10], measurement system analysis (MSA) illustrates methods used to quantify stability, bias, discrimination, repeatability, reproducibility and variation of a particular measurement system. It also assists in showing the relationship between measurement error and process variation/product tolerance. Its main purpose is to analyse the measurement system and not the process performance.

- Discrimination – Is the extent to which a measurement system can divide various measurements into relevant data categories.
- Stability – A system is stable when measurements are consistent over time, referred to as statistical stability. Measurement system stability can only be determined once the statistical stability is reached. This is determined by evaluating the standard deviation using an R-chart or S-chart.
- Bias – Refers to a difference in an observed measurement and the relevant reference value.
- Repeatability – Once variation stays consistent, the measurement system can be seen as repeatable. There must be no out of control point, thus special causes of variation within the system.
- Reproducibility – When different evaluators of the results, obtain consistent results, the measurement system can be viewed as reproducible.

It is stated by Wang (2011:14603) [13] that the measurement system study obtains the size of the measurement error and the sources of the error. Once this is determined, you must determine whether the system shows stability. Depending on the results, it is determined how to improve the system. The variability of the measurement system must be recognised and separated from the variation of the process.

5.3.4 Cause and Effect Matrix (C&E)

According to Otto (2005) [7], the Cause and Effect (C&E) Matrix identifies and provides an understanding of the relationship between the key input variables (KIV – the X's) and the key output variables (KOV – the Y's). Understand that the X's - control the Y's.

Y's - Process output variables or customer requirements associated with process performance/defect measures

X's - Process input variables associated with the sources of variation.

$$Y = f(X_1, X_2, \ldots, X_k)$$

A cause is classified as a KIV that is outside of the specification limit and an Effect is classified as a KOV that is outside of the specification limit. The C&E matrix provides input to the FMEA.

			Key Process Output Variables																
		Customer Importance																	
		Customer Rank																	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
			KPOV1	KPOV2	KPOV3	KPOV4	KPOV5													
		Process Step	KPIV															Rank	Rating	Total
Process Steps & Key Process Input Variables	1	Step 1	KPIV 1															1		0
	2		KPIV 2															1		0
	3	Step 2	KPIV 3															1		0
	4		KPIV 4															1		0
	5																			
	6																			
	7																			
	8																			
	9																			
	10																			
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	12																			
	13																			
	14																			
	15																			
	16																			
	17																			
	18																			
	19																			
	20																			
		Reverse Total	0	0	0	0	0													
		Reverse Score	0	0	0	0	0													
		Reverse Rank	1	1	1	1	1													
		Target																		
		LSL																		
		USL																		

Figure 15 - Cause and Effect Matrix Example

Otto (2005) [7]

Pyzdek (2003:263)[10] states that a C&E matrix is a tool that organises the knowledge, of different members of a group, relating to a specific problem. KIV's and KOV's are related to one another by using the already completed process map as the source of information. Each KIV is assigned a score which indicates their relationship to each KOV and each KOV is scored according to their importance/priority.

5.3.5 Failure Mode and Effect Analysis (FMEA)

Failure mode and effect analysis (FMEA) is described by Pyzdek (2003:596)[10] as an attempt to identify potential failures and their chance of occurring, their effect on the process and the possibility that it will not be detected. FMEA will assign resources to opportunities with high potential. Pillay (2001:70) [9] refers to FMEA as a decision making tool which provides the necessary information for conducting risk management. In summary the FMEA identifies the inputs with a high risk factor and provides improvement actions.

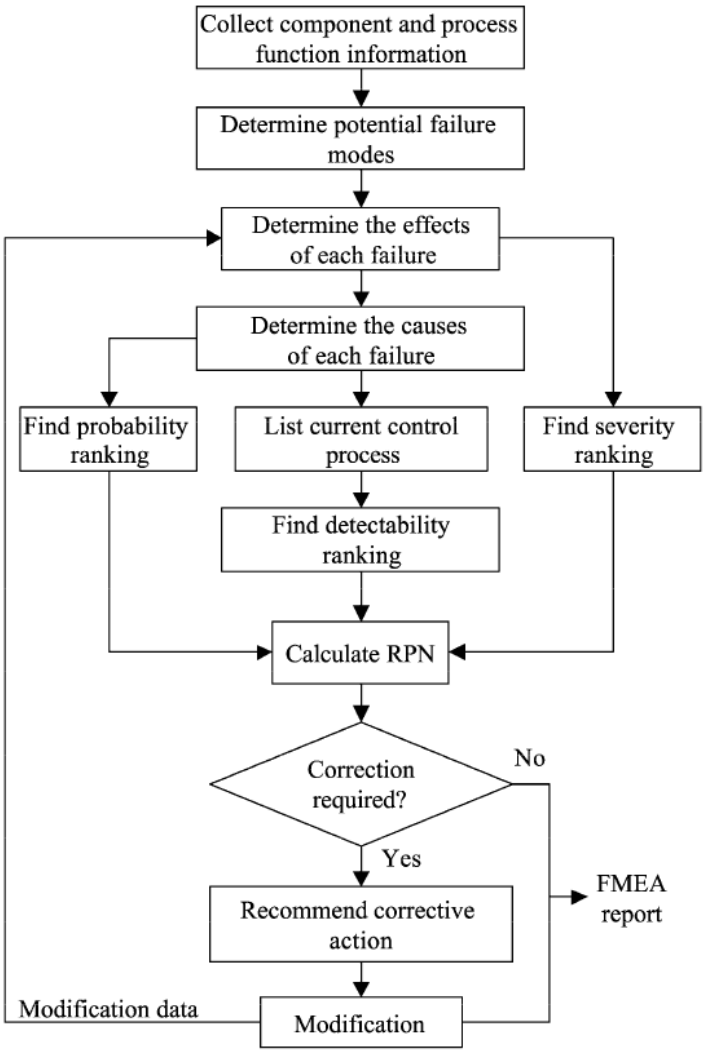


Figure 16 - FMEA Process

Pillay (2001:70) [9]

6 Data Gathering

This section contains the measurement phase of the DMAIC methodology in which data analysis is conducted to determine the current capability of the filler and the accuracy of the data available/collected.

6.1 Current Routine Fill Height Performance Analysis

Current fill height analysis conducted by the filler operators are performed using the 12 bottle sampling methodology as described in fill height management in Section 5.2.1.5. The results of each fill operators analysis is recorded in eQMS.

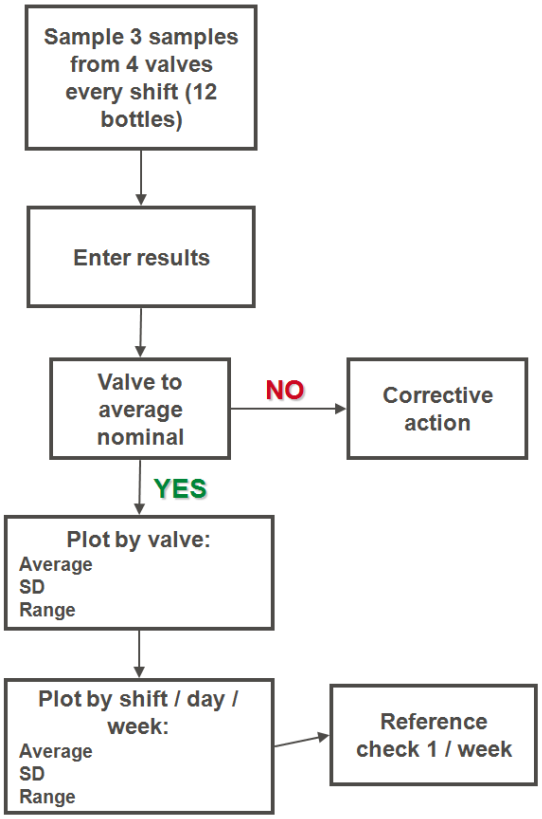


Figure 17 - 12 Bottle Sampling Methodology

For the purpose of this project the relevant data for all 176 was collected from eQMS. This data was captured in eQMS over a period of two to three weeks. The total filler performance in terms of fill height was calculated from the data collected by the fill operators and summarised by a few descriptive statistics.

Table 7 - Descriptive Fill Height Statistics from Current Routine Performance

Statistic	Measurement (in mm)
Mean($\bar{X}$)	71.59188
Minimum	68.4
Maximum	73.9
Range	5.5
Standard dev. - S_{LT}	0.948629

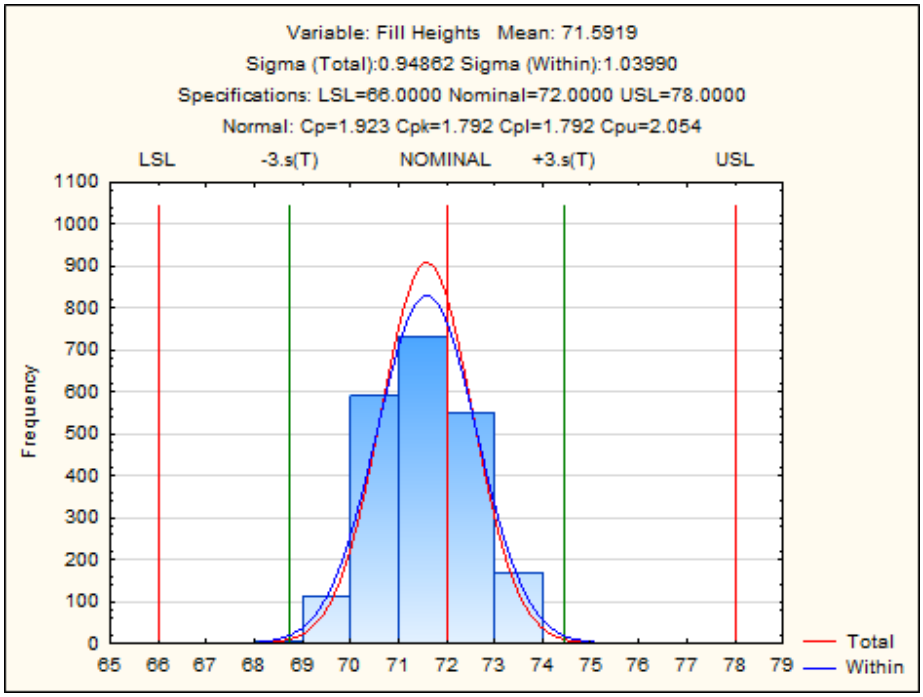


Figure 18 - Current Routine Fill Height Performance

The graph indicates that the process is close to the target and that all points are within the specification limits. As discussed in the brief of the project, it is believed that the fill heights are not being sampled and recorded according to the best practices, thus the results are considered to be suspect.

6.2 Fill Height Capability Study

The initial data was gathered using the filler capability study methodology described in Section 5.2.2. This method is used to assess the ability of the filler to meet specifications by measuring how good the individual valves are. The initial data was collected in order to establish the as-is capability of Alrode line 8. The capability study was performed on the entire filler which comprises of 176 valves (See Figure 19). The fill height average, standard deviation and range were calculated per valve and can be seen on the initial data sheet in Appendix B.

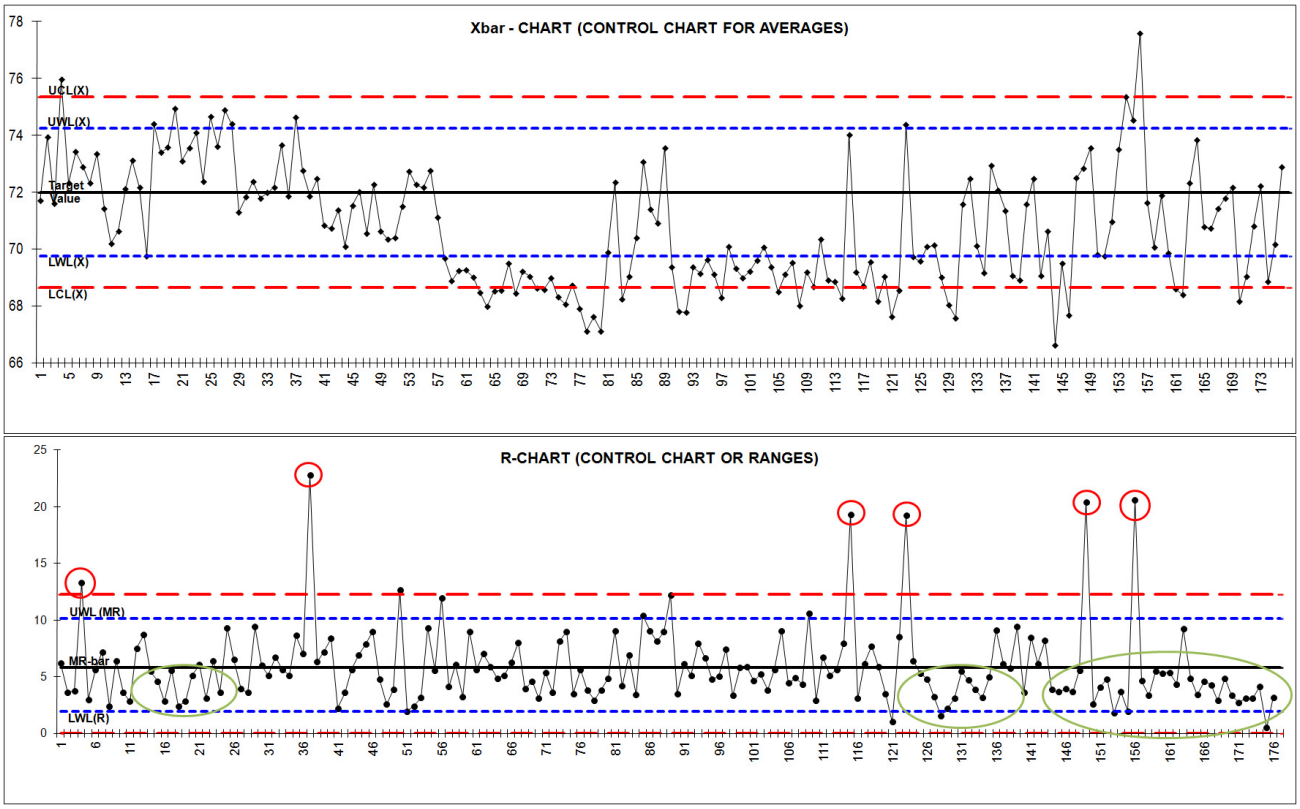


Figure 19 - X Barbar and Rbar chart

From Figure 19 the red and green circled point on the R-chart represents the worst and best valve performance respectively. The valves identified in green, thus represents the best inherent performance of the process. The performance data of these valves, with respect to their fill height, was used to calculate the short term standard deviation of 1.649 which was used to determine the capability of the process as seen in Table 9. The chart clearly identifies many valves performing beyond the specification limits, these valves must be addressed or the reason for the out of control average must be identified. There are also a number of occurrences where two out of three consecutive points fall beyond the warning limits (WL) or where eight or more consecutive points fall on the same side of the centreline. The process is thus out of control and unstable.

Table 8 - Descriptive Fill Height Statistics from the Capability Study

Statistic	Measure (in mm)
Mean ($\bar{\bar{X}}$)	70.75111
Minimum	62.98
Maximum	90.06
Range	27.08
Standard dev. - S_{LT} (long term - performance)	3.255916
Standard dev. - $\hat{\sigma}$ (short term - capability)	1.6490

The total filler capability was calculated as a baseline capability for the filler by using the basic statistics along with the specification limits defined according to the Trade Metrology Act. The results can be seen in Table 9. The calculations were as follows:

$P_{pk} = \text{Min}\left[\frac{\bar{\bar{X}}-LSL}{3S_{LT}}, \frac{USL-\bar{\bar{X}}}{3S_{LT}}\right]$

$= \text{Min}\left[\frac{70.75-66}{3(3.26)}, \frac{78-70.75}{3(3.26)}\right]$

$= \text{Min}[0.48641, 0.74223]$

$= 0.48641$

$P_p = \text{Min}\left[\frac{\bar{\bar{X}}_0-LSL}{3S_{LT}}, \frac{USL-\bar{\bar{X}}_0}{3S_{LT}}\right]$

$= \text{Min}\left[\frac{72-66}{3(3.26)}, \frac{78-72}{3(3.26)}\right]$

$= \text{Min}[0.61427, 0.61427]$

$= 0.61427$

$C_{pk} = \text{Min}\left[\frac{\bar{\bar{X}}-LSL}{3\hat{\sigma}}, \frac{USL-\bar{\bar{X}}}{3\hat{\sigma}}\right]$

$= \text{Min}\left[\frac{70.75-66}{3(1.65)}, \frac{78-70.75}{3(1.65)}\right]$

$= \text{Min}[0.960, 1.466]$

$= 0.960$

$C_p = \frac{USL-LSL}{6\hat{\sigma}}$

$= \frac{78-66}{6(1.65)}$

$= 1.213$

Table 9 - Baseline Fill Height Capability

Capability Index		Performance Index	
Lower Specification Limit	66.00	Lower Specification Limit	66.00
Nominal specification Limit	72.00	Nominal specification Limit	72.00
Upper Specification Limit	78.00	Upper Specification Limit	78.00
Off Target	0	Off Target	-1.25
Pp (performance index)	0.61427	Ppk (performance demonstrated excellence)	0.48641
Cp (potential capability)	1.213		
Cpk (demonstrated excellence)	0.960		

The capability and performance indices with their interpretation can be seen in the table below. These interpretations are based on Table 5 and 6 in Section 5.3.2.1 of the literature review which contains the indices interpretations.

Table 10 - Indices from Capability Study Interpretation

Indices	Value	Interpretation
Ppk	0.48641	Process is not performing/ conforming: High probability that some output are outside specification limits.
Pp	0.61427	Process is not capable: Even if excessive variation is addresses, a high probability exists that some output will be outside specification limits.
Cpk	0.960	Process is not capable: Even if process is centered on target, a high probability exists that some output will be outside specification limits.
Cp	1.213	Process is marginally capable: At its best (on target with smallest variation), a very small probability exists that output is outside spec limits.

In order to illustrate the basic statistics a method called SCONS (Shape, Centre, Outliers, Normality and Spread) was implemented. The shape, centring and spread of the data can be seen in the histogram (Figure 20). The outliers of the process will be identified by the use of a box and whiskers chart as shown in Figure 21. Lastly the normality of the data will be illustrated in the X bar and R chart as seen in Figure 19.

From Figure 20 it was identified that there are data points outside of the specification limits of 66mm and 78mm. The process was also found to be off target (72mm) with an average fill height of 70.75mm.

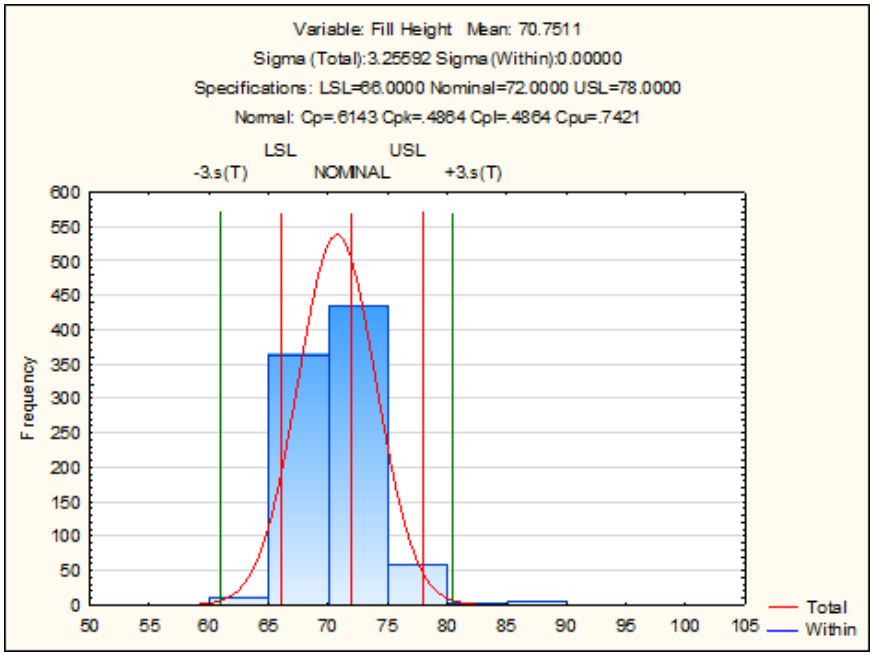


Figure 20 - Initial Fill Height Capability Study

The box and whiskers diagram is used with the goal of identifying outliers. Because of the number of valves, 4 separate graphs were done in order to avoid unreadable data. From Figure 20 and Figure 21, many outliers can be easily identified and this indicates that the system is not in control. The outliers identified refer to the valves that need to be addresses, as they are currently out of specification. The special causes of variation of these valves must be identified.

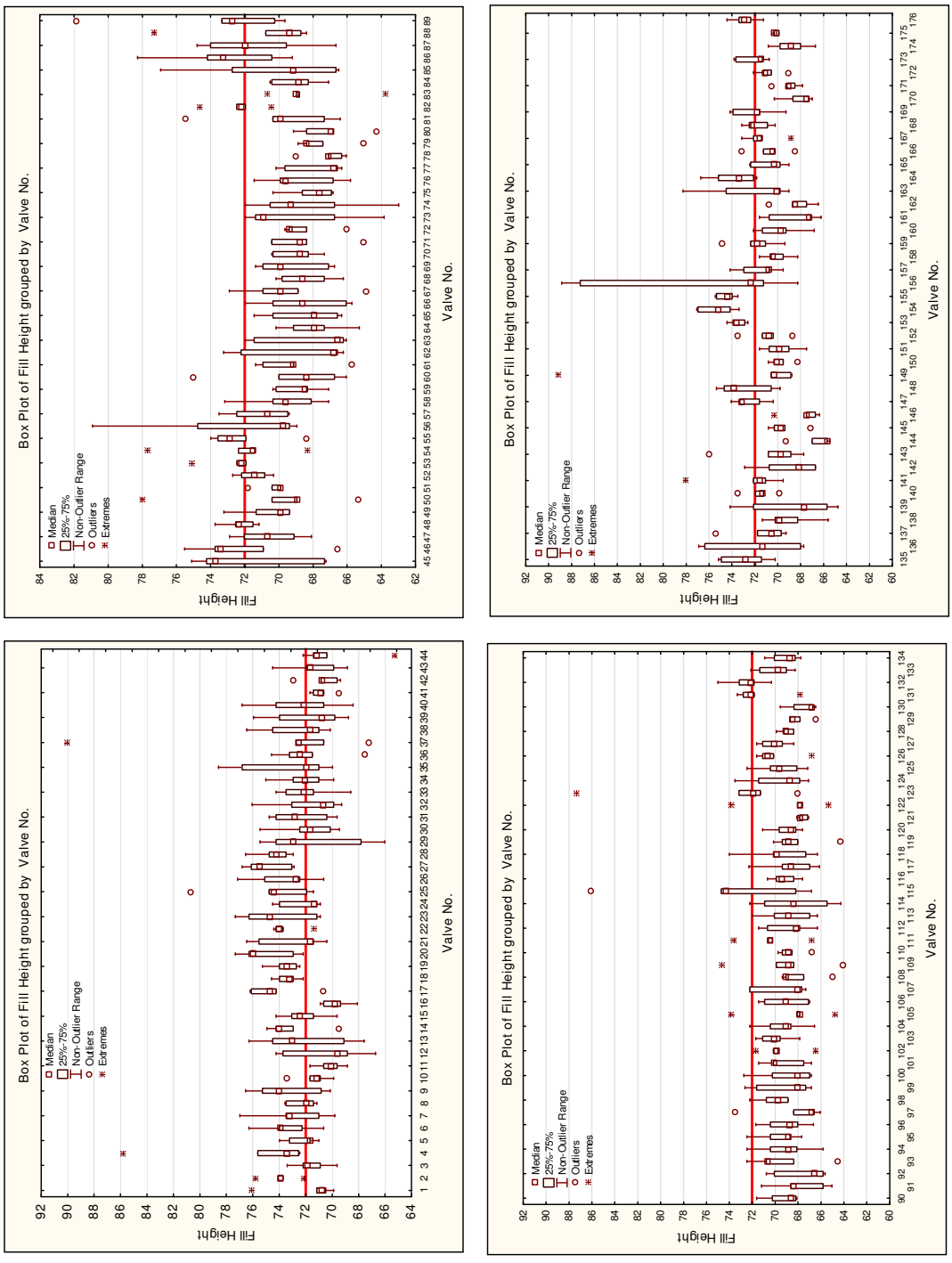


Figure 21- Box and Whiskers Chart

In Figure 22 the individual valve standard deviation is shown and thus the valves which are not performing under the limit of 2mm standard deviation can be easily identified.

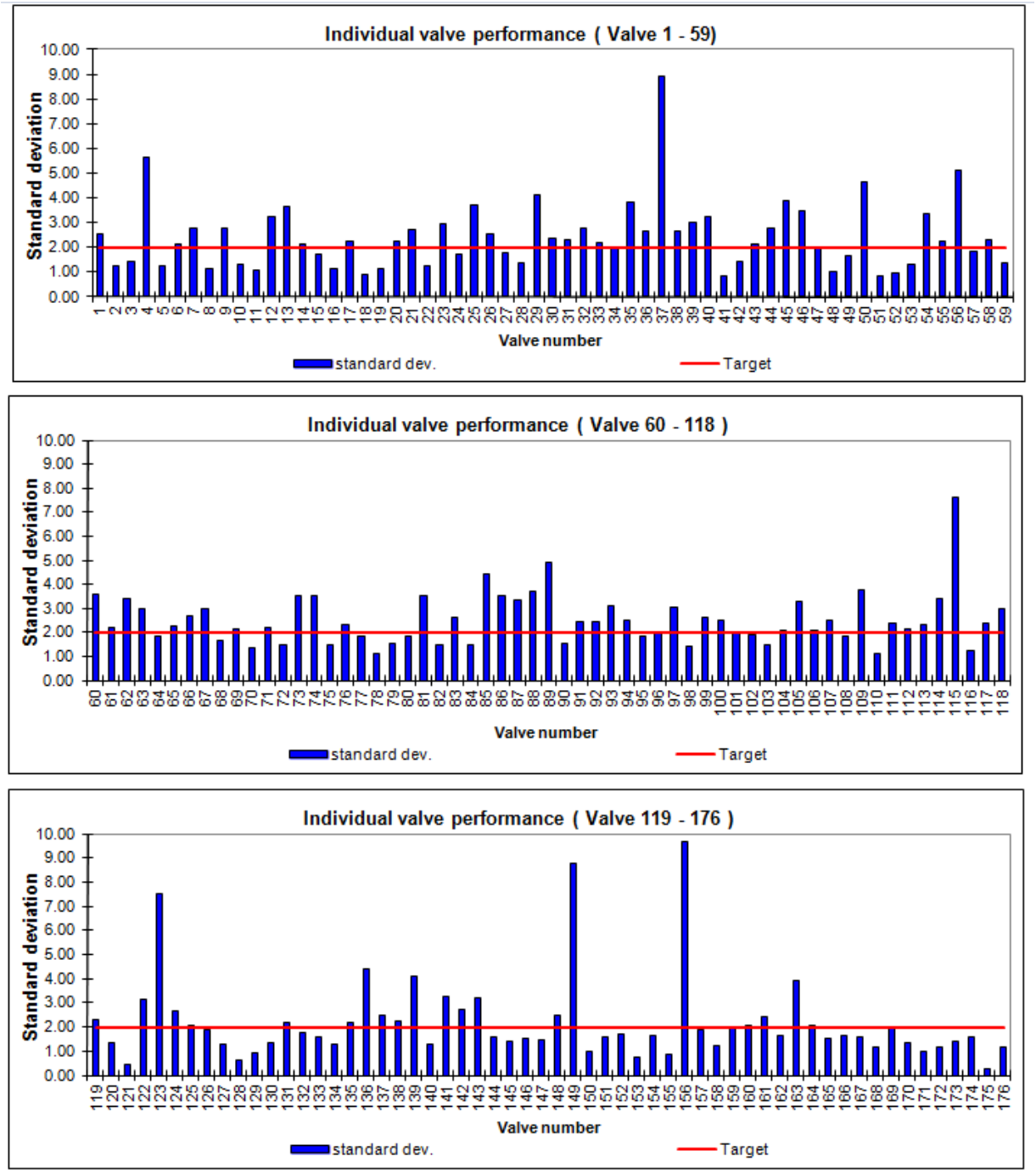


Figure 22 - Individual Valve Performance

6.3 Measurement System Analysis (MSA) - Audit

MSA quantifies the stability, repeatability and reproducibility and variation of a particular measurement system. It identifies the relationship between the measurement error and process variation/product tolerance.

The fill height sampling method, policy and procedures are used as a baseline for this audit. The purpose of the audit is to verify the effectiveness and efficiency of the fill operators and the method they use to conduct fill height sampling.Due to good measurement instrument management at SAB a Gauge r and R will not be required for this project, as the measurement system (the Akitek) is considered to be accurate. The audit identifies the problem areas with regards to the sampling methodology and an action list to solve these problems will then be compiled. The audits are executed by observing the fill operators while they conduct fill height sampling. The audits were completed for certain fill operators on line 8. The document below was drawn up and used for auditing purposes.

Fill Heights – Alrode Line 8 **MSA Audit**

Date: _____ Shift: _____

Time Analysed: _____ Time Sampled: _____

Fill Operator: _____ Team Leader: _____

Does the fill operator perform the following steps when sampling fill heights:

Task	Y/N
Record the conditions under which the samples are taken[1]	
Check to see if speed is at a constant 50000bph	
Conduct per valve sampling of 4 consecutive valves	
Sample 3 bottles per valve	
Resample when they are unsure if the correct bottle was sampled[2]	
Clearly mark bottles once they are sampled	
Allow samples to stand for 45 -60min	
Check settings of FA-100 version 2.7.0.[3]	
Calibrate the Akitek properly	
Verify calibration (Delta fill = 2.2 and fill level = 69.8)	
Record results accurately	
Did the team leader monitor the entire fill height measurement process?	
Additional Remarks:	

[1] Conditions include the date, time, BBT, BBT temperature, speed, jetting pressure, density, CO2 etc.

[2] If the rejecter provides more than one bottle simultaneously, there is no way of knowing which bottle is from the valve sampled.

[3] The settings must be completed according to the Akitek fill auditor, which includes data such as the pack size, zero-correction (compensation), nominal fill level etc.

Figure 23 - MSA Audit

From conducting the audits, it was found that the operators do not follow the proper methodology. The following are the main problem areas which were identified:

- There is no check done to see if the filler speed is at a constant 50000 bph
- Operators do not resample if/when they are unsure if the correct bottle was sampled (this occurs when the PFBI rejecter rejects more than one bottle at a time)
- Samples aren't analysed within the 45-60 minutes, thus samples are often only analysed after an hour has passed. The longer the sample stands the more the temperature will drop and this will affect the fill height of the samples.

Fill Heights – Alrode Line 8 **MSA Audit**

Date: 17 April 2012 Shift: Morning

Time Analysed: 12:45 Time Sampled: 14:00

Fill Operator: Frank Team Leader: _____

Does the fill operator perform the following steps when sampling fill heights:

Task	Y/N
Record the conditions under which the samples are taken[1]	N
Check to see if speed is at a constant 53000bph	N
Conduct per valve sampling of 4 consecutive valves	Y
Sample 3 bottles per valve	Y
Resample when they are unsure if the correct bottle was sampled[2]	N
Clearly mark bottles once they are sampled	Y
Allow samples to stand for 45 -60min	N
Check settings of FA-100 version 2.7.0.[3]	N
Calibrate the Akitek properly	Y
Verify calibration (Delta fill = 2.2 and fill level = 69.8)	N
Record results accurately	Y
Did the team leader monitor the entire fill height measurement process?	Y
Additional Remarks: PFBI rejecter failure. More than one bottle rejected at a time, caused confusion regarding which bottle should be sampled.	

[1] Conditions include the date, time, BBT, BBT temperature, speed, jetting pressure, density, CO2 etc.

[2] If the rejecter provides more than one bottle simultaneously, there is no way of knowing which bottle is from the valve sampled.

[3] The settings must be completed according to the Akitek fill auditor, which includes data such as the pack size, zero-correction (compensation), nominal fill level etc.

Figure 24 - Audit Example

6.4 Data Gathering Conclusion and Recommendations

6.4.1 Current Routine Fill Height

According to the routine data that's collected by the operators and entered into eQMS, as summarised in Table 7, the process is conforming to the specifications. This is contrary to the findings of the capability study, as summarised in Table 8, which showed that the process is not conforming to the specifications. The capability study outcome also shows a very high standard deviation and a lot of under-performing valves compared to the routine performance. The suspicion of management that the fill heights are not being sampled and recorded according to the best practices is thus confirmed.

6.4.2 Capability Study

From the capability study the following can be deducted:

- The control charts (Figure 19) and the Box and Whiskers plot (Figure 21) show that the process is out-of-control in that the individual valves are not performing consistently. In certain cases, individual valves are completely under filling (for example, valves nr 17 to 30 filling at 74mm), while others are completely over filling (for example, valves nr 60 to 80 filling at 68 mm). Furthermore, certain valves are completely inconsistent, as the fill heights of three consecutive bottles from the same valve show a huge variation (for example valves nr 80 to 84 shows a variation of 10 mm).
- The control charts show that certain valves (for example, valves 29 to 33) are on target, while the some valves are very consistent (for example, valves nr 18 to 24 and the others circled in green in Figure 19).
- The performance index (Ppk = 0,48) shows that the process is not conforming to the specifications
- The capability indices show that:
    - According to Pp = 0,6 if all the valves can be centred on the target value, the process will still not conform to the specifications
    - According to the Cpk =0,96 if all the valves can be controlled so that the variation in the consecutive bottles, filled by the same valve, is consistent according to the smallest variation of the best performing valves, the process will almost conform to the specifications.
    - According to the Cp = 1,2 if all the valves can be cantered on target with minimum variation, then the process will conform to the specification limits.

Thus, the capability indices derived from the initial data gathered such as the Cp which is equal to 1.2 are low when compared to the desired capability value that SAB identified as 1.33. It is thus recommended that SAB reengineers the process, but the project's purpose will only be to reach the capability of 1.2.

6.4.3 Summary

Descriptive stats from the capability study indicate that the mean performance is 70.3mm with a standard deviation of 3.26 (see Figure 25); this indicates that the process is not performing on target with a high standard deviation. This contradicts the stated routine performance (data sourced from eQMS) which indicates a mean performance of 71.6mm with a standard deviation of 0.95. The capability study has thus proven that there is a great need for improvement with regards to fill heights, as the data gathered during routine performance, seems to be unreliable due to incorrect sampling and logins of data; this has been proven by the MSA audit. Furthermore the MSA audit identified that there are often problems with the PFBI rejecter, causing confusion regarding which bottle to sample.

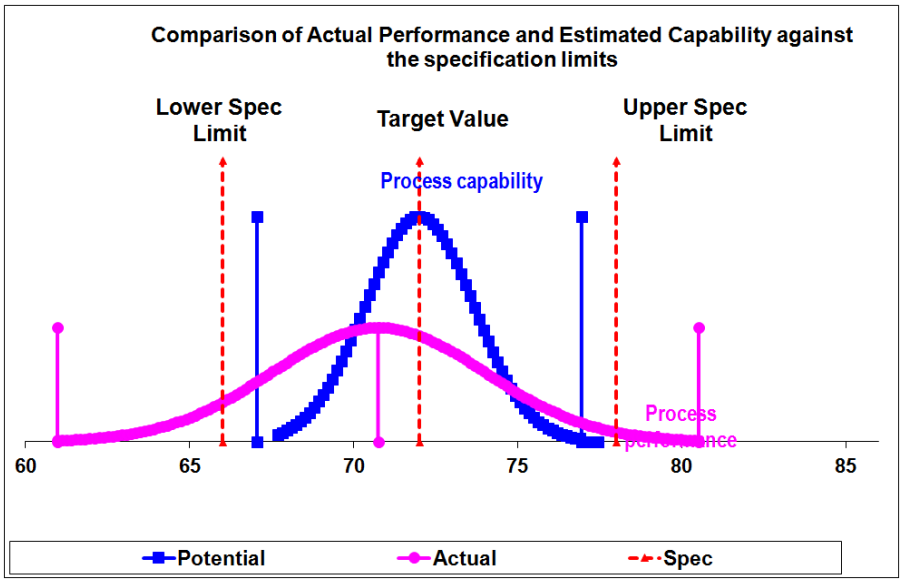


Figure 25 - Performance and Capability against Specification Limits

Due to these findings, the following specific goals were identified:

- Find an approach by which the process standard deviation can be reduced to be less than 2mm.
- Find an approach by which the process can be stabilised so the fill heights of all the valves is equal to or as near as possible to 72mm as the standard deviation will allow
- Develop a statistical process control system (SPC) for monitoring and controlling fill heights of individual valves.
- Find an approach by which the fill height sampling and analysis methodology can be accurately performed by the fill operators.
- Develop a supplementary method to ensure the PFBI is rejecting accurately

7 Analysis

The define phase of the DMAIC methodology was used to define the project objectives and scope the project properly, whilst the measurement phase defined the current process and established the project metrics through the use of process maps, a literature study and data measurement. The next phase of the DMAIC methodology is the analysis phase, which will include both the Cause and Effect Matrix (C&E Matrix) and the Failure Mode and Effect Analysis (FMEA).

7.1 Cause and Effect Matrix (C&E)

The Cause and Effect Matrix (C&E) as defined in Section 5.3.4 of this report, relates the key input variables (KIV) - to the key output variables (KOV) of the process. The low-level process map which can be found in Section 4.1.2 is used as a source of information for the Cause and Effect Matrix. The matrix is used to identify what process inputs should be carried forward in the project by prioritising the inputs.

The following steps were completed to construct the Cause and Effect Matrix:

1) Selection of the primaryY_1 output of this project took place, which is identified as fill heights.
2) Selection of the counter balance Y_2output to the primary output took place, which was identified as the quality of the beer. The beer quality refers to the dissolved oxygen levels (DO's).
3) The primary (Y_1) and counter balance (Y_2) were then rated based on their importance, according to a scale of 1-10 with 1 being the minimum.

	Process Output	
	Fill Height	**Quality**
Importance	10	8

4) The inputs (X's) shown on the low-level process map, along with the corresponding process steps were carried over to the matrix.
5) The inputs were then related to the primary and counter balance through the use of a rating system. The rating represents the strength of correlation between the inputs and outputs and is done on a scale of 1, 3 and 9 with 1 being low/no correlation. The actual rating was conducted with a team of subject matter experts which included amongst others:Two Six-Sigma black belts, one of which is the line manager, the filler specialist, the line maintenance manager and the line planner

Rating	
9	high
3	medium
1	low
0	none

6) In order to retrieve a total for each process input, multiply the column and add across the row.
7) The totals were then sorted in descending order.

The resulting, sorted, Cause and Effect Matrix from the group effort can be seen in Table11.

Table 11 - Cause and Effect matrix (sorted)

		Process Output	
	Importance	10	8

Process Step	Process Input	Fill Height (@ target)	Quality (DO's)	Total
Bottle Positioning	Tulip rubber	9	9	162
Bottle Positioning	Hanger bracket	9	9	162
Bottle Positioning	Lift cylinder pressure	9	9	162
Triple Evacuation	Vacuum pump	9	9	162
Triple Evacuation	CO2 return channel	9	9	162
Triple Evacuation	Solenoids	9	9	162
Triple Evacuation	Tulips	9	9	162
Triple Evacuation	Lift cylinder pressure	9	9	162
Triple Evacuation	Valve	9	9	162
Pressurisation	Tulip	9	9	162
Pressurisation	CO2 channel	9	9	162
Pressurisation	Solenoids	9	9	162
Pressurisation	CO2 Pressure	9	9	162
Pressurisation	Valve	9	9	162
Pressurisation	Pressure on solenoids	9	9	162
Pressurisation	Lift cylinder pressure	9	9	162
Filling	Beer	9	9	162
Filling	Beer temperature	9	9	162
Filling	Counter pressure CO2	9	9	162
Filling	Solenoids	9	9	162
Filling	CO2 (gas channel)	9	9	162
Filling	Lift cylinder	9	9	162
Filling	Hanger brackets	9	9	162
Filling	Valve	9	9	162
Pre-and Final relief	Valve	9	9	162
Pre-and Final relief	Solenoid	9	9	162
Jetting and Fobbing	Jetter nozzle size	9	9	162
Jetting and Fobbing	Jetter pressure	9	9	162
Jetting and Fobbing	Jetter temperature	9	9	162
Jetting and Fobbing	Jetter position	9	9	162
Jetting and Fobbing	Star wheels	9	9	162

Jetting and Fobbing	Bottle guides	9	9	162
Triple Evacuation	Bad positioned bottle	9	3	114
Triple Evacuation	Sensor (timing)	9	3	114
Filling	Bowl level	9	3	114
Filling	Bowl level control (4 capacitive probes)	9	3	114
Filling	Filling probe	9	3	114
Pre-and Final relief	Filled bottle	9	3	114
Pressurisation	Air free bad positioned bottle	3	9	102
Filling	Correction factor	9	1	98
Crowning	Filled jetted bottles	1	9	82
Jetting and Fobbing	Filled bottle open to atmosphere	0	9	72
Crowning	Crown	0	9	72
Crowning	Crown platforms	0	9	72
Crowning	Crown thraights	0	9	72
Inspection	Uncrowned filled bottle	0	9	72
Bottle Positioning	Lift cylinders	3	3	54
Bottle Positioning	Ride tracks	3	3	54
Pressurisation	Hanger Brackets	3	3	54
Filling	Platform	3	3	54
Pre-and Final relief	Relief chamber	3	3	54
Bottle Positioning	In feed worm	3	1	38
Bottle Positioning	In feed guides	3	1	38
Inspection	PFBI (Preliminary Full Bottle Inspector)	3	0	30
Inspection	Rejecter	3	0	30
Crowning	Crown shoe's	0	3	24
Crowning	Crown piston heights	0	3	24
Bottle Positioning	Platforms	1	1	18
Pressurisation	Air free good positioned bottle	1	1	18
Pressurisation	Platform	1	1	18
Filling	Pressurised good positioned bottles	1	1	18
Pre-and Final relief	Atmosphere	1	1	18
Bottle Positioning	Star wheels	1	0	10
Bottle Positioning	Bottle	0	0	0
Bottle Positioning	Conveyors	0	0	0
Triple Evacuation	Good Positioned Bottle	0	0	0
Pressurisation	Lift cylinder pressure	0	0	0
Inspection	Crowned filled bottle	0	0	0
Inspection	Conveyors	0	0	0

From the Cause and Effect Matrix (Table11), the highest rated inputs (X's) were identified so that they can be carried over further. However, it is clear in the table that there are many process inputs, relevant to their specific process steps that will have a significant impact on fill height (Y_1) and quality (DO's) (Y_2). These inputs all have a very high rating of 162 as compared to the rest of the inputs' ratings.

With a Cause and Effect Matrix it is ideal to identify the minimal amount of inputs, as these are carried over to the FMEA. Due to this reason and for simplification purposes, the subject matter experts suggested that the process inputs that are the same be grouped together, thus minimising the total number of inputs carried over. This can be done seeing that the inputs with the same descriptions are actually the same components; they were only classified separately as they are involved in more than one process step. Due to the nature of the filling process, simplification was only done for the inputs with the highest ratings. After simplification of the sorted matrix, the following process inputs were identified:

Table 12 - Highest Rated Process Inputs

No.	Process Input	Process Step
X1	Tulips	Bottle Positioning
		Triple Evacuation
		Pressurisation
X2	Hanger Bracket	Bottle Positioning
		Filling
X3	Lift cylinder pressure	Bottle Positioning
		Triple Evacuation
		Pressurisation
X4	Vacuum pump	Triple Evacuation
X5	CO2 return channel	Triple Evacuation
X6	Solenoids	Triple Evacuation
		Pressurisation
		Filling
		Pre-and Final relief
X7	Valve	Triple Evacuation
		Pressurisation
		Filling
		Pre-and Final relief
X8	CO2 channel	Pressurisation
		Filling
X9	Lift cylinder	Filling
X10	Jetter nozzle size	Jetting and Fobbing
X11	Jetter pressure	Jetting and Fobbing
X12	Jetter temperature	Jetting and Fobbing
X13	Jetter position	Jetting and Fobbing
X14	Star wheels	Jetting and Fobbing
X15	Bottle guides	Jetting and Fobbing
X16	CO2 Pressure in channel	Pressurisation
X17	Pressure on solenoids	Pressurisation
X18	Counter pressure CO2	Filling

A total of 18 process inputs (X's) were identified. As defined in the literature study of the C&E Matrix in section, the inputs (X's) control the outputs (Y's):

$$Y_1 + Y_2 = f(X_1, X_2, \dots, X_{18}, X_{Insignificant})$$

$$Y_1 = Fill\ Height$$
$$Y_2 = Quality\ (DO's)$$

7.2 Failure Mode and Effect Analysis (FMEA)

The Failure Mode and Effect Analysis is fully defined in Section 5.3.5 as a method/tool used to identify a potential failure, its chance of occurring, the effect of it on the process and the possibility of not detecting it.

This Figure demonstrates the steps that were followed to complete the FMEA. Each of these steps was completed for each one of the 18 process inputs identified by the C&E Matrix. These steps were conducted with the subject matter experts team which included: two Six-Sigma black belts, one of which is the line manager, the filler specialist, the line maintenance manager and the line planner. The process inputs(X's) identified through the use of the Cause and Effect Matrix, as seen in Table 12, was used as input into the FMEA.

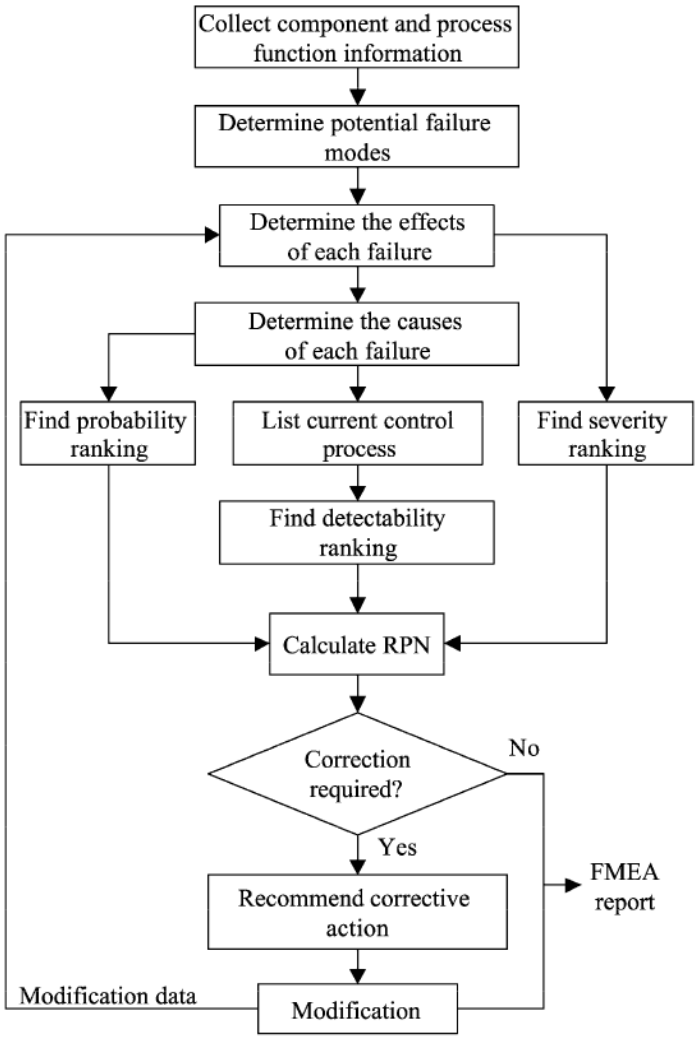


Figure 26 - FMEA Process Flow

The following ranking is done for a FMEA:

- Severity (SEV) - scale of 1-10 with 1-lowest and 10-highest
- Occurrence (OCC - probability) - scale of 1-10 with 1-lowest and 10-highest
- Detection (DET) - scale of 1-10 with 1-least possibility of detection and 10-maximum possibility of detection

Calculating the RPN (Risk Priority Number)

- The RPN = Severity(SEV) x Occurrences(OCC) x Detection(DET)

Table 13 - FMEA

Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes	O C C	Current Controls	D E T	R P N
What is the process step	What is the Key Process Input?	In what ways does the Key Input go wrong?	What is the impact on the Key Output Variables (Customer Requirements) or internal requirements?	How Severe is the effect to the customer?	What causes the Key Input to go wrong?	How often does cause or FM occur?	What are the existing controls and procedures (inspection and test) that prevent either the cause or the Failure Mode? **Should include an SOP number.**	How well can you detect cause or FM?	
Bottle Positioning	**Tulips**	Non OEM tulips installed	Fill height variation	9	Cost of OEM spares too high	8	Nothing, up to the Unit manager (UM) , maintenance controller and maintenance planner to decide	1	72
Triple Evacuation		Tulip rubber damaged	Fill height variation	9	burst bottles	9	PIMS & POMS at filer- manage non performing valves	1	81
Pressurisation							Valve and tube practices on maintenance days	1	0
		Tulip maintenance practices poor	Fill height variation	9	no best practice in place & lack of preventative maintenance (PM)schedules	10	Valve and tube practices on maintenance days	1	90
Bottle Positioning	**Hanger Bracket**	Damaged/bent hanger bracket	Fill height variation	7	burst bottle & poor setup	9	PM schedules on maintenance day	2	126
Filling		Maintenace practices poor	Fill height variation	7	no PM schedules in place	5	PM schedules on maintenance day	3	105
Bottle Positioning	**Lift cylinder pressure**	Too low	No fill to low fill	9	supply pressure not sufficient	1	PilMS & POMS (Operator reaction)	1	9
Triple Evacuation		Too high	almost no impact	1	pressure setup problematic	1	PilMS & POMS (Operator reaction)	1	1
Pressurisation									0
Triple Evacuation	**Vacuum pump**	Not enough vacuum pressure	no fill height impact, but a quality impact	1	Poor vacuum pump operation	1	PilMS & POMS (Operator reaction)	1	1
Triple Evacuation	**CO2 return**	Blocked CO2 return channel	no fill height impact, but a quality impact	1	CO2 build up or CIP practice	1	Nothing.	9	9
Triple Evacuation	**Solenoids**	Slow reaction of solenoids	fill height variation	9	Solenoid age (wear life)	2	Nothing	9	162
Pressurisation		Air leaks	fill height variation	9	poor maintenance	5	Nothing	9	405
Filling		Poor connection on solenoids	fill height variation	9	poor maintenance/wear	2	Nothing	9	162
Pre-and Final relief		Damaged by hygiene practices	fill height variation	9	water ingress into electronics (operator with high pressure guns)	9	WI 17 exist but might not be followed	9	729
Triple Evacuation	**Valve**	Valve leaking	fill height variation	9	poor valve and tube practices	9	Nothing	7	567
Pressurisation			fill height variation	9	PM schedules not in place	9	PM schedules on maintenance day	9	729
Filling		Seals perished		9	Valve performances practices not in place during running operaions	9	PIMS & POMS & reaction of operator	9	729
Pre-and Final relief									0

Table 14 - FMEA Continued

Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
What is the process step	What is the Key Process Input?	In what ways does the Key Input go wrong?	What is the impact on the Key Output Variables (Customer Requirements) or internal requirements?	How Severe is the effect to the customer?	What causes the Key Input to go wrong?	How often does cause or FM occur?	What are the existing controls and procedures (inspection and test) that prevent either the cause or the Failure Mode? **Should include an SOP number.**	How well can you detect cause or FM?	
Pressurisation	**CO2 channel**	CO2 channel blocked	fill height variation	9	CO2 purity	2	Utilities check CO2 purity	2	36
Filling		CO2 pressure low	fill height variation	9	CO2 supply pressure from utilities	2	PIMS & POMS & reaction of operator	2	36
Filling	**Lift cylinder**	Lift cylinder slow	fill height variation	9					0
Jetting and Fobbing	**Jetter nozzle size**	Incorrect size (too big/small)	fill height variation	9	Standards not followed (PIMS and POMS)	9	Nothing	10	810
Jetting and Fobbing	**Jetter pressure**	too low	fill height variation	9	Standards not followed (PIMS and POMS)	9	PIMS & POMS & reaction of operator	1	81
		too high	fill height variation	9	Standards not followed (PIMS and POMS)	9	PIMS & POMS & reaction of operator	1	81
Jetting and Fobbing	**Jetter temperature**	too high	fill height variation	9	Standards not followed (PIMS and POMS)	9	PIMS & POMS & reaction of operator	1	81
		too low	fill height variation	9	Standards not followed (PIMS and POMS)	9	PIMS & POMS & reaction of operator	1	81
Jetting and Fobbing	**Jetter position**	incorrect position (too high/low)-height	fill height variation	9	Standards not followed (PIMS and POMS)	9	PIMS & POMS & reaction of operator	1	81
		not positioned over bottle	fill height variation	9	Standards not followed (PIMS and POMS)	9	PIMS & POMS & reaction of operator	1	81
Jetting and Fobbing	**Star wheels**	back lash on star wheels (worn)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567
		Incorrect starwheels used for brand	fill height variation	9	Operator used wrong starwheels during change over	9	Changeover WI	3	243
Jetting and Fobbing	**Bottle guides**	Setup incorect	fill height variation	9	setup standards not followed by operator	9	Changeover WI	3	243
		bottle guides worn (backlash)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567
Pressurisation	**CO2 Pressure in channel**	Too high	fill height variation	9	Utility supply pressure or filler settings	2	CO2 pressure managed by utilities	2	36
		Too low	fill height variation	9	Utility supply pressure or filler settings	2	CO2 pressure managed by utilities	2	36
Pressurisation	**Pressure on solenoids**	solenoid worn	fill height variation	9	No clear evaluation practices for maintenance	9	Air pressure managed by utilities	2	162
									0
Filling	**Counter pressure CO2**	too high	fill height variation	9	Utility supply pressure or filler settings	2	CO2 pressure managed by utilities	2	36
		too low	fill height variation	9	Utility supply pressure or filler settings	2	CO2 pressure managed by utilities	2	36

Once the FMEA has been completed, it is sorted based on the RPN ratings. For the process inputs with a maximum RPN it will be recommended that action be taken on them. Seeing as experience with an FMEA as well as with the filler of line 8 is essential in selecting the most critical process inputs, the FMEA was completed over several meetings with the subject matter experts team from SAB's Alrode packaging department.

Table 15 - FMEA Sorted & Filtered

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
X1	Pressurisation	**Solenoids**	Air leaks	fill height variation	9	poor maintenance	5	Nothing	9	405
	Pre-and Final relief		Damaged by hygiene practices	fill height variation	9	water ingress into electronics (operator with high pressure guns)	9	WI 17 exist but might not be followed	9	729
X2	Triple Evacuation	**Valve**	Valve leaking	fill height variation	9	poor valve and tube practices	9	Nothing	7	567
	Pressurisation			fill height variation	9	PM schedules not in place	9	PM schedules on maintenance day	9	729
	Filling		Seals perished		9	Valve performances practices not in place during running operaions	9	PIMS & POMS & reaction of operator	9	729
X3	Jetting and Fobbing	**Jetter nozzle size**	Incorrect size (too big/small)	fill height variation	9	Standards not followed (PIMS and POMS)	9	Nothing	10	810
X4	Jetting and Fobbing	**Star wheels**	back lash on star wheels (worn)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567
	Jetting and Fobbing		Incorrect starwheels used for brand	fill height variation	9	Operator used wrong starwheels during change over	9	Changeover WI 15	3	243
X5	Jetting and Fobbing	**Bottle guides**	Setup incorect	fill height variation	9	setup standards not followed by operator	9	Changeover WI 15	3	243
	Jetting and Fobbing		bottle guides worn (backlash)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567

The process inputs that were identified after sorting and filtering the FMEA are as follows:

1) Solenoids
2) Valve
3) Jetter nozzle size
4) Star wheels
5) Bottle guides

For each of these inputs, not all of their failure modes are seen as critical. As seen in Table 15, only certain failure modes for each input were identified as high risk. The potential causes and current controls of these potential failure modes must be addressed. The$X$'s and$Y$'s have thus been reduced by the FMEA, from the C&E Matrix results to the following:

$$Y_{Fill\ Height} + Y_{Quality} = f(Solenoids, Valve, Jetter\ nozzle\ size, Star\ wheels, Bottle\ guides, Insignificant)$$

8 Improvement Plan

The improvement plan is part of the next phase of the DMAIC methodology which is the improvement phase. The goal of the improvement plan is to get the fill height process on target with a minimum standard deviation, without compromising quality (DO levels) and to ensure the fill operators accurately perform the routine fill height analysis methodology. Furthermore the fill height analysis methodology requires a supplementary method in order to determine if the PFBI is rejecting the correct samples and an SPC system is required to address the individual valve performance.

8.1 Improvements Initiated w.r.t. Fill Operator Compliance

Improvements have been completed or initiated with regards to certain problems that could be easily addressed. These problems were identified during the MSA Audit and are mostly due to fill operators that are not conducting the fill height analysis methodology properly. The tasks which the fill operators do not complete during fill height sampling are considered to be crucial in obtaining accurate results. These results are important as it is used to determine the performance of the filler and should these results be inaccurate, under-performing filler valves may be missed instead of identified and fixed immediately. The tasks that the fill operators often don't perform include:

- Recording sampling conditions
- Ensure sampling at a speed of 50000bph
- Resample when unsure if the correct bottle was sampled (due to PFBI rejecter failure)
- Allow sample to stand for 45 -60min
- Verify the settings of the FA-100 version 2.7.0 (software used to capture data on computer)
- Verify calibration of the Akitek

The above tasks were identified as part of the fill operators' procedures that must be followed. In order to resolve these problems the fill operators need to follow the correct procedures during the execution of their work.

The following was done in order to address the above mentioned problem:

- All documentation relating to the filler and the fill height analysis methodology was updated:
  - The 12 bottle sampling methodology was properly documented and updated and then replaced the 20 bottle sampling procedure in the Best Practices Guide.

  - The Packing manual in Appendix C with the packing test method for fill heights does not contain the 12 bottle sampling methodology but the 20 bottle sampling methodology and the competency test within the document (this is the current audit document) is vague and outdated – The Packing Manual was updated with the 12 bottle sampling methodology and the competency test is updated/replaced with the MSA auditing document developed during this project.

- Once all documentation was updated, the fill operators were retrained with regards to the 12 bottle sampling method and the quick fix routines which they will use should the results from the sampling methodology show an out of control valve.
- Change management took place on line 8 – The performance incentives of the fill operators were removed from their goals. The closer the fill heights were to the target value the higher the incentives received by the operators. Thus, this provided motivation for the fill operators to record false data.

8.2 Preliminary Full Bottle Inspector (PFBI) Capability study

One of the tasks that fill operators often don't include during fill height procedures is that they do not resample when they are unsure if the correct bottle was sampled. The uncertainty often arises due to the failure of the PFBI rejecter. The fill operators select the valve number which they must sample, along with the number of bottles which they must sample from that particular valve on the filler valve monitor (FVM). The PFBI rejecter more often than not rejects a bottle from the wrong valve or it rejects more than the specified number of bottles.

In the case of rejection of a bottle due to under fill, the PFBI screen identifies the valve from which the bottle originated. The PFBI is thus used to select the desired valve/valves for fill height sampling and the number of bottles required from each particular valve.

PFBI capability studies are performed in order to confirm the synchronisation of rejection. Rejection is synchronised if and when the actual valve which was rejected, corresponds to the rejected valve shown on the PFBI screen. In order to conduct fill height sampling it is essential that the PFBI rejection is confirmed.

The PFBI capability study will be conducted by drilling a hole in the bottom of a bottle. The bottle will then be placed on the line. Start-up the filler and when at a normal running speed (50000bph), identify the valve which filled this particular bottle. The valve will easily be spotted as this bottle will result in a definite under fill. Once this under filled bottle is rejected, the operator can verify that the bottle identified on the PFBI screen corresponds to the valve identified. This needs to be done for 35 bottles which should all be 100% synchronised otherwise the system will be considered unreliable. Should the synchronisation be correct, the study can be commenced, otherwise the PFBI capability study should be repeated after the relevant competent person has corrected the PFBI synchronisation. The routine performance of the operators using the 12 bottle sampling methodology captures the data of all 176 valves in two to three weeks' time, thus it is recommended that the PFBI capability study be completed by the operator that samples valve number 1. The PFBI capability study will thus be conducted every two to three weeks.

8.3 FMEA Improvement Plan

The FMEA identified the main process inputs that have the largest effect on the primary output which is fill heights and the counter balance which is quality(DO's).

$$Y_{Fill\ Height} + Y_{Quality} = f(Solenoids, Valve, Jetter\ nozzle\ size, Star\ wheels, Bottle\ guides, Insignificant)$$

The following improvements are only actions recommended based on the results of the FMEA and were completed with the team of subject matter experts at SAB Alrode's packaging department. These suggestions take into account what the failure modes and the potential causes are of the failure mode, as well as the current controls and procedures that prevent either one of these. Action has been taken on some of these problems, by the responsible persons, based on the actions recommended.

Table 16 - FMEA Improvements

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
1	Pressurisation	**Solenoids**	Air leaks	fill height variation	9	poor maintenance	5	Nothing	9	405	Weekly Maintenance Schedules	Maintenance Planner (Willem	PM schedule put in place	9	3	7	189
	Pre-and Final relief		Damaged by hygiene practices	fill height variation	9	water ingress into electronics (operator with high pressure guns)	9	WI 17 exist but might not be followed	9	729	Cleaning, WI 17 reviewed and updated. Covers designed for solenoids	Filler Specialist (Russel Lange)	Re -trained cleaners for WI 17. Covers implemented	9	5	7	315
2	Triple Evacuation	**Valve**	Valve leaking	fill height variation	9	poor valve and tube practices	9	Nothing	7	567	As part of SIC practices, on POMS implement hourly check for leaking valves	WCM- World class manufacturing facilitator (Angus Swartz)	PIMS & POMS updated	9	6	5	270
	Pressurisation			fill height variation	9	PM schedules not in place	9	PM schedules on maintenance day	9	729		WCM- World class manufacturing facilitator (Angus Swartz)		9	7	7	441
	Filling		Seals perished		9	Valve performances practices not in place during running operaions	9	PIMS & POMS & reaction of operator	9	729	Insure current practices for PIMS, POMS and QFR followed		Audit done. PIMS and POMS retrained	9	7	7	441
3	Jetting and Fobbing	**Jetter nozzle size**	Incorrect size (too big/small)	fill height variation	9	Standards not followed (PIMS and POMS)	9	Nothing	10	810	Put in PM schedule to check jetter nozzle size weekly. Remove all incorrect sizes	Maintenance Controller	Not yet done				
4	Jetting and Fobbing	**Star wheels**	back lash on star wheels (worn)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567	Put in PM schedule to check where backlash occurs, more frequently.	Maintenance Controller	Not yet done				
	Jetting and Fobbing		Incorrect starwheels used for brand	fill height variation	9	Operator used wrong starwheels during change over	9	Changeover WI 15	3	243	Mark each brands starwheels in different colours. UpdateWI 15 for QCT	Maintenance Controller	Not yet done				
5	Jetting and Fobbing	**Bottle guides**	Setup incorect	fill height variation	9	setup standards not followed by operator	9	Changeover WI 15	3	243	Review and update WI 15	Maintenance Controller	Not yet done				
	Jetting and Fobbing		bottle guides worn (backlash)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567	PM schedule to pick up wear rate		Not yet done				

For the process inputs on which action has been taken, namely the valves and the solenoids, the severity, occurrence and determination ratings were re-evaluated and assessed with tyhe team of subject matter experts. These ratings allowed for a new RPN value to be calculated for these process inputs, which shows an improvement compared to the previous RPN ratings. The actions recommended are further discussed in detail, on the following page, for each of the process inputs' potential failure modes.

1) Solenoids

Table 17- Improvements on Solenoids

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
1	Pressurisation	**Solenoids**	Air leaks	fill height variation	9	poor maintenance	5	Nothing	9	405	Weekly Maintenance Schedules	Maintenance Planner (Willem	PM schedule put in place	9	3	7	189
	Pre-and Final relief		Damaged by hygiene practices	fill height variation	9	water ingress into electronics (operator with high pressure guns)	9	WI 17 exist but might not be followed	9	729	Cleaning, WI 17 reviewed and updated. Covers designed for solenoids	Filler Specialist (Russel Lange)	Re -trained cleaners for WI 17. Covers implemented	9	5	7	315

- Air leaks: Currently air leaks are caused by poor maintenance as there are no controls included for this in the maintenance plan. It is recommended that it should be checked during the weekly maintenance schedules. Action has been taken on this matter, seeing as additional preventative maintenance (PM) schedules have been put in place. They now manually search for oil leaks, as no leaks are permitted. The PM schedule and the tasks scheduled can be seen in Appendix D. This will provide a better understanding of what maintenance schedules comprise of. The maintenance planner will be responsible for this action taken.

- Solenoids damaged by hygiene practices: The problem is that water ingress into electrical components occurs due to the incorrect hygiene practices executed by the cleaners. There are current controls regarding this problem, namely work instruction 17 (WI 17) which contains the hygiene practices that must be followed. The problem is that the cleaners do not always follow these instructions. The actions recommended for this problem was that WI17 be reviewed, updated and retrained, as well as designing covers for the solenoids. The solenoid covers were designed in order to prevent water from reahing the electrical components and then short circuiting. The cleaners have been retrained in WI17 and the solenoid covers have been implemented. WI 17 can be seen in Appendix E. The fill specialist will be responsible for the actions taken.

2) Valves

Table 18 - Improvements on Valve

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
2	Triple Evacuation	**Valve**	Valve leaking	fill height variation	9	poor valve and tube practices	9	Nothing	7	567	As part of SIC practices, on POMS implement hourly check for leaking valves	WCM- World class manufacturing facilitator (Angus Swartz)	PIMS & POMS updated	9	6	5	270
	Pressurisation			fill height variation	9	PM schedules not in place	9	PM schedules on maintenance day	9	729				9	7	7	441
	Filling		Seals perished		9	Valve performances practices not in place during running operaions	9	PIMS & POMS & reaction of operator	9	729	Insure current practices for PIMS, POMS and QFR followed	WCM- World class manufacturing facilitator (Angus Swartz)	Audit done. PIMS and POMS retrained	9	7	7	441

- Valve Leaking: Leaking valves are caused by poor valve and tube practices. As part of the short interval control (SIC) practices, hourly checks on the valve pressure have been recommended on the process input monitoring sheet (PIMS) and the process output monitoring sheet (POMS), which will indicate if valves are leaking. Regarding this matter, PIMS and POMS have been reviewed and updated. PIMS and POMS can be seen in Appendix F. The world class manufacturing facilitator (WCM) will be responsible for the actions taken regarding the leaking valves, as well as for the actions taken on the perished seals.

- Seals perished: Seals often perish due to PM schedules an valve performance practices that are not in place during operations or that are not being followed. It is recommended that the current practices for PIMS, POMS and quick fix routines (QFR) be followed. This was done by retraining PIMS, POMS and QFR for the operators.

3) Jetter Nozzle Size

Table 19 - Improvements on Jetter Nozzle Size

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
3	Jetting and Fobbing	**Jetter nozzle size**	Incorrect size (too big/small)	fill height variation	9	Standards not followed (PIMS and POMS)	9	Nothing	10	810	Put in PM schedule to check jetter nozzle size weekly. Remove all incorrect sizes	Maintenance Controller	Not yet done

- Incorrect Size: The jetter nozzle sizes ar often either too big or too small because the fill operators do not follow the standards of PIMS and POMS. There are currently no controls over this, thus it is recommended that jetter nozzle size checks become part of the weekly PM schedule. All incorrect sizes that are identified should be removed immediately. The execution of this action recommended will be the responsibility of the maintenance controller.

4) Star Wheels

Table 20 - Improvements on Star Wheels

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
4	Jetting and Fobbing	**Star wheels**	back lash on star wheels (worn)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567	Put in PM schedule to check where backlash occurs, more frequently.	Maintenance Controller	Not yet done
	Jetting and Fobbing		Incorrect starwheels used for brand	fill height variation	9	Operator used wrong starwheels during change over	9	Changeover WI 15	3	243	Mark each brands starwheels in different colours. UpdateWI 15 for QCT and retrain	Maintenance Controller	Not yet done

- Backlash on star wheels: Back lash on the star wheels occur seeing that ther are no clear wear standards on the PM schedules, thus there is no control over this problem. It is recommended that a PM schedule be put in place to identify where the backlash occurs. This preventative maintenance should be scheduled to take place on a frequent basis. If this improvement recommendation is implemented it is the responsibility of the maintenance controller to ensure that the PM schedule is followed.

- Incorrect star wheels used for brand: Incorrect star wheels are often present in the jetting and fobbing process due to operators that used the wrong star wheels during changeovers. Since there is a document which contains the quick changeover work instructions, namely WI 15, it is recommended that the WI15 document be updated and retrained. Another recommendation is to mark each brands star wheels in different colours. The maintenance controller will be responsible this action.

5) Bottle Guides

Table 21 - Improvements on Bottle Guides

	Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
5	Jetting and Fobbing	**Bottle guides**	Setup incorect	fill height variation	9	setup standards not followed by operator	9	Changeover WI 15	3	243	Review and update WI 15 and retrain	Maintenance Controller	Not yet done
	Jetting and Fobbing		bottle guides worn (backlash)	fill height variation	9	No clear wear standards on PM schedules	9	Nothing	7	567	PM schedule to pick up wear rate		Not yet done

- Setup incorrect: The setup standards for bottle guides are not followed by the operators. The WI15 document containing the setup standards should be reviewed, updated if necessary and operators should be retrained. The maintenance controller will be responsible for this action.

- Bottle guides worn: Bottle guides often get to worn because there are no clear PM schedules that assist in identifying when bottle guides should be replaced. PM schedules should be used by the maintenance controller to pick up the wear rate.

8.4 Statistical Process Control System (SPC System)

The implementation of an SPC system is recommended in order to allow the fill operators to monitor and control the filler valves. This will assist in identifying individual valves that are not on target or not consistent. The objectives of the SPC system will include:

- To monitor and control fill height variation of all 176 filling valves
- To reduce the fill height variation for each of the filling valves by eliminating or reducing the common cause for of fill height variation for each of the valves. This means addressing all the process inputs identified in the FMEA as well as making use of the QFR.
- To achieve a fill height that is as close to the target value as possible, that will ensure conformance to the volume specified by the packaged quantity of its brand, that satisfies the Trade Metrology Act and that optimises beer loss.

8.4.1 Recommended Decision Process Flow

The SPC system will follow the decision process flow as seen in Figure 27.

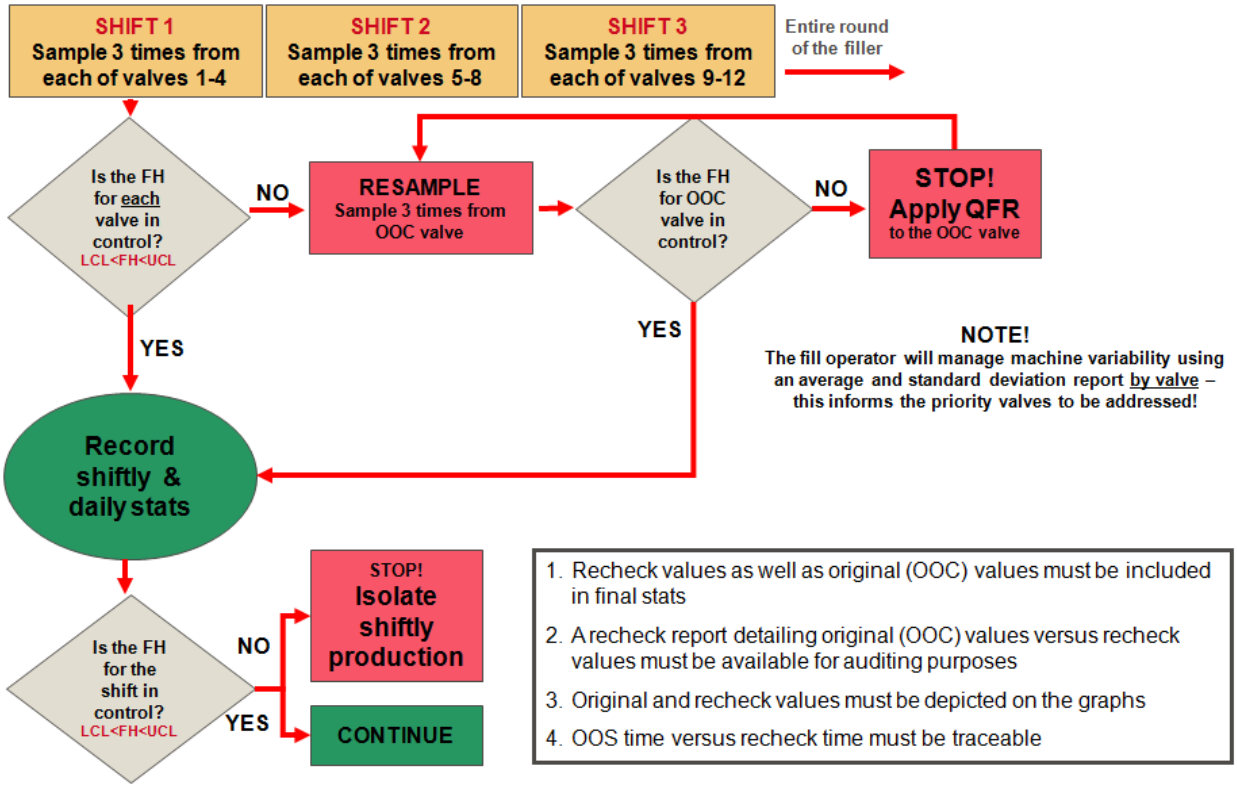


Figure 27 - Decision Process Flow with Control Charts

The fill operators will conduct their routine fill height performance according to the 12 bottle sampling methodology. For each shift, the fill operator which is conducting the sampling will sample 3 bottles from each of 4 valves. The fill operator will be considered to be responsible for those 4 valves during his shift, as he must take action on the valves, should they show out of control results.

The fill operator should, after sampling, capture the data and plot it on the control charts. The control charts will contain control limits which will be used together with the run rules to determine if the valve is out of control (OOC). Re-sampling should first lake place, should the valve appear out of control. The new sample data should again be plotted on the control chart. Quick fix routines should be applied if the valve still shows to be out of control, else the data will just be recorded for the shift and daily statistics.

8.4.2 Recommended Control Limits

The control limits for the control chart will be calculated through the use of the capability study's data. These control limits should be updated every time a capability study is conducted. The data collected during the capability study can be seen in Section 6.2, Figure 19. The valves circled in green on Figure 19, represents the best inherent performance of the process, thus these fill height performance values were used to calculate the short term standard deviation of 1.649mm. The short term standard deviation is used to calculate the control limits of the process; the control limits indicate the limits between which the system should be cable of performing.

Table 22 - Xbarbar and Rbar Charts

n	D3	D4	A2	d2
1	0	3.267	2.660	1.128
2	0	3.267	1.880	1.128
3	0	2.574	1.023	1.693
4	0	2.282	0.729	2.059
5	0	2.114	0.577	2.326
6	0	2.004	0.483	2.534
7	0	1.924	0.419	2.704
8	0	1.864	0.373	2.847
9	0	1.816	0.337	2.970
10	0	1.777	0.308	3.078

$\bar{\bar{X}}_0$ = 72mm

$\bar{R}_0$ = 3.84mm

$\hat{\sigma}$ = 1.649 (short term stabdard dev. - capability)

D_4 = 2.114 (for n = 5 samples – from Table 22)

A_2 = 0.577 (for n = 5 samples – from Table 22)

D_3 = 0 (for n = 5 samples – from Table 22)

$\bar{\bar{R}}_0$ Chart

$UCL_R = +3\sigma L_R = D_4\bar{R}_0$

$= 8.11$

$LCL_R = -3\sigma L_R = D_3\bar{R}_0$

$= 0$

$UWL_R = +2\sigma L_R = \bar{R}_0 + 2/3(UCL - \bar{R}_0)$

$= 6.68$

$LWL_R = -2\sigma L_R = \bar{R}_0 - 2/3(\bar{R}_0 - LCL)$

$= 1.28$

$\bar{\bar{X}}_0$ Chart

$UCL_{\bar{X}} = +3\sigma L_{\bar{X}} = \bar{\bar{X}}_0 + A_2\bar{R}_0$

$= 74.21$

$LCL_{\bar{X}} = -3\sigma L_{\bar{X}} = \bar{\bar{X}}_0 - A_2\bar{R}_0$

$= 69.79$

$UWL_{\bar{X}} = +2\sigma L_{\bar{X}} = \bar{\bar{X}}_0 + 2/3(UCL_{\bar{X}} - \bar{\bar{X}}_0)$

$= 73.48$

$LWL_{\bar{X}} = -2\sigma L_{\bar{X}} = \bar{\bar{X}}_0 - 2/3(\bar{\bar{X}}_0 - LCL_{\bar{X}})$

$= 70.52$

8.4.3 Recommended Control Charts

The fill operators should be provided with a visual display of an Xbar and R chart that contains the control limits calculated in Section 8.4.2. An X bar will show the average fill height per valve, while the R chart shows the range of the measurements taken per valve. As previously mentioned, the control limits must be updated every time a capability study is conducted. The chart will allow sample data to be plotted against the control limits. The operators should fill in the fill height measurements of each of the three bottles sampled per valve, for 4 valves . Operators will have to make use of the control chart every shift after conducting the 12 bottle sampling methodology. After capturing the data, the fill operators should immediately view the results.

Thus, once the fill operator has captured and plotted the results from his shift, he must interpret the results of the average fill height ($\bar{X}$), using the first run rule.

Run Rules:

1) The average or standard deviation is beyond the control limits.
2) Two out of three consecutive points exceed the charts warning limit.
3) Eight or more consecutive data points are on the same side of the centreline.

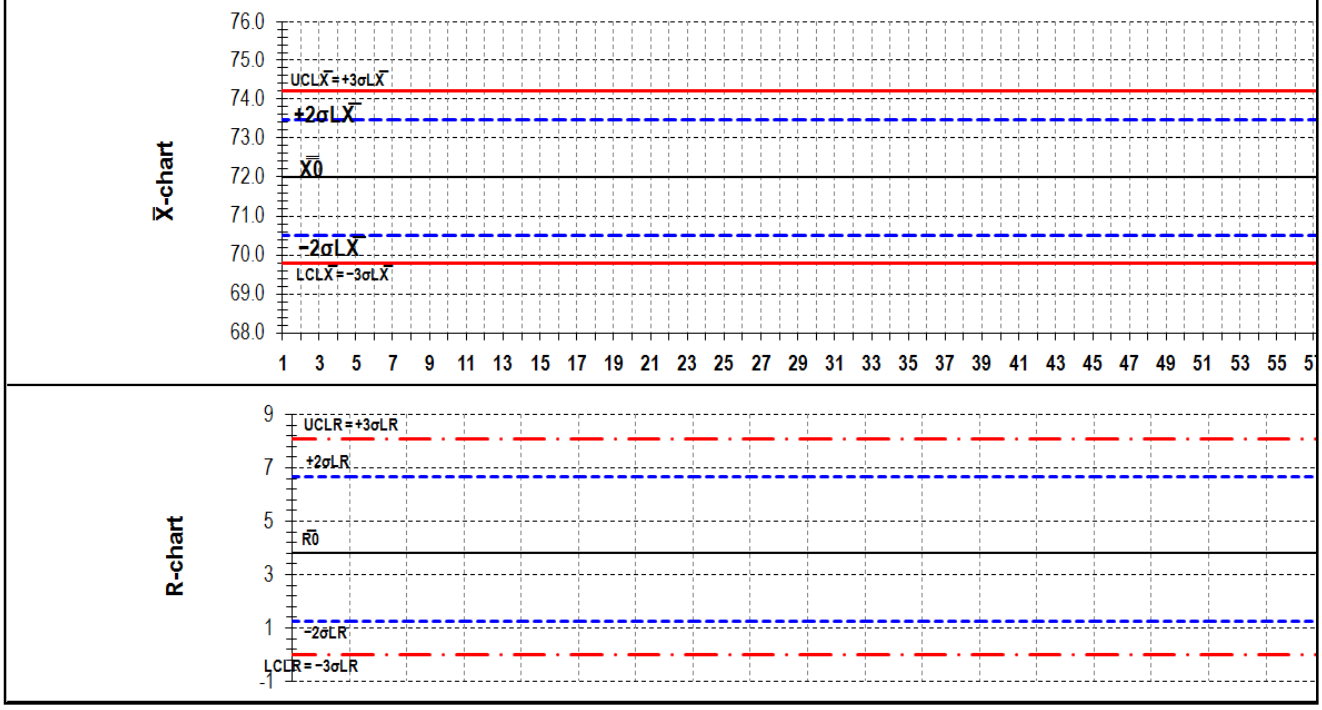
These rules are used to identify when a process is unstable and out of control. Thus, should the results meet any one of these three rules, it will be an indication that the filling process or individual valve is out of control. Only the first rule is applicable in this case, where the focus of the fill operators will be to improve individual valves. The other two rules are applicable when looking at the results of the entire filler, in other words at all 176 valves. For the R chart it is desirable to achieve the lowest possible values, indicating less variation in the fill heights per valve and also to avoid any out of control points beyond the upper control limits.

After interpreting the results, the operator should proceed according to the decision process flow recommended in Section 8.4.1., based on the results of the control chart. The control chart provides for all 176 valves; however the Table below only demonstrates a few. The SPC can be found on the disc attached to the project.

Table 23 - Control Chart for SPC System

SA Breweries Alrode	12 Bottle Sampling Methodology GENERAL INFORMATION AND DATA COLLECTION	Line: 8 Process: Filling Characteristic: Fill Heights 2012
Product Upper specificationLimit:	78.0	
Target Value	72.0	
Product Lower specification Limit:	66.0	

Operator/Technician																	
Shift																	
Month																	
Date																	
Valve	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Data X1																	
X2																	
X3																	
$\bar{X}$ =																	
R =																	



8.4.4 Recommended Quick Fix Routine (QFR)

According to the decision process flow, if the fill height is outside of the control limits or in other words a valve is identified as out of control, the fill operator should resample to confirm the results. After re-sampling, if the valve is still not conforming, the fill operator should make use of quick fix routines (QFR) to address the problem. Once he has done this, he may proceed with the decision process flow. The QFR's that are the most relevant to the project can be seen below. Once the QFRs have been completed resample the relevant valves and updated the data captured.

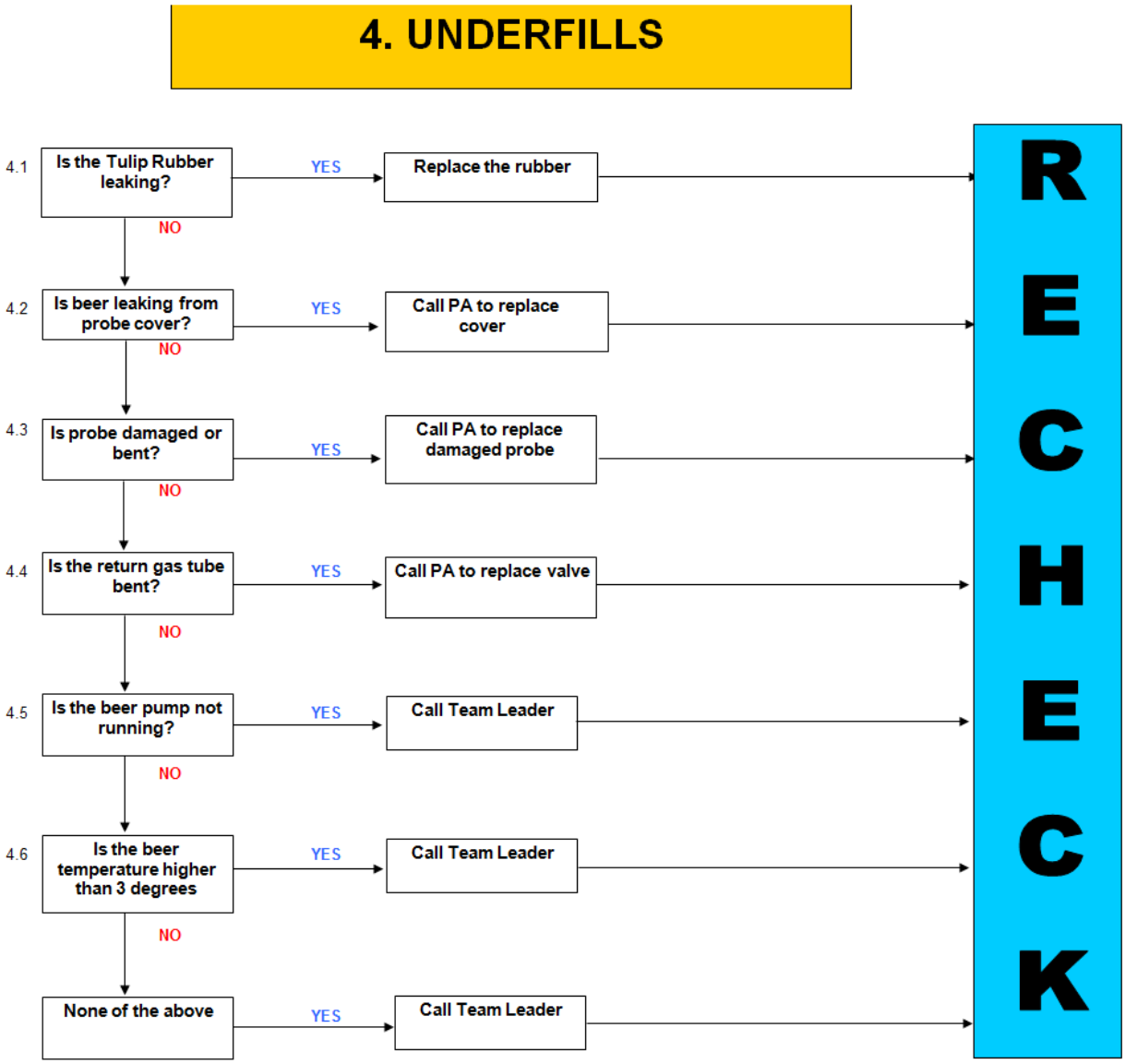


Figure 28 - Under Fills QFR

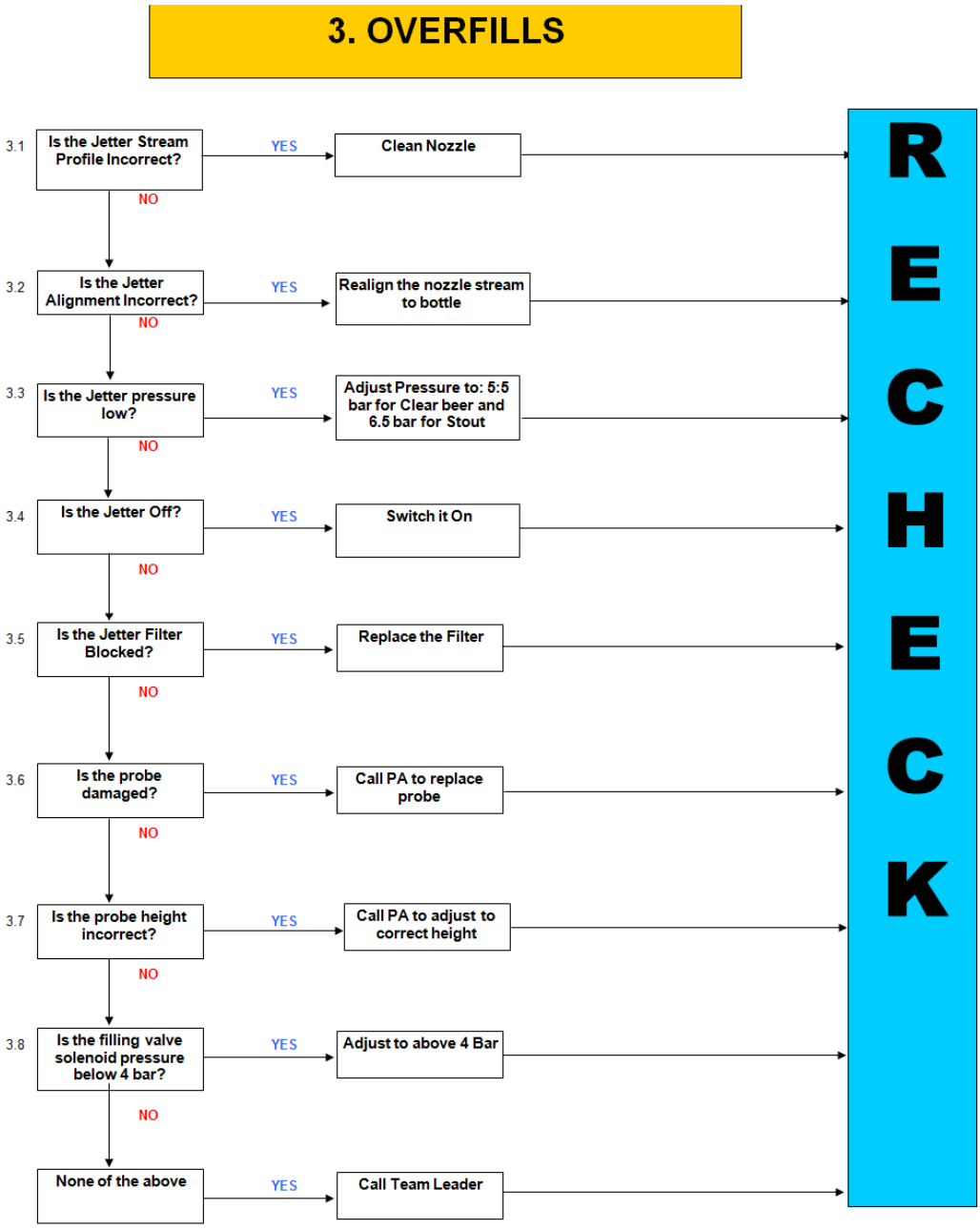


Figure 29 - Over Fills QFR

8.4.5 Recommended Design Options

It is recommended that the SPC system be integrated into the eQMS program. The data is all ready being captured into eQMS by the operators and it currently only displays the results against the specification limits defined by the Trade Metrology Act. It is thus recommended that the control charts also be displayed in order to monitor and control the fill height process. This will allow quicker response times to under performing valves.

8.4.6 Best Practices Guide – 13 Step Approach

There is currently only a best practices guide for mechanical fillers, even though line 8 uses an electronic filler. Thus a need for an electronic filler Best Practices Guide was identified and it was decided that the Best Practices Guide should also include steps to address the worst performing valves of the filler. The steps to addressing the worst performing valves were completed, for the electronic fillers Best Practices Guide, with the subject matter experts' team at Alrode's packaging department. Thirteen steps were identified.

Once data has been captured for valve 1-176 by the fill operators during their shifts over a two to three week period, it means that the SPC system has been completed for all 176 valves. It is suggested that every time the SPC system is completed for all 176 valves, that the 13 step approach be applied if necessary. It will only be necessary if there are out of control valves identified on the SPC systems control charts, through the use of run rule 2 and 3 in Section 8.4.3.

The 13 step approach:

1) Record the beer temperature, filler bowl pressure and beer CO2 content.

- Making use of the 13 step process template(Figure 30), record all relevant information on the process and verify all inputs on the Filer Data sheet
- Having verified and ensured that all Inputs are within control sampling can start

2) Select the worst performing valve from the capability study.

- These results will form the baseline for the study going forward

3) Replace the tulip:

- Stop the filler and replace the tulip rubber on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original tulip.

4) Replace the cradle on the valve:

- Stop the filler and replace the cradle on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original cradle.

5) Replace the complete valve:

- Stop the filler and replace the complete valve of the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original complete valve.

6) Replace air pipes

- Stop the filler and replace the air pipes on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original air pipes.

7) Replace main solenoid

- Stop the filler and replace the main solenoid on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original main solenoid.

8) Replace vacuum solenoid

- Stop the filler and replace the vacuum solenoid on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the vacuum solenoid.

9) Replace relieve solenoid

- Stop the filler and replace the relieve solenoid on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original solenoid.

10) Replace pressure solenoid

- Stop the filler and replace the pressure solenoid on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the original pressure solenoid.

11) Replace electronic card

- Stop the filler and replace the electronic card on the selected valve.
- Allow the filler to speed up to normal running speed and sample 12 fill height samples from the valve.
- Return the electronic card.

12) Analyse the results and establish the change variable that is closest to specification.

- Once step 1- 11 have been completed take the samples to the laboratory and analyse each set of samples using the Akitek.
- Record the results in the space provided on the 13 step template.
- Note: Once all the results have been captured look at the change variable that had the biggest impact on valve performance, meaning that a significant reduction in standard deviation is noted (i.e. if changing the spreader rubber had the most positive effect on the valve's performance it is seen as the change variable with the most impact)

13) Select the 2nd worst performing valve from the capability Study.

- Having identified the change variable from 1st valve, take 12 baseline samples from the 2nd selected valve
- Once the 12 baseline samples have been taken, stop the filler and replace the item that was identified as the significant change variable for the 1st valve in steps 3-11 above, e.g. Step 3: Replace the hanger rubber:
- Allow the filler to speed up to normal running speed and sample another 12 fill height samples from the 2nd selected valve, do fill height analysis on these samples

Once the 13 step approach has been completed:

- If the changed variable does not work on the 2nd identified valve:
  Should it happen that the initial identified change variable has no significant impact on the performance of the 2nd valve, restart the first 11 process steps at step 3 for the identified valve, follow the process through until another change variable has been identified and tested.

- If the changed variable does work on the 2nd valve:
  If the standard deviation from the 1st and 2nd valve sample improves when compared to the baseline samples continue to replace the same change variable on 4 more underperforming valves. Should the change variable identified in steps 3-9 have a significant impact on all 6 sample valves performance, continue to plan the replacement of the component on all filling valves at the earliest opportunity.

The data capturing sheet for the 13 step approach can be seen in Figure 30. This spread sheet can be found on the disc attached to the project.

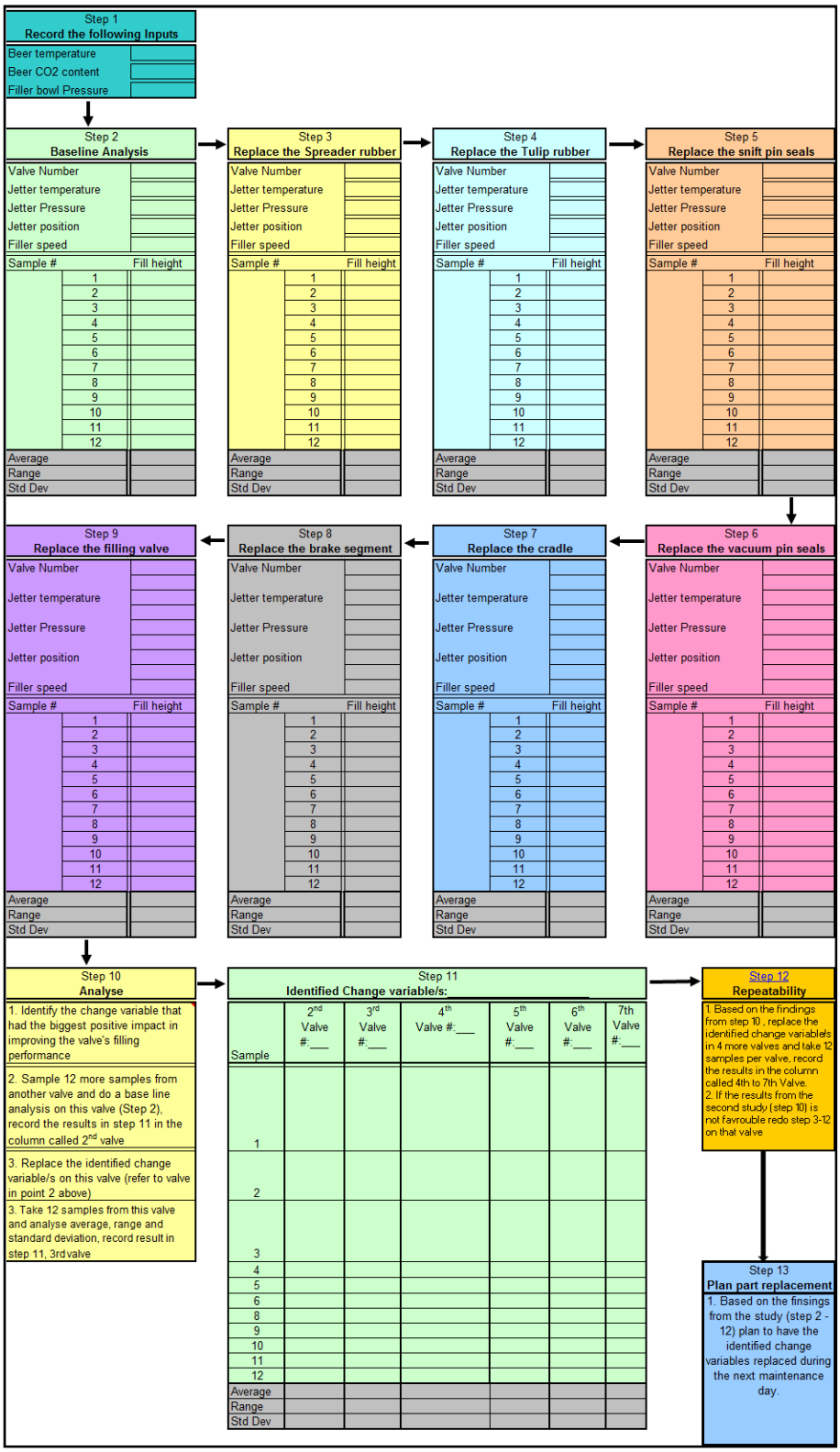


Figure 30 - 13 Step Approach Template

9 Critical Success Factors

The cooperation of employees of line 8 is critical to the success of the implementation of this improvement plan. It is crucial that the operators and cleaners follow the best practices guides and that they adhere to their training in QFR, WI's and PIMS and POMS. The SPC system will form part of the best practices regarding the fill height procedures, should it be implemented.

In order to ensure that employees follow the above mentioned practices, the following recommendations were made:

- The performance incentives that form part of the fill operators' goals should under no circumstances be linked to fill heights. This will ensure that operators aren't tempted to record false data (showing that the fill height is on target when it isn't), in order to receive their incentives.
- PIMS and POMS, as well as the best practices, SPC system and QFR should be retrained annually and when necessary.
- Weekly audits should take place during maintenance.
- Weekly audits should take place to ensure cleaners are following WI17. WI17 contains performance criteria which can be used for the audit. See Appendix E.
- In order to ensure the accuracy of the data captured in eQMS during the routine fill height sampling (12 bottle sampling methodology) by the operators, audits need to be performed regularly. The fill operators should not be informed of when an audit will take place. This will motivate them to always be prepared and to conduct fill height sampling according to the correct procedure every time.
- Capability studies should be conducted at least every 3-4 months by an independent party. This data should then be used not only to evaluate the performance and capability improvement of the filler, but also to evaluate the accuracy of the routine fill height performance data captured in eQMS. Thus, the capability study results and the results from the routine fill height performance of the fill operators must be compared. The comparison will indicate if operators aren't sampling correctly or if they are capturing false data.

10 Estimated Improvement

The improvement plans main focus is to improve fill heights which in turn will reduce SAB's production cost as most of the valves are currently over filling. The estimated improvement only refers to the implementation of the FMEA improvements. This is due to the fact that the FMEA improvements are the only improvements that can be quantified in terms of fill height. The estimated improvement of fill height is also used to estimate the financial benefits which can be achieved, should the FMEA improvement plan be implemented. The estimations with regards to fill heights and financial benefits can however be higher if the SPC system is followed diligently.

10.1 Estimated Fill Heights Improvement

The measure or extent to which the FMEA improvements suggested will impact or affect the fill height mean and standard deviation will not be known until after implementation of the improvement plan has taken place. Thus, the measures calculated below are only estimates of the extent to which fill height will improve.

In order to calculate the impact of each critical process input identified, the RPN ratings calculated in the FMEA (See Table 13, 14 and 15) were used. The assumption is made that the weight of each inputs RPN rating relative to the total of the RPN ratings has a direct relationship to the fill height of each valve.

Calculation Method (see Table 24):

- The actual totals seen in Table 24 for RPN (equal to 5587) and the RPN weight (equal to 100) includes all 19 process inputs seen in both the Cause and Effect (Table 12) and the Failure Mode and Effect Analysis (Table 13 and 14).
- The actual total for the fill height off target value (equal to 1.25mm) is the actual current value measured during the capability study of line 8, which can be seen in Section 6.2 and Table 9.
- The RPN weight for each critical process inputs were used to calculate the portion of the actual totals for which each of them are responsible.
- The total responsibilities refer to the total RPN weight or fill height for which these five critical inputs are responsible.
- The improved value indicates the value to which the fill heights actual total has improved.

Table 24 - Estimated Improvement

	Process Step	Key Process Input	RPN	RPN Weight (%)	Fill Height Off Target (mm)
1	Pressurisation	**Solenoids**	405	5.570	0.070
	Pre-and Final relief		729	10.026	0.125
2	Triple Evacuation	**Valve**	567	7.798	0.097
	Pressurisation		729	10.026	0.125
	Filling		729	10.026	0.125
3	Jetting and Fobbing	**Jetter nozzle size**	810	11.140	0.139
4	Jetting and Fobbing	**Star wheels**	567	7.798	0.097
	Jetting and Fobbing		243	3.342	0.042
5	Jetting and Fobbing	**Bottle guides**	243	3.342	0.042
	Jetting and Fobbing		567	7.798	0.097
Total Responsibility			**5589**	**76.867**	**0.961**
Actual Total			**7271**	**100**	**1.25**
Improved Value					**0.289**

The current standard deviation at which the fill height process is operating is equal to 3.256mm, as measured in the capability study (see Section 6.2 and Table 9). However, in order to determine the extent to which standard deviation will improve, we need to take into account what standard deviation the system is capable of under the best conditions. It has been proven in Section 6.2 that without reengineering the system will not be capable of a standard deviation less than 1.649mm.

Estimated standard deviation improvement:

$$= \text{Standard deviation capability} \times \frac{100}{Total\ responsibility\ of\ RPN\ weight}$$

$$= 1.649 \times \frac{100}{76.867}$$

$$= 2.15\text{mm}$$

From the calculations in Table 24 it can be seen that the critical inputs identified:

- are responsible for 76.87% of the fill height problems
- can reduce the 1.25 by which the fill height is off target to only 0.289mm off target
- can reduce the 3.256mm standard deviation of fill height to a standard deviation of 2.15mm

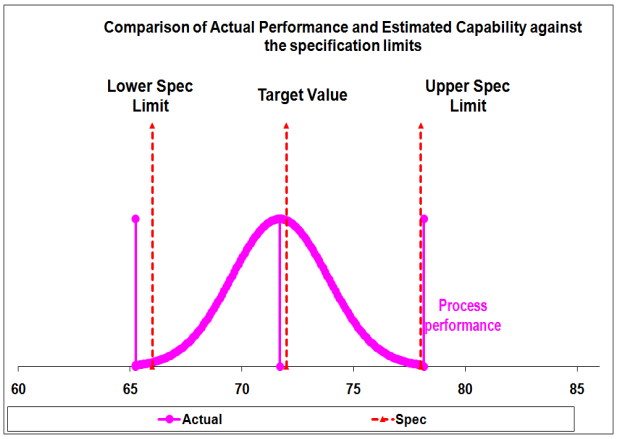


Figure 31 - Estimated Process Performance after Improvements Implemented

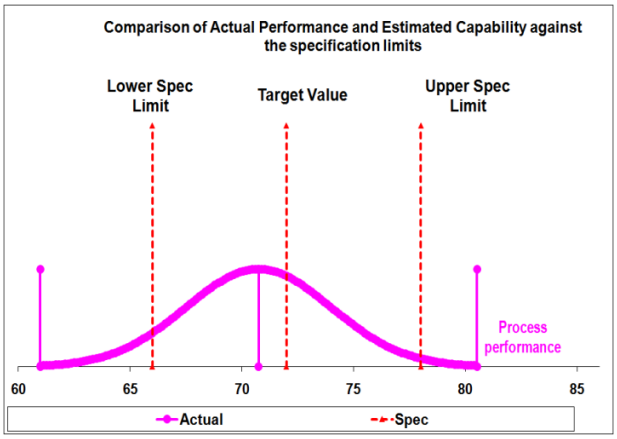


Figure 32 - Process Performance before Improvements Implemented

he process will then have an improved fill height mean of 71.7mm and a standard deviation of 2.15mm. The realistic capability index is calculated below, the realistic capability refers to the performance of the process after the FMEA improvements have been implemented and the estimated improvements have been achieved.

C_p(Realistic) $= \text{Min}\left[\frac{\bar{\bar{X}}-LSL}{3S_{LT}}, \frac{USL-\bar{\bar{X}}}{3S_{LT}}\right]$

$= \text{Min}\left[\frac{71.7-66}{3(2.15)}, \frac{78-71.7}{3(2.15)}\right]$

$= \text{Min}\,[0.88, 0.98]$

$= 0.88$

The table below shows a summary of the fill height process' current performance, capability and realistic capability. The capability refers to the performance of the process under perfect conditions where the process variation is under control and the process is on target. The data shown in the table can be seen in Section 6.2 and Section 9.1.

Table 25 - Estimated Improvement Summary

	Fill Height Mean ($\bar{\bar{X}}$)	Off Target	Standard dev.	Ppk - Current Performance Index	Cp – Capability Index under perfect conditions	Cp (Realistic) – Capability Index under estimated improved conditions
Currently	70.75	1.25	3.256	0.48641		
Capability	72	0	1.649		1.213	
Realistic Capability	71.711	0.289	2.15			0.88

The calculation of Cp(realistic) indicates that if the standard deviation is reduced from 3.256 to 2.15 and the process is moved closer to the target value, from 70.75mm to 71.7mm, that the actual performance index will improve from 0.48641(see Section 6.2) to 0.88. Even though the index of 0.88 is less than 1, which indicates that the process will possibly not be performing and it will still have a small probability that outputs are outside of the specification limits (see Table 5 Section 5.3.2.1), the improvement from 0.48641 to 0.88 is a significant one. The process will be a lot closer to its desired performance and the probability that outputs will fall outside of the specification limits will be significantly reduced.

Considering that the process' current performance index was 0.48641 and the capability (calculated in Section 6.2) is equal to 1.2, a performance index (realistic capability) of 0.88 will be significantly closer to the process' capability. Should the SPC be followed diligently, the above mentioned improvements will possibly be further improved.

10.2 Financial Benefit

The financial verification was conducted in order to demonstrate the savings which SAB will be able to achieve should the FMEA improvements plan be implemented, in other words, should the fill height be close to or on target and the standard deviation reduced. As SAB does not disclose any financial information regarding the production cost, the market value of a single quart of Carling Black Label will be used as an estimate. An assumption is made that it costs SAB 25% of the wholesale value, for the beer in each quart. The following calculations and results in terms of SAB's loss in potential profit, is only used for the purpose of demonstration that savings can be made by optimising fill heights.

The Cost of a quarts content (cost of beer):

- Cost of a Carling Black Label Quart = R 9.00 (Averagewholesale value)
- %Cost of Beer = 25%
- Cost of a quarts content

  $= Cost\ of\ a\ Carling\ Black\ Label\ Quart \text{x}\ \left(\frac{\%Cost\ of\ Beer}{100}\right)$

  $= 9\left(\frac{25}{100}\right)$

  = R 2.25

The Fill height measured from base of the bottle to the fill level:

- The fill height nominal specification limit = 72mm
- The length of a Carling Black Label quart =285mm
- Fill height measured from base to the fill level
  = Length - Nominal Specification Limit
  = 285mm - 72mm
  = 213mm

Cost per millimetre of beer $= \frac{Cost\ of\ a\ quarts\ content}{Fill\ height\ measured\ from\ base}$ x 100

$= \frac{2.25}{213}$ x 100

= 1.06c/mm

The current performance was found to be off target by 1.25mm, resulting in an over fill. This data can be seen in Section 6.2 and Table 9 of the report. In Section 9.1, Table 24 shows that the amount by which the fill height is off target, is estimated to improve from 1.25 mm to 0.289mm once the FMEA improvement plan has been implemented (realistic capability). In Section 6.2, Table 9 shows that the process is capable of being on target (capability).

Table 26 - Fill Height Off Target Improvement Calculation

Calculation	Capability (On target, variation controlled)	Realistic Capability (FMEA improvements implemented)
Fill height off target improvement	= 1.25 - 0 = 1.25mm	= 1.25 - 0.289 = 0.961mm

Should the FMEA improvement plan be implemented, it is estimated that the fill height will improve with 0.961mm. This will thus be the improvement on which savings will be made. Currently the amount of savings is seen as a loss in potential income.

Loss in potential income per quart = Cost per millimetre of beer x Fill height off target improvement

Table 27 - Loss in Potential Income per Quart

Calculation	Capability (On target, variation controlled)	Realistic Capability (Improvements implemented)
Loss in potential income per quart	= 1.06c/mm x 1.25mm = 1.325 =1.33c/quart	= 1.06c/mm x 0.961mm = 1.01866 =1.02c/quart

Line 8 of SAB Alrode is currently producing at a rate of 50000bph - 53000bph. Assuming they produce at a minimal rate of 50000bph the loss in potential income per hour will be as follows:

- Loss in potential income per hour
  = Loss in potential income per qua x Production rate per hour
- Loss in potential income per day
  = Loss in potential income per hour x Production hours per day
- Loss in potential income per month
  = Loss in potential income/day x Average production days/month
- Loss in potential income per year
  = Loss in potential income/day x Average production days/year

Table 28 - Loss in Potential Income per Year

Calculation	Capability (On target, variation controlled)	Realistic Capability (Improvements implemented)
Loss in potential income per hour	= 1.33 x 50000 = 66500c/hour = R665/hour	= 1.02 x 50000 = 51000c/hour = R510/hour
Loss in potential income per day	= 665x 24 = R15 960	= 510x 24 = R12 240
Loss in potential income per month	= 15960x 30 = 478 800/month	= 12240x 30 = R367 200/month
Loss in potential income per year	= 15960 x 365 = R5 825 400/year	= 12240 x 365 = R4 467 600/year

The total loss in potential income per year is a clear indication that a significant amount of savings that can be made by implementation of the FMEA improvement plan. As previously stated, SAB does not disclose any financial information, thus the cost of implementing the FMEA improvement plan cannot be accurately estimated. Without this estimation, there is no way to guarantee that the amount of savings which can be made will justify the cost of implementation. However, the chances are small that improvement cost will be as high as the yearly savings which can be made.

11 Conclusion

Results yielded from the capability study conducted, indicated that the process is capable of performing close to target with a reduced standard deviation. Through analysis of the filler process, the critical process inputs with the greatest influence on fill heights were identified. Recommendations were made on what action should be taken to reduce the negative influence of these critical process inputs. Based on these recommendations, the improvement of fill heights and the financial benefits were estimated. These estimations show that the improvements suggested are capable of improving the filler process up to a point where the performance of the process is close to the desired outcome. Further improvements were suggested to address individual valves, such as an SPC system, along with the 13 step approach and quick fix routines, which should be used by fill operators to monitor and control fill heights. This will allow problematic valves to be addressed immediately. Best practices to be performed on a regular basis were recommended along with the critical success factors of this project. The critical success factors address the problem of fill operators that don't perform their tasks accurately. Should these further suggestions be implemented along with the improvement of the critical process inputs, the fill heights and financial benefits will show an even further improvement, which justifies the means of this project. Finally, thank you to all the people that were involved in this project, especially E. Pieters the line manager and project sponsor, W.P. Breytenbach the project leader and the team from SAB's Alrode packaging department.

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Appendices

Appendix A: Gantt chart

The Gantt chart was developed with regards to the activities and deliverables in the work break down structure. It illustrates the estimated time of completion for each of the activities and tasks. Engineering test weeks and examinations were taken into account during the construction of the chart. The Gantt chart may be subject to change as the project progresses

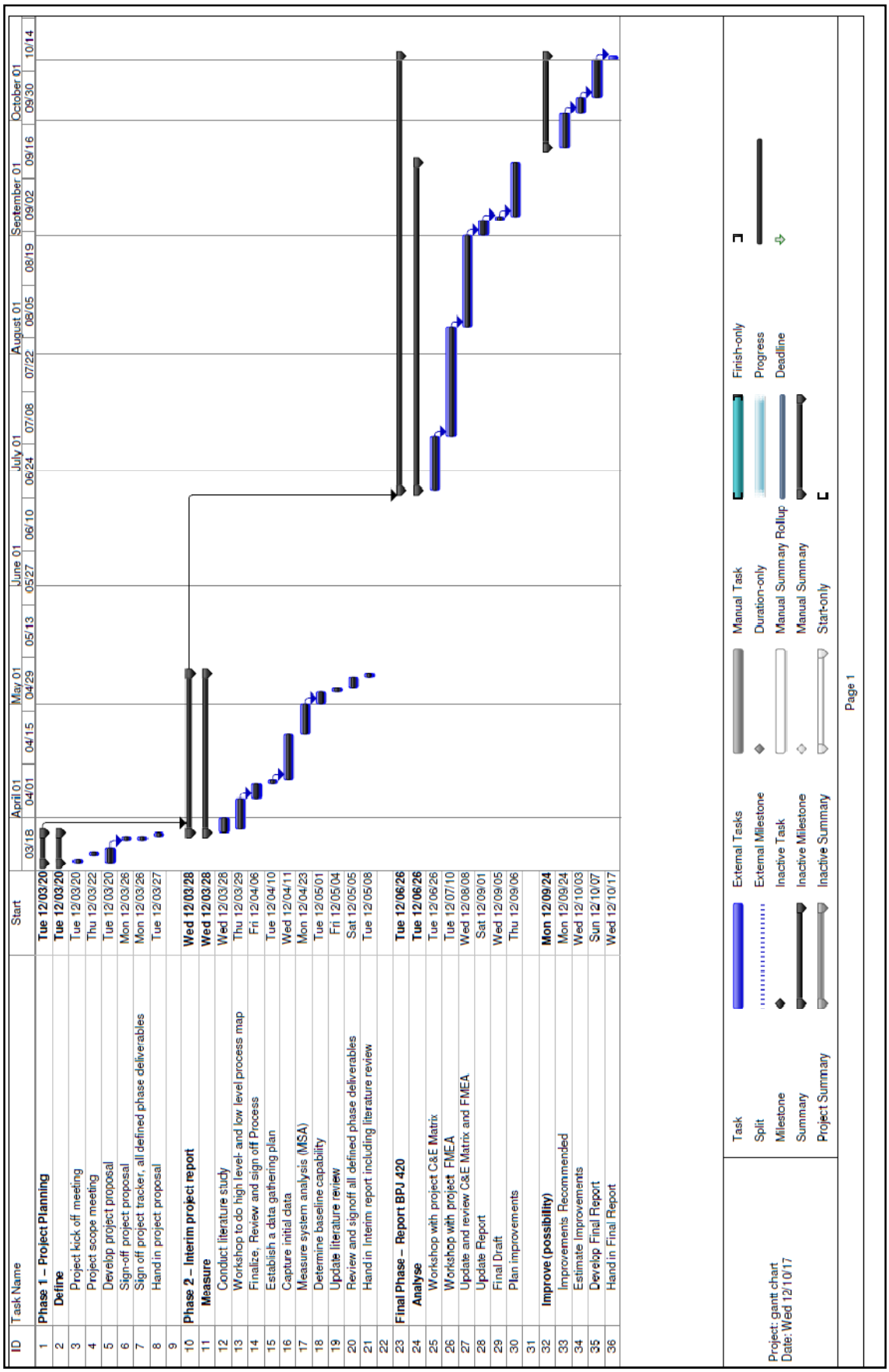

Figure 33 - Gantt Chart

Appendix B: Initial Data

Table 29 - Initial Data

Filler capability study Date: 12/8/2011 Line #: 8 Filler #: 1

TOTAL FILLER PERFORMANCE

average	70.75
range	27.08
standard dev.	3.26

valve	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
sample 1	70.83	73.73	71.85	72.54	73.99	73.99	73.22	73.56	70.14	70.91	69.63	74.24	69.12	69.46	71.42	68.09	74.24	74.59	72.71	77.32	70.40	74.42	74.76	73.99	71.94
sample 2	71.17	74.07	72.19	72.45	71.00	76.30	73.48	73.48	70.83	71.68	68.86	66.72	74.50	74.93	69.63	69.80	76.21	72.19	73.99	75.95	71.68	74.24	71.17	70.91	74.42
sample 3	69.89	73.90	69.63	75.61	71.68	72.28	71.00	71.94	73.99	71.17	71.68	73.73	67.58	72.96	72.45	70.91	76.12	72.96	73.48	72.96	76.47	71.34	70.91	71.34	80.74
sample 4	70.48	72.19	70.91	73.48	71.68	70.65	69.80	71.42	76.55	73.48	70.14	69.63	76.30	73.99	74.24	70.65	74.76	73.22	72.45	76.30	71.42	74.07	77.32	74.50	71.42
sample 5	76.12	75.78	73.39	85.78	73.22	73.90	76.98	71.17	75.27	69.89	70.65	68.86	73.05	74.24	73.05	69.37	70.65	73.99	75.27	72.19	75.53	73.73	76.30	71.17	74.76
average	71.7	73.9	71.6	76.0	72.3	73.4	72.9	72.3	73.4	71.4	70.2	70.6	72.1	73.1	72.2	69.8	74.4	73.4	73.6	74.9	73.1	73.6	74.1	72.4	74.7
range	6.2	3.6	3.8	13.3	3.0	5.6	7.2	2.4	6.4	3.6	2.8	7.5	8.7	5.5	4.6	2.8	5.6	2.4	2.8	5.1	6.1	3.1	6.4	3.6	9.3
standard dev.	2.52	1.28	1.41	5.63	1.24	2.11	2.75	1.14	2.78	1.32	1.06	3.24	3.66	2.16	1.74	1.12	2.26	0.93	1.13	2.24	2.71	1.27	2.93	1.72	3.71

valve	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
sample 1	72.71	76.81	76.55	66.04	69.46	72.88	69.29	73.48	69.89	76.81	72.45	70.65	74.50	73.99	76.81	71.42	70.83	71.68	71.17	74.24	73.39	70.65	71.51	73.22	78.01
sample 2	72.45	76.12	73.48	72.96	70.14	69.63	69.89	74.24	71.00	78.60	74.59	67.24	76.47	70.83	72.19	69.46	69.37	74.50	72.19	67.24	73.73	72.02	71.17	69.89	68.95
sample 3	77.15	72.88	74.24	75.44	71.68	70.40	70.65	72.19	72.02	69.97	67.58	72.71	71.68	69.80	70.65	70.91	69.63	69.89	70.40	75.10	75.53	69.12	73.73	71.34	68.95
sample 4	75.10	75.53	72.96	74.24	72.45	74.76	73.05	71.42	72.96	71.00	71.51	90.06	70.14	68.77	74.24	70.65	72.96	68.86	71.42	67.32	66.55	68.09	72.36	69.37	65.36
sample 5	70.65	73.05	74.76	67.83	75.44	74.24	76.04	68.60	75.01	71.94	73.22	72.54	71.00	75.95	68.43	71.68	70.83	71.94	65.27	73.73	70.91	72.88	72.54	69.37	70.40
average	73.6	74.9	74.4	71.3	71.8	72.4	71.8	72.0	72.2	73.7	71.9	74.6	72.8	71.9	72.5	70.8	70.7	71.4	70.1	71.5	72.0	70.6	72.3	70.6	70.3
range	6.5	3.9	3.6	9.4	6.0	5.1	6.8	5.6	5.1	8.6	7.0	22.8	6.3	7.2	8.4	2.2	3.6	5.6	6.9	7.9	9.0	4.8	2.6	3.8	12.7
standard dev.	2.53	1.81	1.39	4.13	2.34	2.28	2.78	2.19	1.95	3.81	2.65	8.90	2.64	3.00	3.23	0.86	1.42	2.16	2.77	3.91	3.47	1.98	1.00	1.65	4.68

valve	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
sample 1	70.40	70.31	71.94	71.51	73.99	69.80	69.48	68.11	70.16	68.37	70.93	66.57	66.06	67.34	66.57	68.63	72.90	69.82	66.75	68.80	70.42	69.39	70.93	70.51	66.83
sample 2	69.89	72.71	72.45	72.36	71.94	74.76	72.47	67.09	70.34	66.75	65.72	72.22	71.96	67.94	66.32	70.34	68.88	66.23	70.93	67.34	70.42	66.06	71.96	69.31	67.60
sample 3	69.89	70.83	75.10	71.42	72.88	80.91	69.39	73.16	68.37	69.99	69.14	66.83	66.57	65.29	67.94	66.06	64.86	67.34	71.36	68.28	68.80	69.65	63.84	66.75	68.63
sample 4	71.85	71.42	72.19	77.66	73.56	68.95	73.50	69.65	67.09	66.06	71.36	73.24	66.23	69.14	70.34	71.96	69.91	68.63	69.91	70.34	68.37	69.39	71.36	71.96	66.92
sample 5	69.89	72.19	71.94	68.35	68.43	69.37	70.68	70.34	68.45	75.04	69.14	66.23	71.45	70.16	71.45	65.72	70.93	70.16	67.09	70.42	65.04	68.37	66.75	62.98	70.34
average	70.4	71.5	72.7	72.3	72.2	72.8	71.1	69.7	68.9	69.2	69.3	69.0	68.5	68.0	68.5	68.5	69.5	68.4	69.2	69.0	68.6	68.6	69.0	68.3	68.1
range	2.0	2.4	3.2	9.3	5.6	12.0	4.1	6.1	3.3	9.0	5.6	7.0	5.9	4.9	5.1	6.2	8.0	3.9	4.6	3.1	5.4	3.6	8.1	9.0	3.5
standard dev.	0.85	0.98	1.34	3.38	2.22	5.13	1.83	2.33	1.36	3.58	2.22	3.41	2.98	1.85	2.28	2.69	2.99	1.66	2.16	1.33	2.20	1.49	3.53	3.54	1.46

valve	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
sample 1	69.91	66.57	67.09	65.04	68.37	67.34	72.22	63.75	68.88	76.92	73.24	71.96	70.76	69.65	68.20	68.63	70.08	70.68	65.81	68.88	66.66	66.66	68.88	67.34	67.00
sample 2	71.45	69.65	68.97	68.88	66.83	66.40	72.47	68.80	70.51	66.49	78.28	74.01	69.39	70.25	71.62	65.81	65.81	68.37	68.88	68.71	71.70	66.06	72.22	66.83	68.11
sample 3	66.83	66.83	66.06	68.37	64.27	75.46	71.96	68.97	70.42	69.14	70.42	74.78	77.34	73.33	68.11	71.19	66.57	70.76	68.11	72.47	68.71	73.50	70.76	71.62	72.73
sample 4	65.81	70.16	66.32	67.43	66.92	69.91	74.61	70.68	68.28	72.73	74.18	66.66	68.37	72.73	70.25	65.04	70.76	64.52	72.47	67.69	70.42	66.83	68.88	68.11	66.83
sample 5	69.65	66.32	67.09	68.37	69.14	70.34	70.42	68.97	67.09	66.66	69.22	69.57	68.71	81.87	68.63	68.37	65.63	72.47	70.42	70.42	68.03	68.37	69.74	72.64	70.25
average	68.7	67.9	67.1	67.6	67.1	69.9	72.3	68.2	69.0	70.4	73.1	71.4	70.9	73.6	69.4	67.8	67.8	69.4	69.1	69.6	69.1	68.3	70.1	69.3	69.0
range	5.6	3.8	2.9	3.8	4.9	9.1	4.2	6.9	3.4	10.4	9.1	8.1	9.0	12.2	3.5	6.1	5.1	8.0	6.7	4.8	5.0	7.4	3.3	5.8	5.9
standard dev.	2.33	1.84	1.14	1.53	1.86	3.53	1.50	2.62	1.46	4.44	3.54	3.33	3.71	4.90	1.53	2.45	2.46	3.07	2.50	1.86	1.98	3.04	1.42	2.64	2.50

valve	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125
sample 1	67.51	66.49	71.70	66.57	67.86	71.45	68.11	69.05	74.69	66.83	73.58	70.68	71.96	70.93	66.83	68.37	72.30	74.01	64.27	68.20	67.17	73.84	71.96	67.09	69.65
sample 2	70.16	69.74	71.10	69.05	73.84	70.93	67.69	69.39	64.10	69.74	70.42	67.86	67.00	64.27	74.69	69.39	68.63	67.34	70.16	71.10	68.11	68.03	87.34	68.71	67.17
sample 3	66.83	69.91	70.08	72.22	68.11	67.09	72.22	69.05	68.37	69.39	66.83	68.20	70.08	68.37	68.20	67.60	69.39	70.16	69.39	67.60	67.86	67.86	68.11	67.86	72.47
sample 4	70.08	71.70	67.86	70.42	67.86	67.00	72.22	65.04	69.91	68.88	70.59	71.45	68.88	65.46	74.27	70.68	66.15	69.91	68.03	68.63	67.86	65.29	71.28	73.50	68.11
sample 5	71.45	70.16	69.57	68.63	64.78	69.14	67.34	67.51	68.88	68.54	70.25	66.32	66.32	72.22	86.15	69.91	67.00	66.32	68.88	69.65	67.09	67.69	73.16	71.45	70.42
average	69.2	69.6	70.1	69.4	68.5	69.1	69.5	68.0	69.2	68.7	70.3	68.9	68.8	68.3	74.0	69.2	68.7	69.5	68.1	69.0	67.6	68.5	74.4	69.7	69.6
range	4.6	5.2	3.8	5.7	9.1	4.5	4.9	4.3	10.6	2.9	6.8	5.1	5.6	8.0	19.3	3.1	6.1	7.7	5.9	3.5	1.0	8.6	19.2	6.4	5.3
standard dev.	1.95	1.90	1.49	2.10	3.29	2.08	2.48	1.81	3.79	1.13	2.39	2.12	2.29	3.41	7.64	1.22	2.39	2.99	2.30	1.38	0.46	3.17	7.49	2.68	2.06

valve	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
sample 1	71.10	69.39	68.37	68.52	66.47	67.83	72.11	69.80	68.26	70.23	68.01	70.57	70.23	67.75	73.48	71.08	68.18	70.83	65.70	70.31	66.38	70.40	74.67	89.20	70.83
sample 2	71.62	71.62	68.37	68.69	66.72	72.79	75.01	72.11	70.06	74.93	76.38	69.71	69.89	65.70	71.25	71.59	72.88	67.75	65.70	67.15	67.49	73.30	69.80	68.77	68.26
sample 3	70.16	70.16	69.22	66.47	68.35	71.85	70.31	71.34	67.75	72.88	71.34	71.77	71.34	72.11	71.34	69.54	70.74	68.86	65.44	70.83	67.49	74.07	75.36	70.31	69.54
sample 4	70.68	68.37	69.91	68.69	69.54	73.30	73.13	68.26	70.91	71.42	67.75	69.29	65.61	74.16	69.89	72.11	66.72	69.80	66.98	69.37	66.72	73.13	73.82	70.57	70.06
sample 5	66.83	71.10	69.14	67.83	66.81	72.11	71.85	69.03	68.77	75.18	76.89	75.44	68.26	64.76	71.94	78.01	66.72	75.95	69.29	69.80	70.31	71.59	70.57	68.86	70.31
average	70.1	70.1	69.0	68.0	67.6	71.6	72.5	70.1	69.2	72.9	72.1	71.4	69.1	68.9	71.6	72.5	69.0	70.6	66.6	69.5	67.7	72.5	72.8	73.5	69.8
range	4.8	3.3	1.5	2.2	3.1	5.5	4.7	3.8	3.2	5.0	9.1	6.1	5.7	9.4	3.6	8.5	6.2	8.2	3.9	3.7	3.9	3.7	5.6	20.4	2.6
standard dev.	1.89	1.30	0.65	0.95	1.32	2.17	1.74	1.60	1.31	2.16	4.40	2.47	2.22	4.08	1.30	3.24	2.70	3.18	1.61	1.42	1.55	1.48	2.50	8.79	0.98

valve	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176
sample 1	69.03	70.83	73.65	77.06	75.36	71.25	74.16	68.26	74.84	72.11	70.74	68.52	78.26	76.72	72.36	73.13	71.59	70.91	74.16	67.49	70.57	71.25	70.74	66.72	70.40	71.25
sample 2	67.49	68.69	72.88	73.39	75.44	87.24	72.96	70.40	71.77	69.71	71.59	67.49	69.03	73.39	69.03	70.31	73.13	72.28	73.90	68.69	67.83	70.57	71.34	68.86	70.31	72.96
sample 3	71.59	71.34	72.62	74.16	74.42	88.86	70.74	70.57	71.08	71.34	67.15	66.47	74.50	75.18	69.80	68.52	71.42	73.13	71.59	66.98	68.52	72.11	73.65	70.83	70.31	74.42
sample 4	70.74	70.40	74.42	76.98	73.99	72.36	69.54	69.54	72.36	66.81	66.21	70.83	69.80	72.11	70.31	70.40	68.86	72.36	71.85	67.32	69.03	71.08	73.82	69.80	69.89	73.39
sample 5	69.89	73.48	73.90	75.18	73.48	68.26	70.74	71.59	69.37	69.29	67.24	68.69	70.06	71.85	72.45	71.25	72.11	70.23	69.29	70.31	69.20	69.03	71.51	68.01	69.89	72.36
average	69.7	70.9	73.5	75.4	74.5	77.6	71.6	70.1	71.9	69.9	68.6	68.4	72.3	73.9	70.8	70.7	71.4	71.8	72.2	68.2	69.0	70.8	72.2	68.8	70.2	72.9
range	4.1	4.8	1.8	3.7	2.0	20.6	4.6	3.3	5.5	5.3	5.4	4.4	9.2	4.9	3.4	4.6	4.3	2.9	4.9	3.3	2.7	3.1	3.1	4.1	0.5	3.2
standard dev.	1.58	1.73	0.74	1.65	0.85	9.68	1.88	1.25	2.00	2.06	2.41	1.62	3.95	2.08	1.54	1.67	1.58	1.18	1.98	1.36	1.01	1.14	1.42	1.59	0.25	1.18

Appendix C: Fill Height Analysis Procedure

Appendix D: PM Schedules

Table 30 - PM Schedule

WEEK BEGINNING - MMONDAY								30-Mar	6-Apr	13-Apr
NUMBER OF WEEKS								1	2	3
PM #	TASK ID.	DESCRIPTION	RESP.	FREQ.	Min	HRS	STATUS			
	AP2466-94	52W CMC INFR RED SCAN SCHEDULE	ACP	52 WEEKLY		0.30	R	0.3		
	AP2466-83	8W CMC VIBRATION SCHEDULE	ACP	8 WEEKLY		0.50	R			
	AP2466-80	4W OIL SAMPLE SCHEDULE	ACP	4 WEEKLY		0.50	S			
TOTAL NUMBER OF HRS PER WEEK PER TRADE						CMC		0.30	0.00	0.00
	AP2466-88	13W ELEC SAFETY SWITCHES SCHEDULE	AEP8	13 WEEKLY		0.10	S			0.1
	AP2466-90	13W ELEC NON-RUNNING SCHEDULE	AMP8	13 WEEKLY		0.50	S			
	AP2466-92	26W ELEC CLEANING SCHEDULE	AEP8	26 WEEKLY		1.00	S			1
	AP2466-99	52W ELEC NON-RUNNING SCHEDULE	AEP8	52 WEEKLY		0.50	S			
	AP2466-84	8W ELEC MOTOR CLEANING SCHEDULE	AEP8	8 WEEKLY		1.00	S			
	AP2466-85	8W ELEC NON-RUNNING SCHEDULE	AEP8	8 WEEKLY		0.50	S			
TOTAL NUMBER OF HRS PER WEEK PER TRADE						E		0.00	0.00	1.10
	AP2466-95	52W INST NON-RUNNING SCHEDULE	AIP8	52 WEEKLY		1.80	S			1.8
TOTAL NUMBER OF HRS PER WEEK PER TRADE						I		0.00	0.00	1.80
	AP2466-72	1W MECH RUNNING SCHEDULE	AMP8	1 WEEKLY		0.50	R			
	AP2466-79	4W MECH RUNNING SCHEDULE	AMP8	4 WEEKLY		0.50	R			
	AP2466-87	8W MECH RUNNING SCHEDULE	AMP8	8 WEEKLY		0.30	R			
	AP2466-71	1W MECH NON-RUNNING SCHEDULE	AMP8	1 WEEKLY		2.50	S			
	AP2466-89	13W MECH NON-RUNNING SCHEDULE	AMP8	13 WEEKLY		3.20	S			3.2
	AP2466-97	**156W MECH BOWL INSP SCHEDULE**	**AMP8**	**156 WEEKLY**		**4.00**	**S**			**4**
	AP2466-98	**156W MECH SAFETY VALVE SCHEDULE**	**ATP8**	**156 WEEKLY**		**1.00**	**S**			**1**
	AP2466-75	2W MECH NON-RUNNING SCHEDULE	AMP8	2 WEEKLY		0.10	S			
	AP2466-93	26W MECH NON-RUNNING SCHEDULE	AMP8	26 WEEKLY		3.80	S			
	AP2466-77	*4W MECH INF CONV SCHEDULE*	*AMP8*	*4 WEEKLY*		*0.50*	*S*			
	AP2466-78	4W MECH NON-RUNNING SCHEDULE	AMP8	4 WEEKLY		3.80	S			
	AP2466-96	52W MECH NON-RUNNING SCHEDULE	AMP8	52 WEEKLY		1.00	S			
	AP2466-100	**52W MECH OVERHAUL FILLING VALVES SCHEDULI**	**AMP8**	**52 WEEKLY**		**40.00**	**S**			
	AP2466-86	8W MECH NON-RUNNING SCHEDULE	AMP8	8 WEEKLY		2.40	S			
TOTAL NUMBER OF HRS PER WEEK PER TRADE						M		0.00	0.00	3.20
	AP2466-74	1W OPER RUNNING DCHEDULE	AOP8	1 WEEKLY		0.10	R			
	AP2466-76	2W OPER RUNNING DCHEDULE	AOP8	2 WEEKLY		0.10	R			
	AP2466-82	4W OPER RUNNING SCHEDULE	AOP8	4 WEEKLY		0.30	R			
	AP2466-73	1W OPER NON-RUNNING SCHEDULE	AOP8	1 WEEKLY		2.20	S			
	AP2466-91	13W OPER NON-RUNNING SCHEDULE	AOP8	13 WEEKLY		0.10	S			
	AP2466-81	4W OPER NON-RUNNING SCHEDULE	AOP8	4 WEEKLY		1.50	S			
TOTAL NUMBER OF HRS PER WEEK PER TRADE						O		0.00	0.00	0.00
TOTAL NUMBER OF HRS PER WEEK								0.30	0.00	2.90

Appendix E: Work Instruction (WI) 17

Appendix F: PIMS and POMS