



# **Cigarette Reject Rate Reduction using a Lean Six Sigma Approach**

**Esteban Berty**

Master Thesis Project

Department of Production Engineering and Management

School of Industrial Engineering and Management

Kungliga Tekniska Högskolan/Royal Institute of Technology

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## **Abstract**

Due to changes in customer demands, companies often need to improve their processes and approach them in different ways. Waste elimination is very important for every company in their quest to reduce costs and use resources efficiently. Variation reduction helps keep processes steady and more accurate. Two powerful tools for process improvement are Lean and Six Sigma, when combined can bring many benefits to organizations that decide to implement them. The amount of continuous improvement tools that each methodology possesses brings the team a great variety of resources to attack and reduce variation in any process.

Lean and Six Sigma methodologies have gain a lot of popularity in recent years. The improvements they bring to companies not only in an economical but as a way to develop professionals are impressive. These methodologies are changing mindsets worldwide and giving quality a new meaning. Lean Six Sigma certifications are a must for every professional looking to improve processes in their organization.

Philip Morris International subsidiary in San Jose, Costa Rica has a great challenge on trying to improve processes in their production facilities to keep with goals and demands from headquarters in Laussane, Switzerland.

This project is involved with the use of Lean and Six Sigma tools to improve the cigarette reject rate in the Marlboro line at Philip Morris. The project is divided in three parts. First an introduction to Lean and Six Sigma and why they are so important for companies now a days. Second, explain the DMAIC methodology used for the realization of the project. Third, explain the implementations made to improve the process and reduce cigarette reject rate.

**Key Words:** Lean, Six Sigma, DMAIC, cigarette reject rate

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## **1. Introduction**

*This chapter provides an introduction to the project. A background of what the existing problem is and the selected solutions on how to improve it are presented.*

### **1.1 Existing problem and importance of its solution**

Companies today are forced to save money and resources if they want to compete in globalized markets. For Philip Morris International in San Jose, Costa Rica this is very important when competing against different brands of cigarettes and against regional affiliates that try to move operations to their countries.

One way to control that resources and materials are being used effectively in companies is with the use of KPI's (Key Performance Indicators). Key performance indicators measure the performance of a process; they indicate the yield of processes so objectives can be achieved.

At Philip Morris production plant, there are four very important KPI's that measure productivity, efficiency and costs. These are Uptime, Secondary Yield, DIM Wastage and CRR (Cigarette Reject Rate).

This project is focused on the CRR (Cigarette Reject Rate) KPI. Cigarette Reject Rate is defined as all the cigarettes in the make, pack machines that do not meet quality requirements (PMI, 2001). These cigarettes are thrown away and there is a big loss in material and tobacco strand that must be re processed. This cost the company more than \$6000 dollars per month on material, work force and tobacco strand.

With this project what we want to do is to improve the cigarette reject rate to at least 1%, so material and tobacco strand are not lost in the process and operation costs will decrease. The improvement done will help the company save money and resources and will also benefit customers since better quality requirements will be achieved. A reduction of 1% in the Cigarette Reject Rate will save the company an estimate of \$6000 dollars per month.

This project will be done using a Lean Six Sigma approach to reduce waste and variation in the process of cigarette elaboration. This methodology has been used worldwide to improve processes not only in manufacturing but also in services.



## **1.2 Delimitations**

Constraints for the realization of this project are:

1. There is no money for investing in new machines, hire working force or use resources that are not a part of the projects budget.
2. Any implementation or change done in the process has to be approved by the project sponsor.

The selected solution is based on the implementation of Lean Six Sigma tools to control waste and variation in the process of cigarette making at the Marlboro production line.

To follow this Lean Six Sigma project, the DMAIC project methodology will be used. Each phase consists of different steps that need to be followed in order to complete the project and each phase will be developed and explained in this work.

This project was made in close consultation with the ASQ (American Society for Quality) certification Black Belt Lean Six Sigma, which I took during the months of March until October 2011.

## **2. Goals and Objectives**

*The main goal of the project as well as the main objective and specific objectives are presented in this part.*

### **2.1 Goal**

Improve and control cigarette reject rate in production line #101 using the Lean Six Sigma methodology, this means eliminating waste and variation in the process of making and packaging the cigarettes.

### **2.2 General Objective**

Improve the Cigarette Reject Rate in production line #101 to at least 1% before the end of August 2011

## 2.3 Specific Objectives

1. Use of the DMAIC methodology to:

- a. Explain each of the phases of the methodology and all the tools needed to successfully improve the cigarette reject rate.
- b. Determine with the use of statistic tools the variation in the studied process.
- c. Determine waste improvements with the use of Lean tools such as Value Stream Mapping and others.
- d. Make improvements in the process without the use of new resources

2. Determine the savings the company will obtain with the implementation of the project

3. Explain how Lean Six Sigma methodology can help companies improve processes and change people's mind about quality and continuous improvement.

## 3. Frame of reference

*This chapter presents a description for Lean and Six Sigma and how their integration can benefit companies that decide to implement them. Also a background of the DMAIC methodology used in the project and an explanation on the five steps that the methodology contains to develop Lean Six Sigma projects.*

### 3.1 Six Sigma

Six sigma is a highly efficient process that focuses on developing and delivering stable products and services in a constant way. It is a management strategy that utilizes statistical tools and project management methodology to achieve profitability and improvements in quality. The average company is at a four sigma level (Harry, 1998).

Snee, (1999) describes six sigma as "A business improvement approach that seeks to find and eliminate causes of mistakes or defects in business processes by focusing on outputs that are of critical importance to customers".

Six Sigma ideas were born at Motorola in 1986 by Bill Smith who first formulated the principles of this methodology. Also six sigma was inspired by other quality improvement

techniques such as TQM (Total Quality Management), quality control and zero defects, these techniques based on gurus such as Deming, Juran, Ishikawa and many others.

Sigma is defined as a statistical term that refers to the standard deviation of a process about its mean. In a normally distributed process, 99.73% of measurements will fall within  $\pm 3.0$  sigma and 99.99966% will fall within  $\pm 4.5$  sigma. Motorola with this study noticed that their processes such as assembling a part, tended to shift 1.5 sigma over time. This means that for a process with a normal distribution and normal variation, specification limits of  $\pm 6$  are needed to produce just 3.4 defects per million opportunities. When said to have a  $\pm 6$  sigma level means the process is working at a perfect level with minimum defects as possible.

In six sigma, failure rate can be referred to as defects per opportunity (DPO) or defects per million opportunities (DPOM). If the measured process only has 3.4 defects every million parts, then the process is said to be at a 6 sigma level. Since perfect processes do not exist, it is common to have a normal process with no more than a 5 sigma.

Sigma Level	ppm
6 sigma	3.4 ppm
5 sigma	233 ppm
4 sigma	6210 ppm
3 sigma	66810 ppm
2 sigma	308770 ppm
1 sigma	697672 ppm

Table 1. Defect levels ppm (parts per million)

Some of the benefits companies can achieve with six sigma implementation are:

- Cost reduction
- Cycle time reductions
- Defect reduction
- Defect reduction
- Culture changes
- Customer relations improvements

### 3.2 Lean Manufacturing

When we talk about Lean, we talk about eliminating waste. Lean concepts were born at the Toyota Company in Japan with gurus such as Singeo Shingo and Taichii Ohno. The Toyota Production System was soon copied by many companies around the world.

In 1990, James Womack's book "The Machine that Changed the World" brought a wider approach to lean and helped introduce the seven types of waste that anyone can encounter in a plant or production process. These seven wastes are:

Waste	Description
<b>Transport</b>	Moving products not required
<b>Inventory</b>	Work in process not being processed
<b>Motion</b>	People moving more than needed
<b>Waiting</b>	Waiting extra time for next process
<b>Overproduction</b>	Producing more than needed
<b>Over Processing</b>	Bad product design quality
<b>Defects</b>	Effort in inspecting and fixing defects

Table 2. Seven Wastes in Lean Manufacturing

Lean techniques are the systematic identification and elimination of waste, implementation of the concepts of continuous flow and customer pull (CSSBB, 2007). Some of the benefits of lean implementation in companies are: lower production costs, system flexibility, higher quality, quicker product development

There are many lean manufacturing tools that help reduce waste, some of these tools are:

Tool	Description
<b>5S</b>	Fundamental first step at any company. 5S mandates that resources be provided in the required location and be available as needed. In other words, have a clean, organized factory.
<b>Poka Yoke</b>	Developed by Shigeo Shingo, this means to mistake proof the process. The idea behind this is to reduce the human error using advice or procedure that catches the mistake before it translate to the product
<b>Visual Controls</b>	The use of production boards, tools boards, schedule boards in the production floor. This brings the workers a display of what is happening at any moment, and if any change must be done.
<b>Value Stream Mapping</b>	A VSM as it is called, helps understand the flow in a process. It is basically a map, with all vital information about the process like cycle time, change over time, suppliers,

customers, etc. Areas of improvement can be found by using this powerful tool.

Table 3. Lean tools used to eliminate waste

### 3.3 Comparison between Lean and Six Sigma

It is said that Lean and Six Sigma have lots of things in common. Both of them focus on satisfying customers and use different tools to do so. Six Sigma focuses on the variation of the processes and applies statistical tools to reduce them; Lean focuses on waste reduction by considering customer inputs.

Both methodologies have an effect on peoples mind sets. They create a culture of continuous improvement and develop a consciousness for process efficiency.

Many problem solving and problem techniques are used by Lean and Six Sigma, for example Pareto analysis, cause and effect diagrams, brainstorming and many others.

Topic	Six Sigma	Lean
<b>Improvement</b>	Reduce variation	Reduce waste
<b>Justification</b>	Six Sigma(3.4 DPMO)	Speed (velocity)
<b>Main Savings</b>	Cost of poor quality	Operating costs
<b>Learning curve</b>	Long	Short
<b>Project Selection</b>	Various approaches	Value stream mapping
<b>Project Length</b>	2-6 months	1 week-3 months
<b>Driver</b>	Data	Demand
<b>Complexity</b>	High	Moderate

Table 4. Comparison between lean and Six Sigma characteristics (Taken from the CSSBB Primer)

With this comparison a very important question comes to mind: Can Lean and Six Sigma be applied together at an organization?

The answer is yes. If by themselves Lean and Six Sigma are very efficient tools, together they can bring more benefits to the company and lean approaches can coexist with the application of six sigma methods. "Lean provides stability and repeatability in many basic processes. Once stability has taken hold, much of the variation due to human processes goes

away. The data collected to support six sigma activities thereby becomes much more reliable and accurate". (Crabtree, 2004).

A large number of companies are combining both methodologies into a Lean Six Sigma approach. They have noticed that if they get a 6% of improvement over time using Lean and another 6% using Six Sigma, when combined they can get up to a 12% improvement.

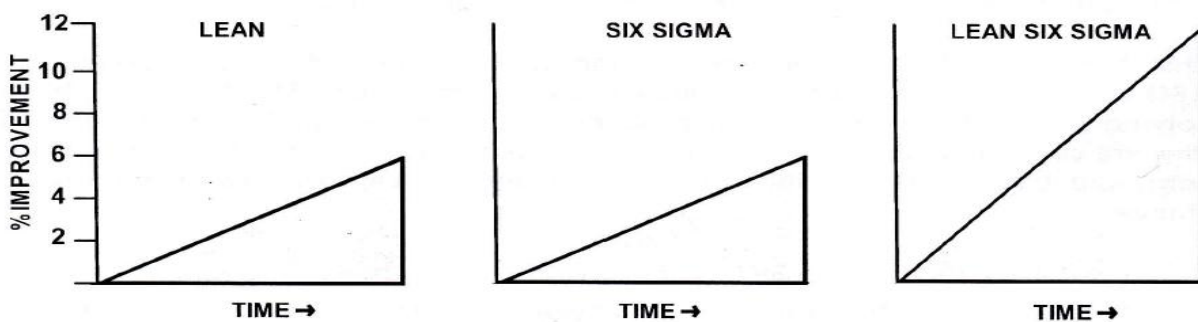


Figure 1. Integration of Lean and Six Sigma

### 3.4 DMAIC Methodology

DMAIC is the methodology used in Lean Six Sigma for the realization of a project. It was developed by Edward Deming and is useful for improving business processes to reduce defects. DMAIC is an acronym for the five step process: Define, Measure, Analyze, Improve and Control. Each step consist of different sub steps were different tools are utilized to cover all parts of the project.

3.4.1 Define: It is the first step of the process. Here is where we decide on the project, the objectives, scope, goals we want to achieve by doing the project and the team members that will help us achieve these goals. Three things are important when we do the Define: the project charter, SIPOC and CTQ Tree.

What is wanted from the Define is:

- Define who the customer is
- Define the project boundaries, the stop and start of the process
- Define which process is going to be improved by mapping the process flow

3.4.2 Measure: To determine if defects have been reduced a base measurement is needed. Accurate measurements will be done in this step, so that we can compare them with future measurements.

Some steps made in this part are:

- Develop a data collection plan for the process
- Collect data to determine the current status, this can be done calculating the sigma level or doing a process capability study

3.4.3 Analyze: In this step all measurements will be analyze, by understanding them we can get to the basic problem easier. The idea is to search for the factors that have the biggest impacts on process performance and determine the roots causes.

What is wanted from the analyze phase is to:

- Prioritize improvement opportunities
- Identify excessive sources of variation
- Identify gaps between current performance and goal performance

3.4.4 Improve: Improving or optimizing processes are done in this step, after all data has been analyze, problems can be attacked more efficiently. Design of experiments is a powerful tool that can be use in this phase; also many lean tools available can help the process eliminate variation, for example poka yoke, visual control and 5's can be very beneficial.

The improvement phase can help us to:

- Create innovative solutions using creativity, technology and discipline
- Develop improvement implementation plans

3.4.5 Control: This is the last step of the DMAIC methodology. Control ensures that processes are being taken care of and that any variance is corrected before it influences the process results.

The control phase can help us achieve:

- Not to go back to how the process was before
- Develop a monitoring plan to control the process

## **4. Research process and practical studies**

*This chapter describes the cigarette process and what the cigarette reject rate means. Explains how the development of the DMAIC methodology was done and which tools were used in each phase of the process.*

### **4.1 Cigarette process**

The process of making the cigarettes is divided in two parts: Primary process and Secondary process. For this project we will consider only the secondary process since here is where the study took place and where the cigarette reject rate is considered. The secondary process is where the making and packaging of the cigarettes take place.

The primary process is where the strand is processed to give the consistency and flavor depending on the cigarette brand. Some brands produced at Tabacalera Costarricense are Marlboro, Derby and Next.

Once the tobacco strand has been processed and flavors are added the strand is taken in special bags that weight approximately 150 kgs, to the tobacco strand room where an operator takes the bags and place them on a conveyor that will transport the strand to the Marlboro line. The strand is transported by suction pipes that take the strand to the MK-9 machine; this machine can produce 4500 cigarettes per minute working at a 60% of its capacity.





Figure 2. Tobacco Strand room



Figure 3. Suction tubes

The MK-9 machine takes the cigarette paper along with the strand and creates a gut that is what the actual cigarette looks like.

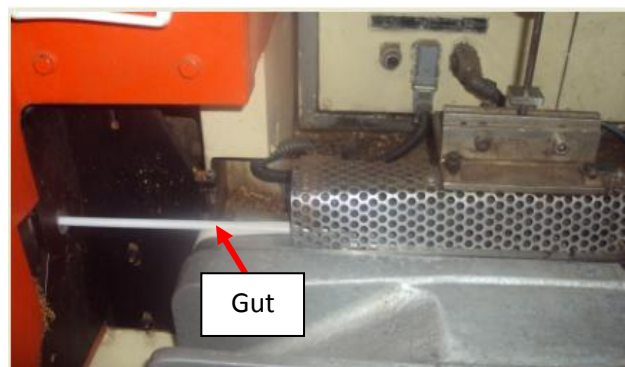


Figure 4. Gut creation in the MK9 machine

Once the gut is created it goes to the HCF machine where the filter and tipping paper are glued to the cigarette and they are cut to give them their final appearance. In this part the cigarette reject rate is considered, since the machine has different sensors that are measuring the characteristics of the cigarette. Some of these characteristics are circumference, ventilation, RTD (resistance to draw) and weight. If any cigarette does not meet these specifications, the machine will not consider it and it will be thrown out of the process for rework.

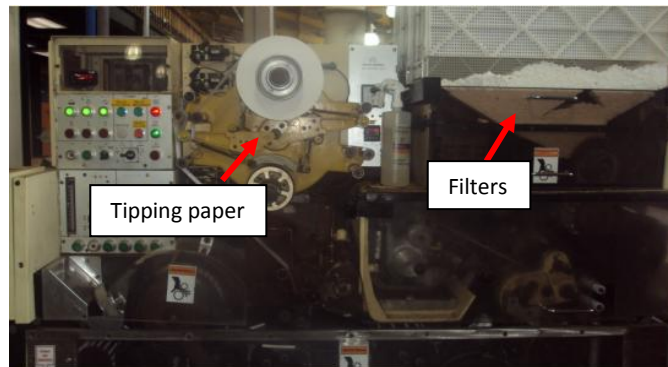


Figure 5. Tipping paper and filter section (MAXS machine)

The MAXs and HCF machines are in charge of taking the cigarettes and stocking them in trays where an operator will check them to verify that quality standards are in order. Here also the cigarette reject rate is considered, some cigarettes may pass the first inspection so the operator has to check if any cigarette is damaged or has an empty tip.

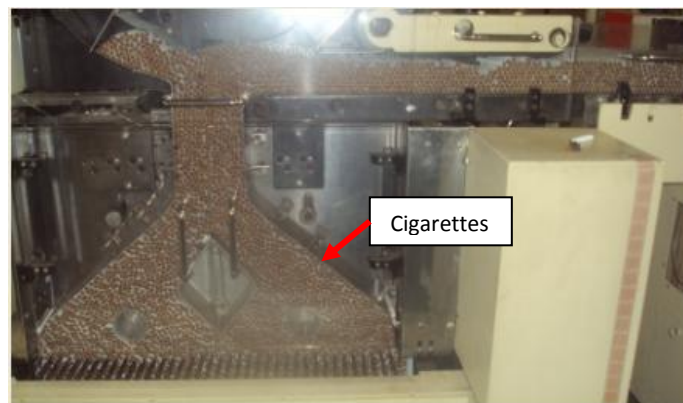


Figure 6. HFC machine

Once the cigarettes are examined, they pass to the packaging machine where the machine takes 20 cigarettes per turn and with the paper and aluminum builds the cigarette box. This box passes to the HLP machine that wraps the box in a thin plastic called poly. Here also the cigarette reject rate is considered, because if a package contains a damaged or defective cigarette, the sensors in the packaging machine will reject the complete cigarette box and all the materials involved in the process would be wasted. The operators from the other processes have to be very careful so that defective cigarettes don't make it to the final packaging process.

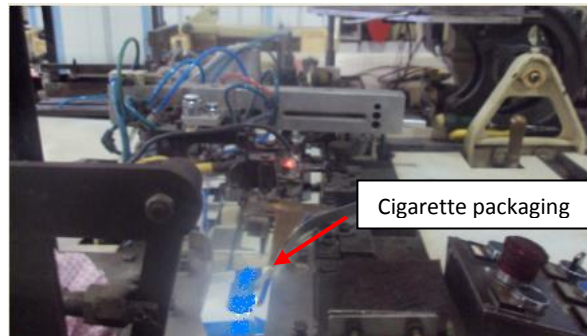


Figure 7. Packaging machine

All boxes are sent to the Marden Edwards machine that packs the boxes in groups of 10, these ten cigarette boxes are called cigarette wheels. Each shipping case contains 50 cigarette wheels.

A complete parquet has 36 boxes; the operator takes each parquet to the pre stock room where they are covered in plastic to preserve the product clean and fresh. The parquets are taken to the finished product warehouse for them to be shipped to different selling points.



Figure 8. Parquets for Marlboro Red

#### 4.2 What is CRR (Cigarette reject rate)?

This is a measure of the percentage of the cigarette throughput in the make/pack groups that is rejected. These values should be used in conjunction with the secondary cigarette yield and cut filler weights per cigarette to judge the performance of cigarette production as opposed to pure machine production capability (PMI, 2008). A complete control inspection of the cigarette process has to be done constantly, to be sure that the cigarettes are meeting quality specifications.

The cigarette reject rate is measured at the MK-9 machine and the packaging machine. Both machines have sensors that reject the cigarettes that do not comply with quality

requirements, for example weight, circumference, ventilation, missing filter, the cigarette has an empty rod, etc.

Even though many efforts are done to try to reduce material waste and tobacco strand re work, there still exist many variation that can be measured and improve to have a more stable process and reduce the rate of cigarettes rejected.

Month	Reject Rate	Target
September	4,9	2,8
October	5	2,8
November	5,1	2,8
December	5	2,8
February	4,9	2,8
April	4,8	2,8
May	5	2,8
June	4,8	2,8

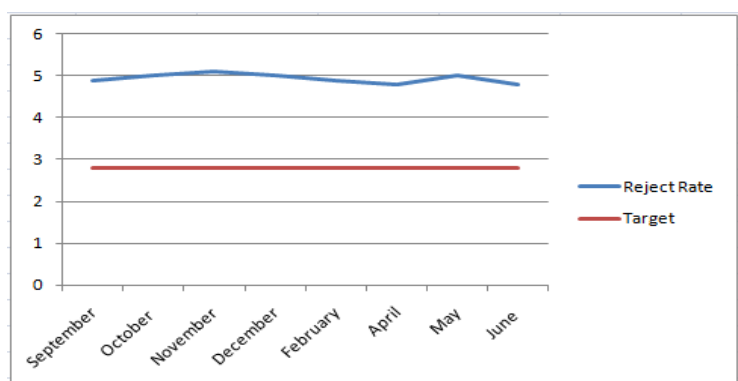
Table 5. Cigarette Reject Rate per month

Figure 9. Cigarette reject rate per month

The graph above, shows the percentage of cigarette rejects in the last months, the target is 2.8% in reject, but the reject rate is far from being close to 2.8

Reducing the CRR is very important because it will help reduce operation costs. Almost every month approximately \$6000 dollars are lost due to material and tobacco waste. All the raw material includes cigarette paper, filters, glue, tipping paper, aluminum, cigarette boxes and poly plastic. This means that about 1 million cigarettes do not make it as final product.

The key performance indicator used at Philip Morris International to control the cigarette reject rate is calculated weekly and monthly and has a goal of 2.8% in the cigarette elaboration process and 0.4% for the packaging process. Each week and month, depending on variations the goal may be achieved. Right now the process presents a reject rate that is between 4.5% and 5%. What we want with this project is to reduce this percentage to at least 1%, which will help us reduce operating costs and give us a better use of the resources.



## 4.3 DMAIC Methodology Implementation

### 4.3.1 Define

#### 4.3.1.1 Project Charter

The first phase in the DMAIC methodology is the Define. As stated in the Define definition, in this phase we define the project, team members, objectives, goals and how long we think the project will take.

All this information is given in the project charter, as shown below

<b>1. Project Name:</b>	<b>Reduction of cigarette reject rate</b>		
<b>2. Company:</b>	<b>Philip Morris International</b>		
<b>3. Department:</b>	<b>Operations</b>		
<b>4. Analyzed Process:</b>	<b>Cigarette production</b>		
<b>Business Case</b>	<b>Team Members</b>	<b>Name</b>	<b>Department</b>
CRR(cigarette reject rate) is an important indicator for the company. The amount of product rejected during the cigarette elaboration causes a loss of approximately \$6000 per month. This waste causes that approx 1 million cigarettes are not delivered to the finish goods warehouse or have to be re processed.	CHAMPION/SPONSOR	Ramon Vega	Operations
	MASTER BLACK BELT	Edwin Garro	
	BLACK BELT	Esteban Berty	Operations
	PROCESS OWNER	Jeffrey Coto	Operations
	GREEN BELTS		
<b>Project Leader</b> Esteban Berty	Team Members	Marlboro cell	
		Carlos Pereira	Oscar Gomez
		Ivan Brenes	Andres Carranza
		Luis Castro	Heiner Mora
		Alvaro Herrera	
<b>Problem Declaration/Opportunity</b>	<b>Others involved in the project</b>		
A high percentage of more than 3% of waste in the elaboration of cigarettes in machine #101 at the Marlboro line, creates a considerable expenditure of materials and an increment on the CRR key performance indicator.	Jonathan Vargas-Maintenance Supervisor Roberto Viquez-Electric Supervisor		
<b>Goal</b>	<b>Constrains</b>		
Improve the cigarette reject rate in the Marlboro line to at least 1% before the end of August 2011.	There is no money for investing in new machines, hire working force or use resources that are not part of the projects budget. Any implementation or change in the process has to be approved by the project sponsor.		

Figure 10. Project Charter for the project

Once the project charter is completed, we proceed with the next step of the Define phase.

#### 4.3.1.2 SIPOC

The next step was creating a SIPOC. It is a process map viewed from a great distance. This means making the process as less specific as possible so it can be viewed by all team members in the same way and everyone understands where is it that we are focusing in

terms of the project. SIPOC stands for suppliers, inputs, process, outputs and customers.

Simon (2001) suggests the following steps for developing a SIPOC diagram:

- Have a the team create the process map
- The process may have 4 or 5 key steps. How is the raw material transformed?
- List the outputs of the process. What is the end product of service?
- List the customers of the output of the process. Who is the end user?
- List the inputs of the process. Where do the materials come from?
- List the suppliers of the process. Who are the key suppliers?
- Last one; involve other team members to check if all steps were done with the correct information.

The SIPOC made for the project is shown below

<b>1. Project Name:</b>	<b>Reduction of cigarette reject rate</b>
<b>2. Company:</b>	<b>Philip Morris International</b>
<b>3. Department:</b>	<b>Operations</b>
<b>4. Analyzed Process:</b>	<b>Cigarette production</b>

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS	REQUIREMENTS
Include all suppliers in the process	Include the inputs of the process	Use space below	Include the outputs of the process	Include customers that received the product	Include customer requirements
Primary process	Tobacco Strand		Cigarettes		Packed product
H.B Fuller	Adhesives			Warehouse	Good quality
IPC	Tipping paper			Distributors	Required quality
Cuextaco	Cigarette Paper				Stated quantity
	Filter tow				

Process general description	
START(The process begins when the following action is executed):	
General steps in the process:	
STEP 1	Tobacco is sent to the MK9 machines from the strand room
STEP 2	MK9 receives the strand and creates a gut with the strand and paper
STEP 3	The filter is glued to the cigarette along with the tipping paper and adhesives
STEP 4	Cigarettes are taken from the machine to the trays
STEP 5	Cigarettes are inspected and sent to the packaging machine
STEP 6	Cigarettes are packed with the aluminum, adhesives and cigarette boxes
STEP 7	Cigarettes are packed in wheels of 10
STEP 8	Shipping cases are done, with 50 wheels each
END (The process ends when the following action is executed):	

Figure 11. SIPOC for the project



#### 4.3.1.3 Critical to Quality (CTQ's)

The third and last step of the Define phase is the CTQ tree. CTQ (Critical to quality) is another way to identify measures related to the requirements of the customers. A CTQ tree will translate customer requirements to numerical requirements for the product or service. In other words, it will help us view which metrics should we attack during the project.

For this project, since we want to reduce waste we will focus on three important metrics for the company. First, the cigarette reject rate indicator that tells us the amount of cigarettes rejected in the process. Second, the Secondary Yield to know how much tobacco strand is lost in the process. Finally, the Uptime metric that refers to the time machines operate continuously and the maintenance they receive. At the end of the project and once we have results from the actions done, we will compare the actual CTQ's with the new ones to see if the improvements made had an impact on the companies key performance indicators.

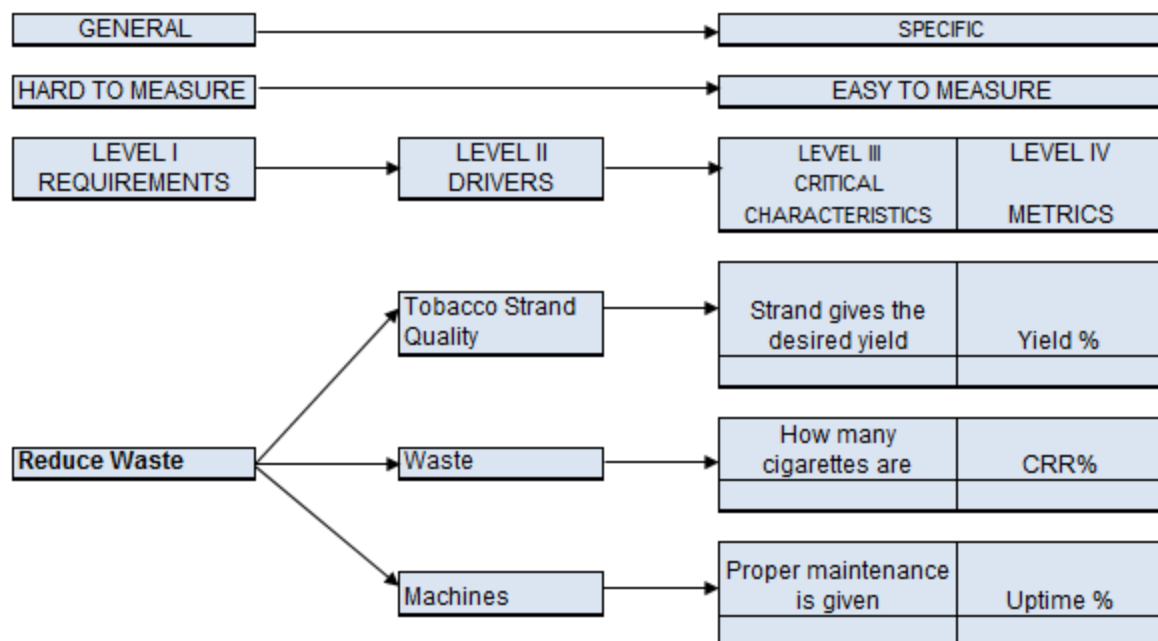


Figure 12. CTQ for the cigarette reject rate

To summarize what was done in the Define phase of the project, the business case, goal, main objectives and the team was created to start the project. The project charter was approved by the project sponsor. The SIPOC chart was then created by the team so everyone could understand what the objective of the project is and which part of the process we will

focus on. The CTQ tree was created to show which metrics mostly affect our final customer so we can study them and try to reduce them.

Once the Define phase is completed a Gantt chart was created, to show the time in which the other phases will be addressed.

Activity	Status	April				May				June				July				August			
Define	P																				
	R																				
Measure	P																				
	R																				
Analyze	P																				
	R																				
Improve	P																				
	R																				
Control	P																				
	R																				
P	Proposed date																				
R	Real date																				

Figure 13. Gantt chart for the realization of the project

### 4.3.2 Measure

The second phase of the DMAIC methodology is the Measurements. Measurements of the actual process are made so they can be compared with the measurements after implementations, so we can tell if our improvements are generating the desired effect.

#### 4.3.2.1 Sigma Level

Sigma level represents the level of variation that exists on the measured process. A low sigma level means that too much variation exists and most probably is not meeting customer satisfaction. A high sigma level indicates that the process is stable and variation exists but can be controlled. Since all processes present variation, it is almost impossible to achieve a  $\pm 6$  sigma level, but a process with more than a  $\pm 4$  sigma level is considered normal.

As stated before, the six sigma level represents the level of variation on the measured process. This was done for the process line #101 and the result showed that the level for the process was about  $\pm 3$  sigma. This means that the process is far away for being a stable,



defect free process. The goal with this project is to reduce the cigarette reject rate and this can be achieved if we increase the sigma level since variation will be reduced and controlled.

The following table shows how the sigma level was calculated

Sigma Level		
Description	Example	Comment
<b>1. Select a step of the process</b>	Cigarettes in line #101	
<b>Input: How many kgs of strand come into the process</b>	15416 kilos/strand	Measured Value
<b>Output: How many cigarettes are produced</b>	21 448 700 cigarettes	Measured Value
<b>2. Yield</b>	0.9336	Measured Value
<b>3. Defect Rate</b>	0.0664	Defect Rate: 1-Yield
<b>Normalize the DPO value per million of opportunities</b>	66400	DPO*1000000
<b>4. Convert value using the DPOM value table</b>	3	93.31%
<b>Result</b>	<b>Shows a low sigma level</b>	

Table 6. Sigma level calculation for the actual process

This was calculated in the following way:

1. First, we need to select a part of the process, in this case the production of the cigarettes in line #101.
2. Second, our input is the average amount of tobacco strand used in average every month for the production of cigarettes.
3. The output is the amount of cigarettes that can be produced with 15416 kilos of strand.
4. The yield comes from the secondary yield key performance indicator; this yield tells us the amount of strand that was used for making the cigarettes. In this case 93% of the strand was used; the other 7% is scrap that was not utilized.
5. The defect rate is calculated with the 1-Yield formula.
6. Once we have the defect rate we multiply it by 1000000 to normalize the defects per million opportunities.
7. The value we obtain, in this case 66400, is the amount of defects we have per million cigarettes made, so we can say that out of one million cigarettes 66400 do not make it as final product.

8. To know the sigma level, we go to the defects level table shown in figure 1 on page 11 of this thesis.
9. As a result we got a sigma level of  $\pm 3$  sigma which represents a low level. This means that variation is presented in the process and is causing a lot of defects and therefore many cigarettes do not comply with quality requirements.

After studying the process and proposing different implementation ideas, the sigma level for the process should increase since variation and waste will be reduced.

#### **4.3.2.2 Value Stream Mapping**

Another way to measure the actual process is by creating a value stream map to help the team analyze the production flow, look for improvements and for every team member to know where the main problem of the project is occurring.

A current state of the process was created to facilitate the process analysis and see where improvements can be done to reduce the cigarette wastage.

Some data included in the map are the cycle time, number of operators, pack size, tack time, lead time and uptime. From the map, it can be seen that we will focus on the MK9 and MAXS machines where the majority of cigarette reject takes place.

According to Rother (1999), some benefits of creating the value stream map are:

- Helps to see the complete process flow
- Identifying sources of waste
- Provides common language for process discussion
- Helps implement new lean ideas into the process

As a continuous improvement tools, a future value stream map can be created. With creative and innovative ideas, new solutions on how the process can be simplified can be drawn in the new map. These improvements can take years for them to occur, but sets a basis on how we want our process flow to be in the future. Developing a future map can help improve things like: reducing cycle and change over time, machine uptime, level the process, use kanban cards and the possibility of making kaizen events.

A value stream mapping process is done as follows:

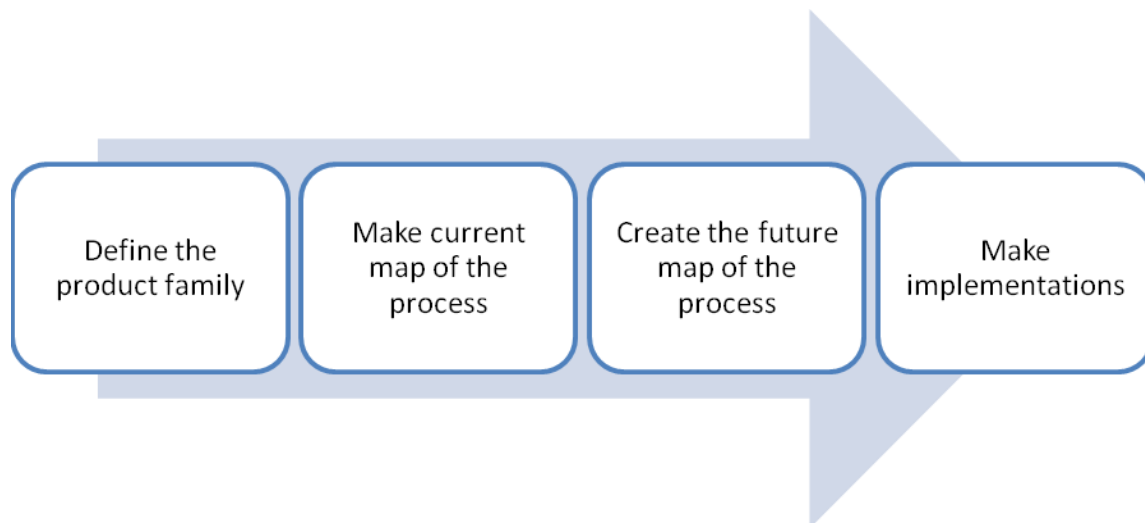


Figure 14. Value Stream mapping process

Some of the value stream map symbols are explained above. [These symbols were taken from the ASQ CSSBB Primer,2011]

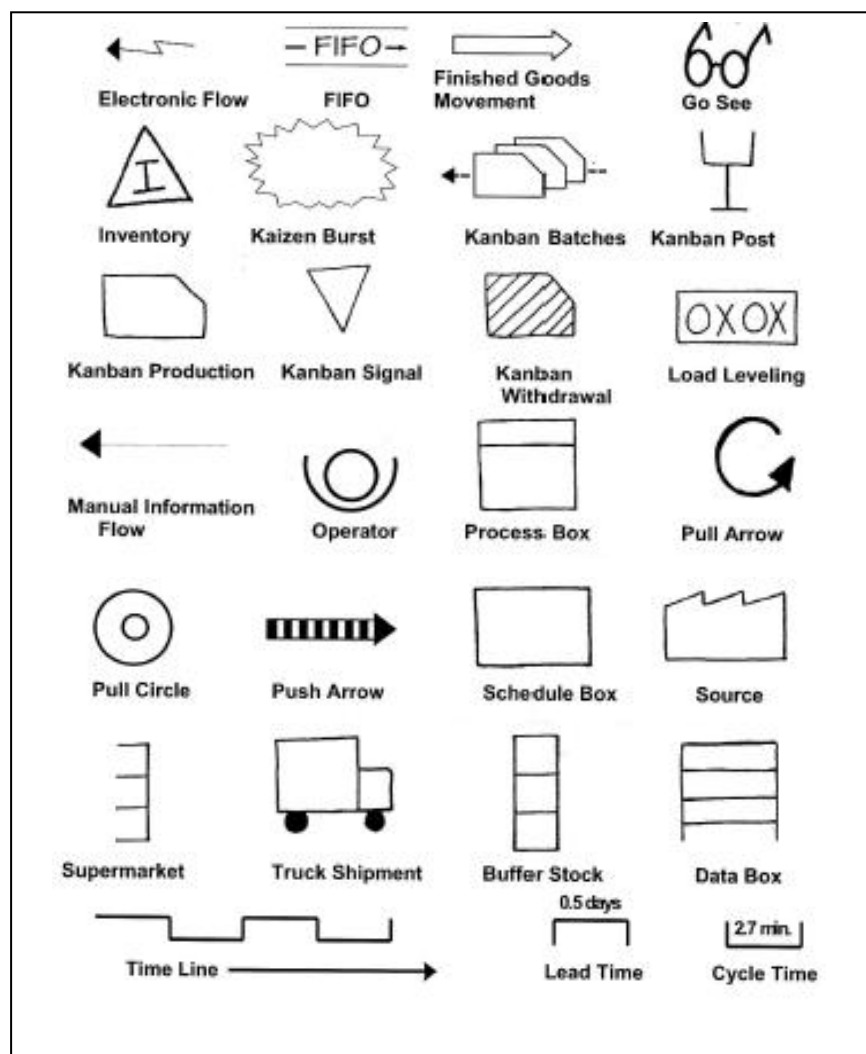


Figure 15. Value stream mapping symbols

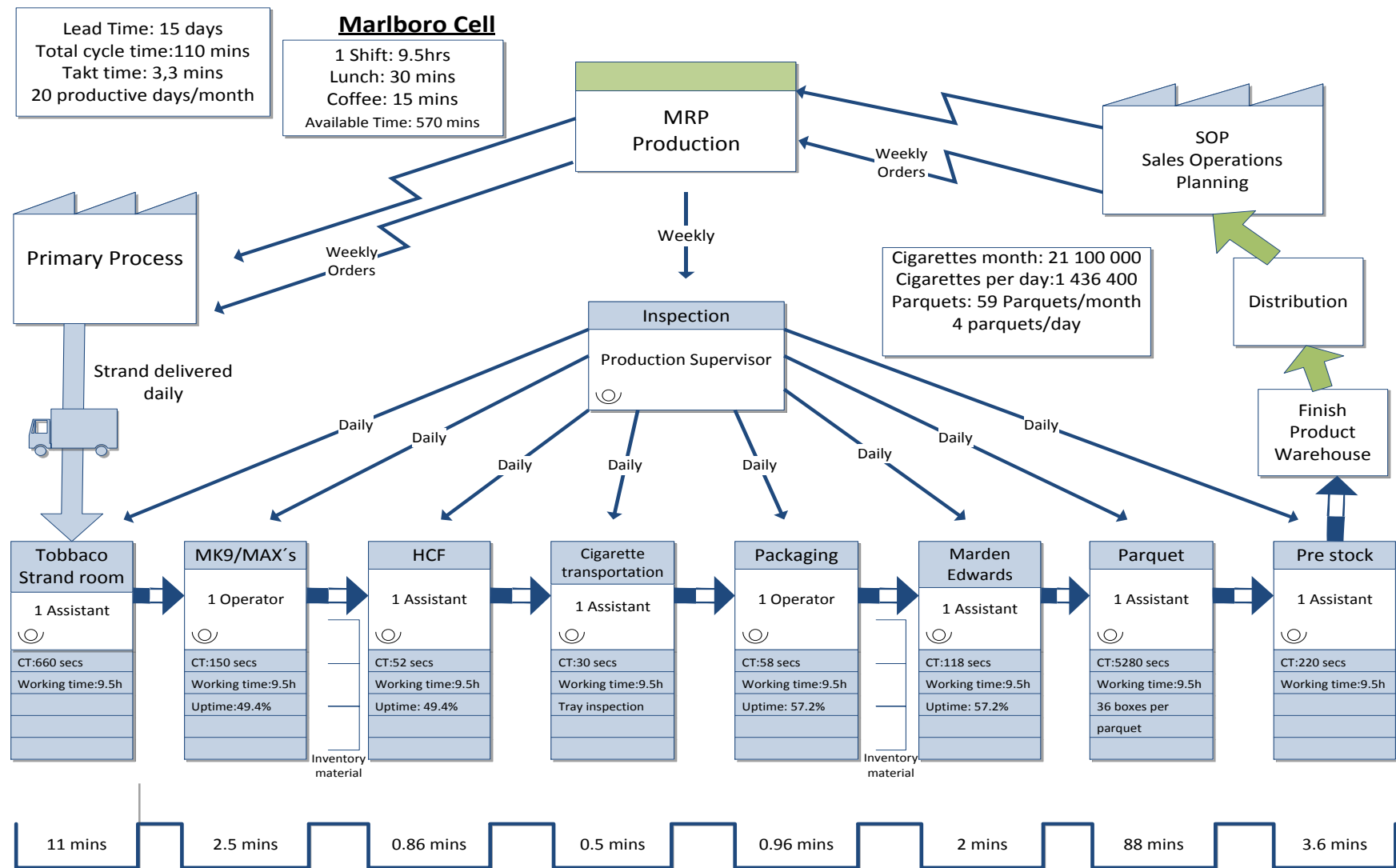


Figure 16. Value Stream Map for the secondary cigarette process

#### 4.3.2.3 Process Capability Study

Another way to measure the process is with the process capability. It is often necessary to compare process variation with specification tolerances to know how stable a process is. A process capability study is divided in three parts:

- a. How is data going to be collected
- b. Collecting the data
- c. Graphics and analyzing the results

The identification of characteristics that will be measured has to meet several requirements CSSBB Primer (2011):

- a. The characteristic should be indicative of a key factor in the quality of the process.
- b. It should be possible to adjust the value of the studied characteristic.
- c. The operating conditions that affect the measured characteristic should be defined and controlled.

There are three process capability indices that tell us if the process we are measuring is capable or not.

- a.  $C_p > 1.33$  Capable
- b.  $C_p = 1$  to  $1.33$  Capable with tight control
- c.  $C_p < 1$  Not capable

The process capability study helps us demonstrate that the process is centered within the specification limits and that the process variation predicts the process is capable of producing parts within the tolerance requirements.

For this project, three characteristics were taken into account to make the process capability analysis. These are the circumference, ventilation and RTD (resistance to draw). These three characteristics were selected because they are very important quality requirements to customers.

1. Circumference: The circumference of the cigarette is determined with a laserlike system. The measuring principle consists of

scanning the cigarette, with a laser beam, which is rotated 360° around its longitudinal axis at a constant speed. The cigarette prevents the laser beam from reaching a photo detector located behind the cigarette. This results in a diameter determination at many separate points. The average circumference is calculated and expressed in millimeters.

2. Ventilation: Air is drawn in the standard smoking direction through an unlit cigarette at a constant airflow of 17.5ml/s (vacuum process). The amount of air sucked through either the perforated tipping paper is measured and compared with the amount of air leaving the mouth end of the cigarette.
3. Resistance to draw: The difference in static pressure is determined between the two ends of a cigarette when air is drawn through it in a flow rate of 17.5ml/s.

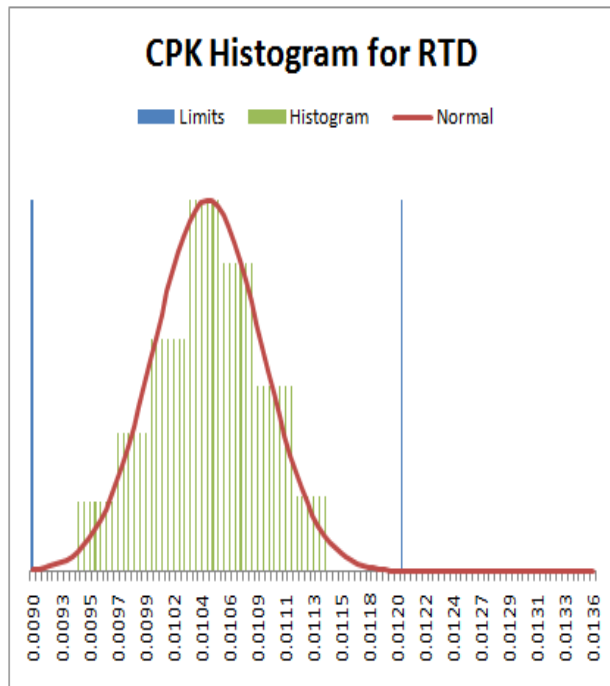
For the process capability analysis, 240 data samples were taken for each of the characteristics, with the help of Stat Solver software, different statistic measurements were made to see if the process is capable of producing within tolerance requirements. It is important to state that all data was analyzed to verify normality. More information about the data can be found in the appendix.

For the cigarettes in production line #101 the target value and tolerances are:

Characteristic	Tolerance	Target Value	Upper Specification Limit	Lower Specification Limit
Ventilation (%)	±4	28	32	24
Circumference (mm)	±0.06	24.55	24.61	24.49
RTD-Resistance to draw (mmWG)	±15	105	120	90

Table 7. Target and tolerance values for the cigarettes in the #101 production line

#### 4.3.2.3.1 Capability Analysis for RTD (Resistance to draw)

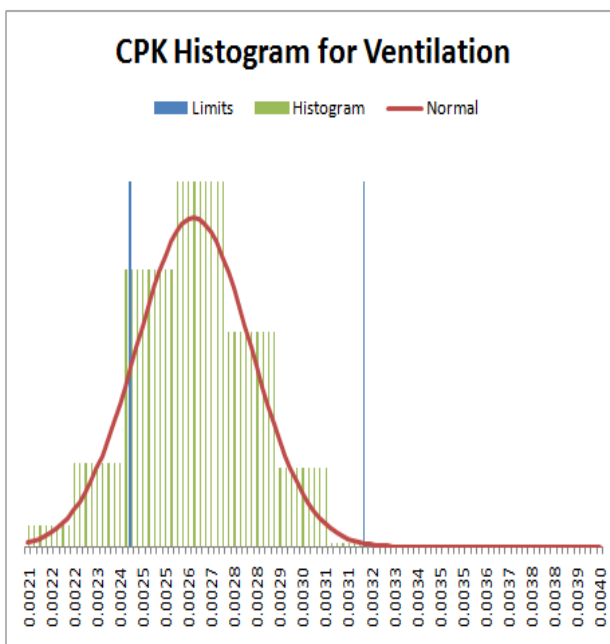


Capability Analysis for RTD	
Number of Classes	8,0000
Max	116,6000
Min	94,0000
RBar	3,4402
Mean	104,5717
StDev	4,3656
Skewness	-0,0361
Upper Spec Limit	120,0000
Lower Spec Limit	90,0000
Ppl	1,1126
PpU	1,1780
Pp	1,1453
Ppk	1,1126
Cpl	1,5926
Cpu	1,6863
Cp	1,6395
Cpk	1,5926
Upper 3s limit	117,6684
Lower 3s limit	91,4749
Observed Performance	
Upper % out	0,00%
Lower % out	0,00%
Total % out	0,00%

Figure 17. Capability study for resistance to draw characteristic

As we can see from the table, for the RTD characteristic the process is capable of producing parts within the tolerance requirements.

#### 4.3.2.3.2 Capability Analysis for Ventilation



Capability Analysis for Ventilation	
Number of Classes	8,0000
Max	33,8000
Min	20,6000
RBar	1,5828
Mean	26,2925
StDev	1,9159
Skewness	0,0687
Upper Spec Limit	32,0000
Lower Spec Limit	24,0000
Ppl	0,3989
PpU	0,9930
Pp	0,6959
Ppk	0,3989
Cpl	0,5446
Cpu	1,3559
Cp	0,9502
Cpk	0,5446
Upper 3s limit	32,0401
Lower 3s limit	20,5449

Figure 18. Capability study for the ventilation characteristic

#### 4.3.2.3.3 Capability study for Circumference

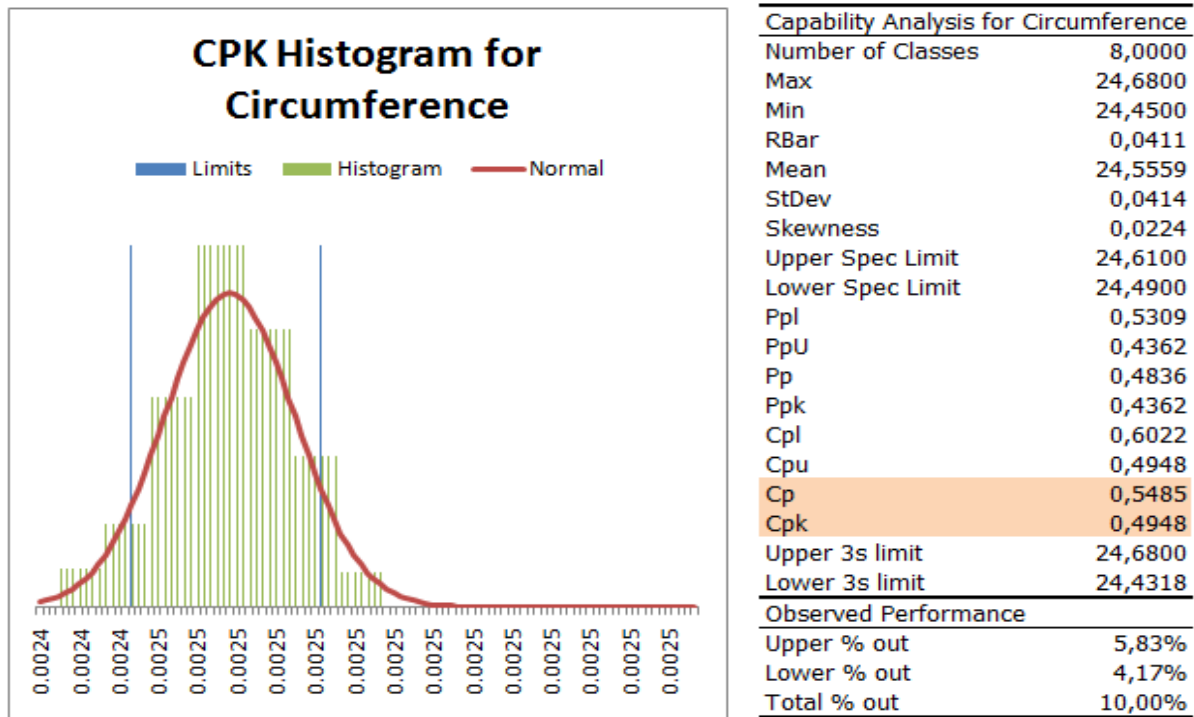


Figure 19. Capability study for the circumference characteristic

For the capability study for ventilation and circumference characteristics, the process is not capable to produce within the required tolerances. Since the process is not able to produce according to specifications, other solutions must be addressed. One problem the process presents to meet specifications is that the machines used are very old and are not able to cope with ideal specifications from the company's headquarters. Proper maintenance of the machines is important to try to obtain the specification target. Creation of an action plan is important for the maintenance of the machines; this plan can be done to give long term, short term and preventive maintenance to different parts of the machines. Also important is to perform inspections of the process, for the production line #101, a cigarette sample is taken every 20 minutes. In this inspection, cigarettes are tested to check that they meet specifications on ventilation, circumference, materials and tobacco strand. Since specifications cannot be changed, what can be done is try to reduce variation and emphasize on handling the scrap and re work efficiently.



#### 4.3.2.4 Pareto Diagram Analysis

A Pareto diagram with the major causes of machine breakdowns was created to check in which problems we can focus during the implementation phase of the project to attack the ventilation, circumference and wastage problems in the cigarette.

The following table shows the major machine breakdowns in minutes for machine #101 for the production of cigarettes.

Machine	Cause of breakdown	Minutes	Percentage
MK9	Jams in the suction chambers of the MK9	798	19%
MAXS	Cigarette problems (rolled, flags)	783	19%
Machine	Machine startup	641	15%
MAXS	Jam in the MK9 drums	386	9%
MK9	Cutting blade changes	268	6%
MK9	Failure in the worm sensor of the mk9	187	4%
MAXS	Failure in the glue system sensor	176	4%
MK9	WIN 1 troubleshooting	170	4%
MAXS	MAXS	140	3%
MK9	Failure in the gut sensor	105	3%
MK9	Cutter adjustments	85	2%
MK9	Diffuser troubleshooting	73	2%
HCF	Electric failure HCF	62	1%
MK9	Sensor failure MK9	60	1%
MAXS	Glue system adjustment	52	1%
MK9	Security pin change	52	1%
MK9	Fan failure in the MK9	35	1%
MAXS	Failure in the main door in the MAXS	35	1%
MK9	Circumference adjustment calibration	25	1%
MK9	Ventilation problems MK9	20	0%
MAXS	High ventilation in the cigarette	11	0%
MK9	adjustment in the empty tip filling	10	0%
MK9	MK9 adjustments	10	0%
MK9	Jam in the cigarette hopper	8	0%
		<b>4192</b>	<b>100%</b>

Table 8. Machine breakdowns that cause cigarette wastage

The Pareto with the major causes of breakdown is shown below

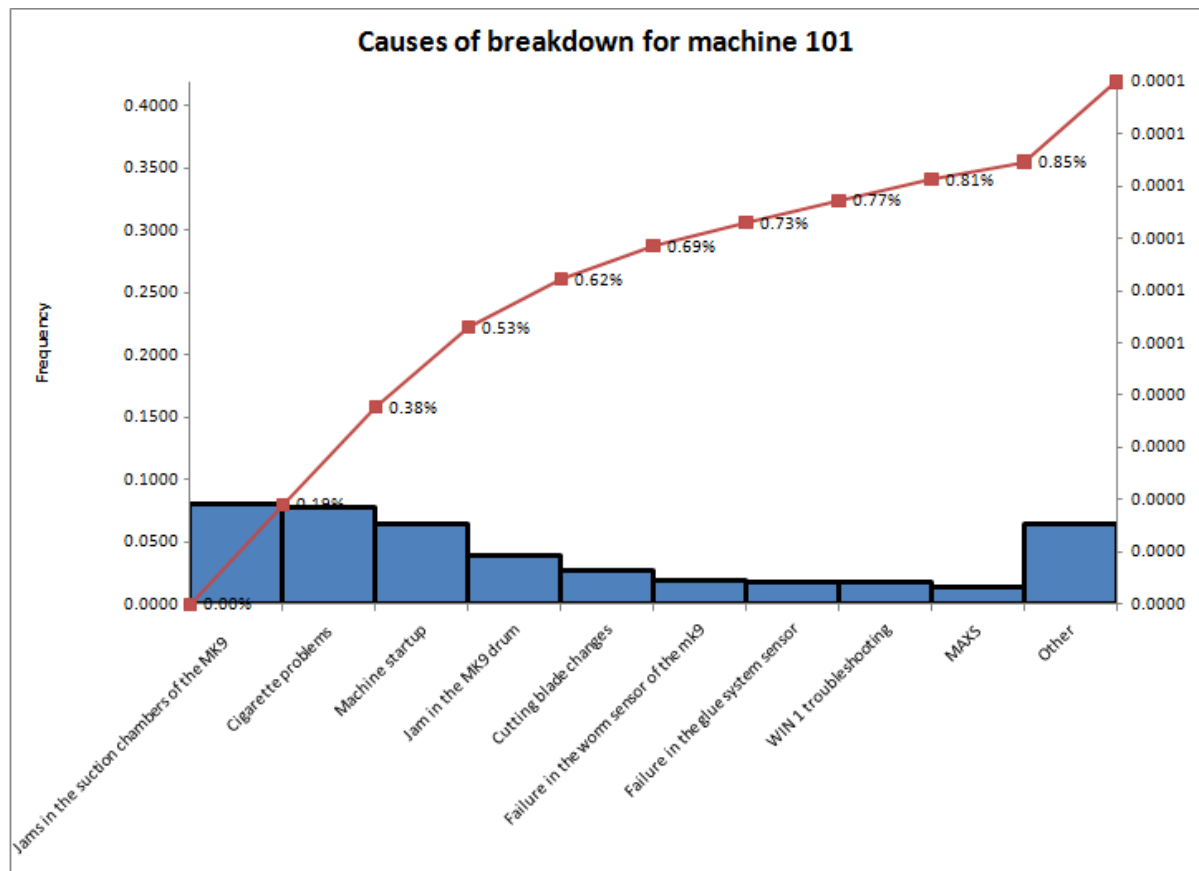


Figure 20. Pareto diagram for the major causes of machine breakdown

From the Pareto, we can see that the major causes of machine breakdown are due to Jams in the suction chambers of the MK9 machines and cigarette problems in the MAXS machine.

To summarize was that done in the Measurement phase of the project, the sigma level was calculated, this level tells us how the process is working and how many defects are being produced in a million parts, a value stream map was created to measure and analyze the process flow and for the team to know possible causes of the cigarette wastage. A process capability study was performed to check if the characteristics of the cigarette fall within the company's specifications for the cigarette production, this study showed that the machines are not capable of producing within specifications for the ventilation and circumference characteristics.

### 4.3.3 Analyze

The next phase of the DMAIC methodology is Analyze. In this phase, as stated before we want to identify excessive sources of variation, search for the factors that have the biggest impacts on process performance and determine the root cause of problems.

According to Pande (2004), there are three ways to analyze the roots cause of problems:

1. Exploring: Investigate data and the process with an open mind to see what can be learned from them.
2. Create hypothesis about the causes: Use new knowledge to identify the causes that produce more defects.
3. Verify or eliminated the causes: Use data or a more detailed analysis of the process to check which of the causes contribute the most to the problem.

Tools used to analyze the data gathered in the Measurement phase are:

	Data Analysis	Process Analysis
Explore	Examine in diferent ways, the data taken from the Measurement phase <b>Tools:</b> Pareto Graph Histograms	Create a process map which reflects what the actual process looks like. <b>Tools:</b> Basic Flowchart
Hypothesis Generation	Utilized everything learned to generate ideas about defects in the process. <b>Tools:</b> Brainstorming Ishikawa Diagram	Use flowcharts to identify areas in which phases of of the process are not clear <b>Tools:</b> Brainstorming
Cause verification	Gather additional data to check if hypothesis are true <b>Tools:</b> Dispersion diagram	Gather new data to cuantify the loss in time in some stages of the process <b>Tools:</b> Flowchart map Value stream mapping

Table 9. Tools for data analyzing

#### **4.3.3.1 Ishikawa Diagram**

One tool used in this phase is the Ishikawa diagram. All team members in the group did a brainstorming session to see which major causes contribute to the waste of cigarettes and these ideas were classified according to the 5M's presented in the Ishikawa diagram.

This diagram is an excellent tool for the group to think about possible causes of the problem, establishing different categories helps the group focus on several possibilities than just a few ones. It also helps to initialize the Analyze phase of the DMAIC methodology.

For the cigarette reject rate, most causes are presented in the Machine category; old machines force to carry out excessive work, lack of preventive maintenance, excessive adjustments and electrical failures. These were some of the causes mentioned by all team members. Also manpower causes were stated as some of the most important factors of waste in the Marlboro line.

The following is the Ishikawa diagram created by the Marlboro cell:

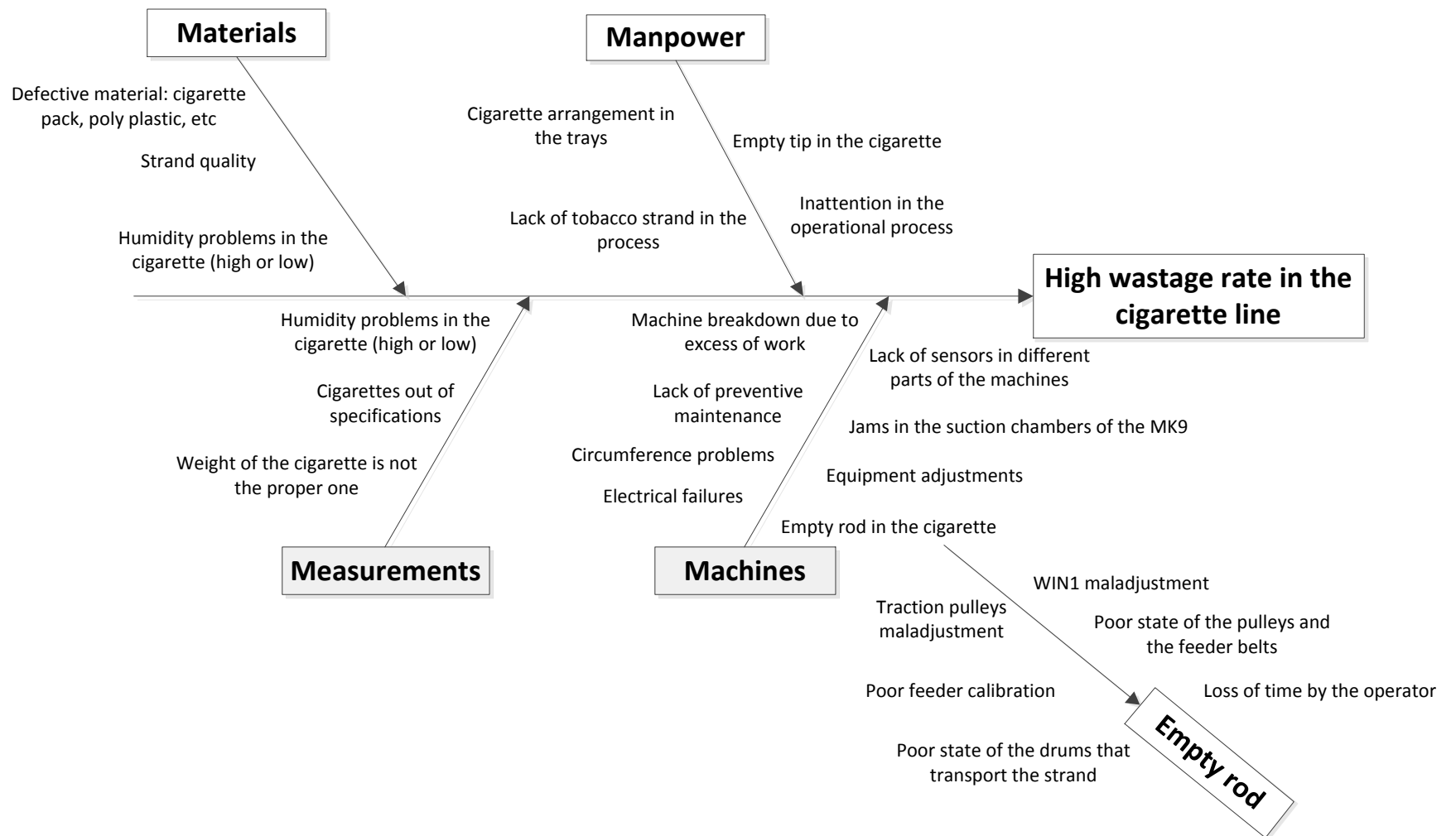


Figure 21. Ishikawa diagram for the cigarette reject rate

To help locate the process true causes, other problem solving tools are available. Some techniques are subjective tools more focused on opinion, and other tools are more analytical and are focus on data obtained in the project. Some of these tools are:

Subjective Tools	Analytical Tools
Ask why, and then ask why again...	Data collection and analysis
Brainstorming	Pareto analysis
Process flow analysis	Data matrix analysis
Plan-do-check-act	Process capability analysis
FMEA Failure Mode and Effect Analysis	Regression analysis
Six thinking hats	Regression analysis

Table 10. Tools for roots cause analysis, Pande (2004)

After doing the Ishikawa Diagram, we asked the technician experts which causes they thought created more cigarette wastage, from their point of view and years of experience. They said that the machines are the number one cause of cigarette rejects.

For the reduction of the cigarette reject rate we concentrated on the machine problems that are the ones stated with causing more cigarette wastage. The number one cause of waste is the empty tip in the cigarette. The causes for the empty tip were also developed in the Ishikawa diagram and an action plan will be developed to attack the empty tip problem.

As seen on the measure phase of the project, the ventilation and circumference problems in the machine will be addressed as one of the possible roots causes. We focused on the two major causes of machine stoppage that create waste; these are the jams in the suction chambers of the MK9 machine and the problems with the rolled cigarettes in the MAXS machine. The last major cause is the empty rod in the cigarette, which occurs when the machine produces the cigarette with a visibly loosed pack that can be squeezed easily.

#### 4.3.3.2 5 Why's tool for root cause analysis

An approach to root cause analysis is the 5 why's analysis. This tool is used when asking the major cause, five times the question why, to get to the bottom of the problem. This tool was

used in the project to connect the causes to the root cause and create an action plan that will be described in the Improve phase of the project. This technique is a Japanese method to determine the roots cause. It is possible to obtain the roots cause of the problem without asking 5 times why, so it is important for the team to be able to know when to stop asking this question.

The following tables shows how the 5W's tool was used to get to the roots cause of the major causes found in the Measure and Analyze phases of the methodology.

	CAUSES	WHY 1?	WHY 2?	WHY 3?	WHY 4?	WHY 5?	PROPOSED SOLUTION
<b>Machines</b>	Cigarette circumference	Because the cigarettes come out with circumference problems	Because the fine adjustment system is unbalanced	Because the operator does not closes the hinge properly	Because the spring from the system is expired	Because the maintenance routines are not changed	Create a specific maintenance plan for the adjustment of the circumference in the machine
	Empty rod in the cigarette	Because the cigarette comes out with an empty tip	Because the tip time is lost	Because the springs and metal tape are stretched	Because the traction pulleys jam with tobacco	Because of the humidity and other components like the casing that cause jams in the pulleys	Make a routine for the adjustment of the pulleys, make a return trial weekly, make an analysis for the humidity of the strand
	Jams in the suction chambers	Because the humidity of the strand is not the correct one	Because the humidity of the strand is not analyzed in the strand room	Because there's no humidity control in the strand room	-----	-----	Improve the humidity control in the strand room, so the strand that passes go to production has the correct humidity
	Rolled cigarette problems	Because cigarettes come out not properly rolled	Because the cutters are not sharp enough or are not adjusted correctly	Because when the machines stops after a shift is not disengage	Because the operator forgets to disengage the machine	Because of the lack of training	Give a training to the operators regarding starting up and shutting down the machines

Table 11. 5 Why's tool for roots cause analysis



To summarize what was done in the Analyze phase, an Ishikawa diagram with the major causes of cigarette reject was created with the team. The major causes for cigarette rejection were the circumference problems in the cigarette, the empty tip and jams in the suction chamber of the MK9. A tool for root cause analysis called 5 why's was used to get to the root cause of the problem and create an action plan on how to address these issues. This action plan will be implemented during the Improve phase of the project to attack the main causes stated in the Measure and Analyze phases.

#### **4.3.4 Improve**

Once the Analyze phase of the project is finished, it is time for the team to discuss the best improvement ideas for the root causes that affect the process.

In the improvement phase, it is important for the team to remember the following (Pande, 2004):

- The implementations selected by the team should be addressed to attack the root cause of the problem and achieve the goal proposed in the project charter
- The selected solutions should be tested to guarantee their effectiveness before they are completely implemented
- Solutions should not be expensive or go over the department's budget, the cost should not surpass the benefits

For the improvements the help of the technicians from the Marlboro cell was important; their expertise helped the team decide on the best options for improvement and to attack the problems as fast as possible.

It is important to plan the time line for the implementations, determine the roles and responsibilities for everyone in the team so the proper implementations are done successfully. The first thing we did in this phase was create an action plan for the proposed implementations. A tool called 5 Ws and 1H was used to create the action plan. This tool answers various questions that are needed during this phase. What, how, who, when, where and why, are answered by the team to know the specific date, assign people and actions that will be taken to address the problem.

The chart below shows the action plan and the specific steps that will be followed to make the improvements.

#### 4.3.4.1 5 Ws and 1 H

<b>What</b>	<b>How</b>	<b>Who</b>	<b>When</b>	<b>Where</b>	<b>Why</b>
<b>Action to be taken</b>	<b>Specific steps</b>	<b>Responsible</b>	<b>Initial and final dates</b>	<b>Specific location</b>	<b>Justification for implementation</b>
Create a specific maintenance plan for the adjustment of the circumference in the machine	Arrange a meeting with technicians Create maintenance plan for the specific parts of the circumference Upload routine to the Maintenance system	Carlos Pereira Esteban Berty	See Gantt Chart	MK9 Machine	There is no maintenance plan to control the variation in the circumference of the cigarette
Make a routine for the adjustment of the pulleys	Set a meeting with technicians Create maintenance plan for the traction pulleys Upload routine to the Maintenance system	Marlboro Cell Technicians	See Gantt Chart	MK9 Machine	There is no routine to prevent jams in the pulleys that cause the empty rod in the cigarette
Improve the humidity control in the strand room, so the strand that passes to production has the correct humidity	Meeting with production manager to let him know the changes that need to be done in the strand room Fix chiller and set proper temperature	Marlboro Cell Technicians	See Gantt Chart	Secondary process workshop	There is no real control for the humidity in the strand room, controlling the humidity will improve the quality of the strand and will help improve the cigarette quality
Train the operators regarding starting up and shutting down the machines	Set meeting with operators Have the cell technician give a training regarding the machines	Carlos Pereira	See Gantt Chart	Production Area	The operator does not have the knowledge of what to do before turning on the machine or when shutting it down
Make a weekly return trial for the Strand humidity analysis	Create maintenance plan for the return trial Make trial every week and keep results in the Maintenance system	Jeffrey Coto	See Gantt Chart	MK9 Machine	The return trial helps prevent empty rod in the production of cigarettes

Table 12. 5W and 1H Action plan

#### 4.3.4.1.1 Gantt chart for proposed improvements

Once the action plan was created, a Gantt chart was made to specify the specific dates in which the actions will take place.

Activity	Status	June				July				August			
Week		1	2	3	4	1	2	3	4	1	2	3	4
Create a specific maintenance plan for the adjustment of the circumference in the machine	P												
	R												
Make a routine for the adjustment of the pulleys	P												
	R												
Strand room humidity control	P												
	R												
Train the operators regarding machine start up and shot down	P												
	R												
Set up a weekly return trial for the strand humidity analysis	P												
	R												
P	Proposed date												
R	Real Date												

Figure 22. Gantt chart for the selected implementations

#### 4.3.4.1.2 Improvements

Once the Gantt chart was developed, each improvement was done according to the schedule. The first implementation was created in the last week of June and at the beginning of July. A specific maintenance plan was created for the circumference of the cigarette. A check list was created with each part that the technician has to give maintenance to. Every week the production supervisor is in charge of checking that the technicians are using the checklist and that proper maintenance is giving to this part of the machine. If a part has to be change or calibrated it, is the technician's responsibility to mark it on the checklist. These actions are done to try to produce as close to specifications to prevent many cigarettes from being rejected in the process. To see the created checklist go to the appendix on page 60.

To know if the maintenance of the circumference in the machine was having the desired effect we compared run charts before and after the improvement. New data was taken and compared with the old data and it showed that variation in the cigarette circumference had decreased and was more stable. This helped reduce the amount of cigarettes the machine was throwing away due to circumference problems.

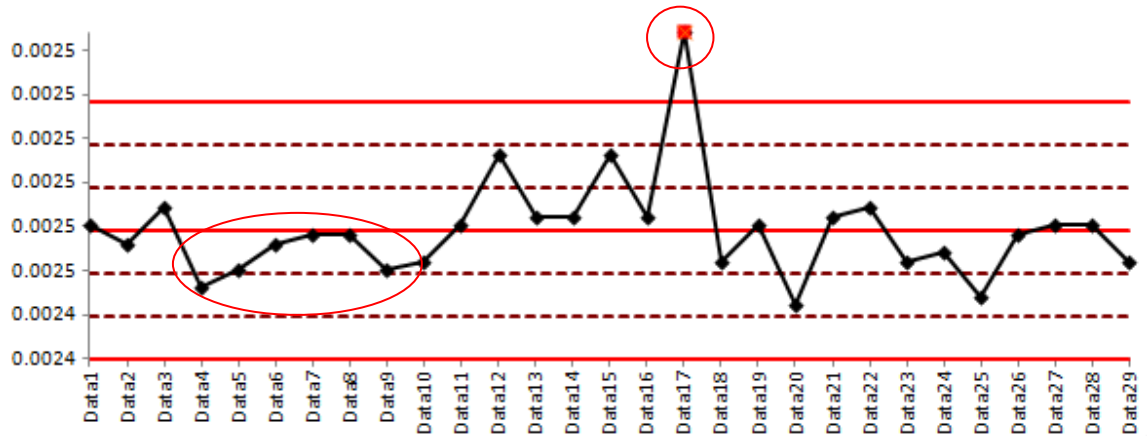


Figure 23. Circumference before improvements

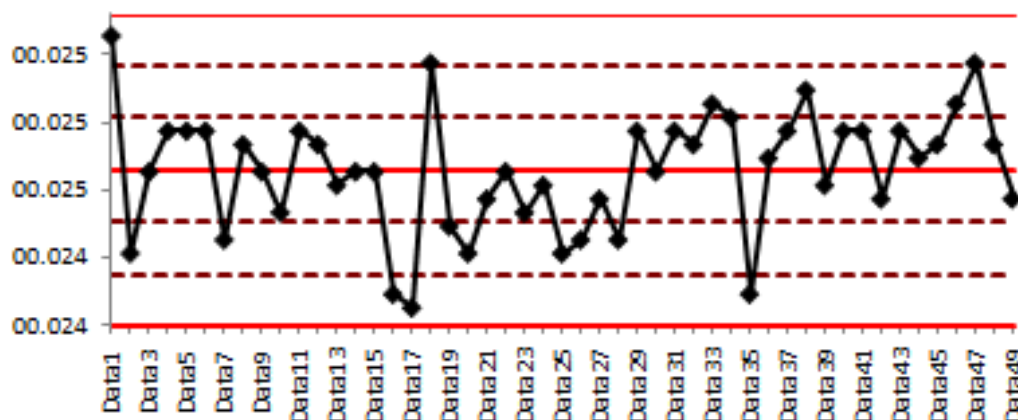


Figure 24. Circumference after improvements

A second checklist was created but this time for the adjustment of the pulleys. Empty rod in the cigarette occurs when the traction pulleys jam with tobacco. There is not a specific maintenance checklist for this problem. With the proper maintenance, it is possible to achieve the goal of reducing waste in this part of the machine. Both checklists were designed with the help of the Marlboro cell technician Carlos Pereira. The creation of the checklists is an action to improve the maintenance given to these parts of the machine, which had no maintenance at all and were causing lots of cigarette waste. The third improvement done

had to do with the jams in the suction chambers of the MK9 machine. These jams occur because the fan propellers that helped with the suction process of the tobacco do not work correctly. The main reason discussed with the team is that they don't work because the strand coming into the process has a different humidity from the one needed for the propellers to work correctly. There is no real control of the humidity of the strand coming into the process; the strand needs to have a specific humidity for the machine to produce cigarettes with fewer defects as possible. The humidity of the strand has to be between the ranges of 12.8% and 13.5%. At the moment of running the humidity test the strand had a humidity of 14.7% and this will have an impact when the strand passes to the production process. To attack this problem, the chiller in the control room was fixed and helped to keep the humidity controlled. This also helped to keep the strand in the appropriate ranges. By attacking this problem this will also have an impact on the circumference and empty rods in the cigarette; since a strand with a better quality will be used.

Another implementation or corrective action that was done was to train the operators to consider the importance of disengaging the machine so the cutters that connect the MK9 machine to the MAXS machine do not disarrange. This has to be done each time the shift is over, because the machine has to run by itself to get rid of the tobacco strand, if the machines are not disengage, the cutters will still run causing them to hit the metal drums above them and disarranging them. If the cutters are disarranged, they will not cut the cigarettes as expected and this is one of the biggest causes of cigarette rejection. The use of visual aids helped us remind the operators to disengage the machines every day; a sticker reminding the operator to disengage the machine was pasted on every machine to help promote a culture of disengagement. The picture below shows the visual aid used for this purpose



Figure 25. Visual aid to remind operators to disengage the machine

The last improvement done on the MK9 machine was making a return trial weekly. A return trial is a test done to the machine to see how many tobacco strand is returned to the process. A normal machine operates between 25%-30% of tobacco return, if the machine is higher than that range; problems with the empty rod begin to occur. Good maintenance practices are also needed to make this trial every week and keep the machine in the proper ranges. A document was created to keep track of the return trials. To measure if this improvement was working as expected a comparison was made between weeks. One week the return trial was not made and the other week it was made. During the week the trial was not done, the machine produced cigarettes with an empty rod 4 times in that week. With the return trial, the machine produced empty rod cigarettes just one time during the week.

Day	Machine without return trial	Machine with return trial
Monday	Produced cigarettes with empty rod	
Tuesday		
Wednesday	Produced cigarettes with empty rod	Produced cigarettes with empty rod
Thursday	Produced cigarettes with empty rod	
Friday	Produced cigarettes with empty rod	

Table 13. Measure for the return trial for the MK9 machine

Once all improvements were implemented, the next thing was to take new measurements to check these implementations and determine if our goal of reducing the cigarette reject rate at 1% was achieved. The improvements were done in the last week of June and through the month of July.

#### **4.3.4.1.3 Results after improvements**

With the creation of both checklists, proper maintenance was given to these parts of the machine. Machine stoppage decreased during the month that the measures for results were taken. The following Pareto shows how these two causes that used to be the ones that most affected the cigarette wastage the most have decreased. Weekly maintenance of these parts is now regularly done; this will be beneficial since other causes can now be attacked to help prevent waste.

Machine	Cause of breakdown	Minutes	Percentage
Machine	Machine startup	622	19%
MK9	Jam in the MK9 drums	612	19%
MK9	Cutting blade changes	522	16%
MAXS	Failure in the worm sensor of the MK9	432	13%
MK9	Jams in the suction chambers of the MK9	268	8%
MK9	Cigarette problems (rolled, flags)	187	6%
MAXS	Failure in the glue system sensor	176	5%
MK9	WIN 1 troubleshooting	170	5%
MAXS	MAXS	140	4%
MK9	Failure in the gut sensor	105	3%

Table 14. Machine breakdowns

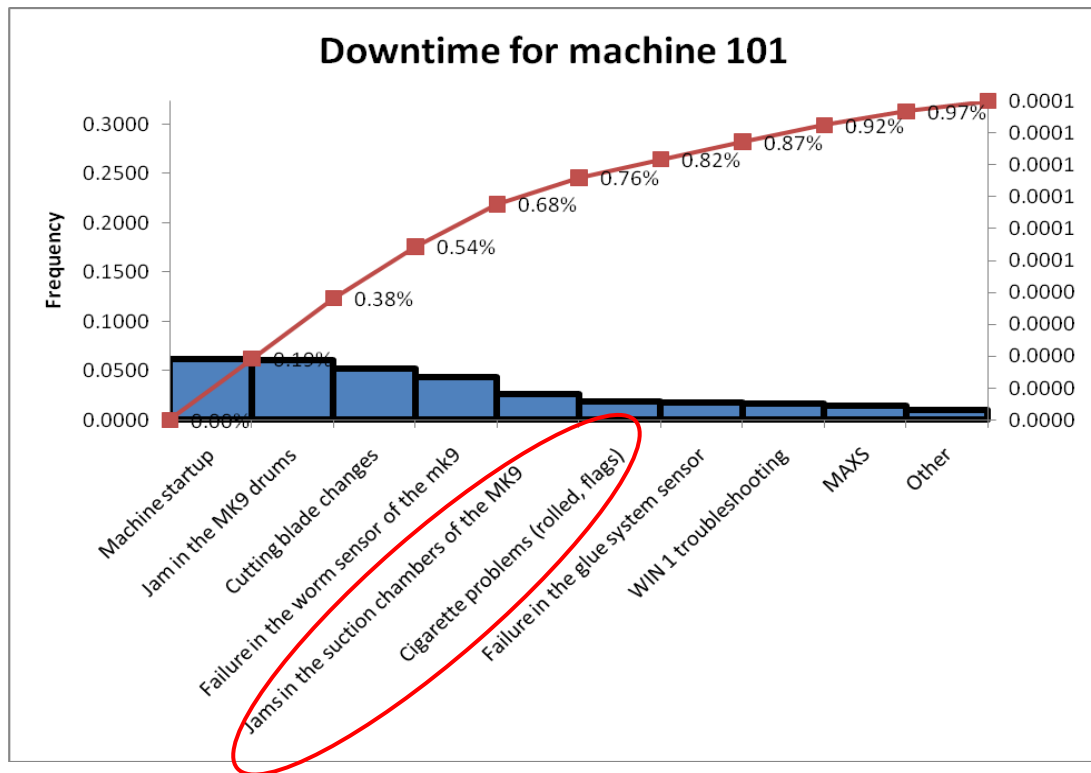


Figure 26. Pareto diagram after improvements

The Uptime was also improved after the implementations done. Improving the humidity of the strand and keeping proper maintenance of the parts helped prevent machine breakdowns from occurring. The graph on the next page shows an improvement in the KPI during the months of June and July.

Month	Uptime %	Target %
January	49,1%	60%
February	52,6%	60%
April	53,4%	60%
May	51,2%	60%
June	54,8%	60%
July	55,1%	60%

Table 15. Uptime Improvement

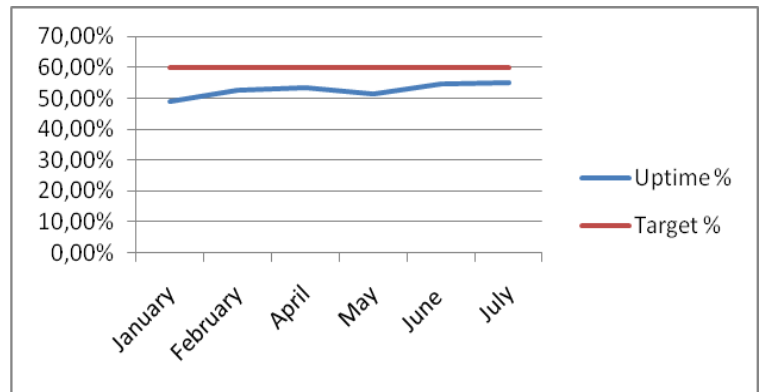


Figure 27. Uptime improvement graph

Another KPI impacted by the improvements was the Tobacco Yield, since the improvements are helping reduce the cigarette wastage, the Yield for the process has improve in the last month.

Month	Yield
January	93,18%
February	93,07%
March	92,64%
April	91,38%
May	92,42%
June	93,36%
July	95,7%

Table 16. Tobacco Yield

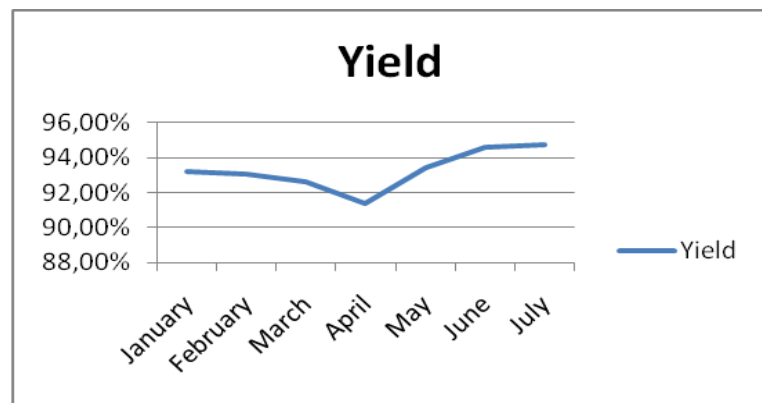


Figure 28. Tobacco Yield Improvement graph

The last and most important KPI for this project is the CRR KPI, it was very rewarding for the team to know that after improvements, results were starting to show. The objective of the project was not completely achieved, but with control and continuos work it can be achieved in the next month. We were able to reduce waste in 0,7% for the month of July.

Month	Reject Rate	Target
February	4,9	2,8
April	4,8	2,8
May	5	2,8
June	4,6	2,8
July	4,1	2,8

Table 17. CRR Improvements table

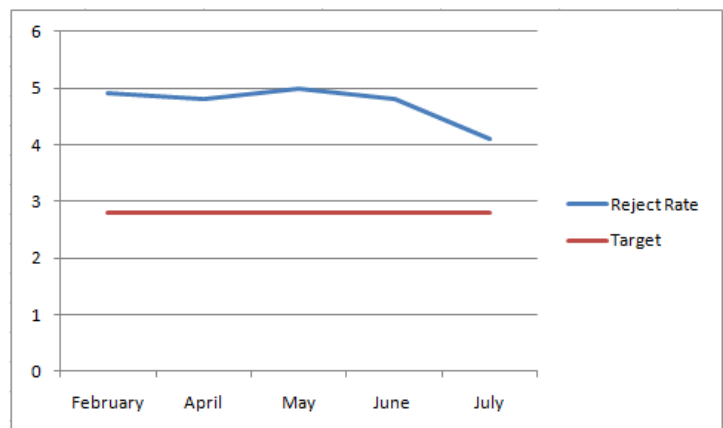


Figure 29. CRR Improvements graph



#### **4.3.5 Control**

The last phase of the DMAIC methodology is control. Once we have done improvements in the process and we know they are working, it is time to set controls so everything achieved in the other phases is not lost through time.

It is very common to see projects that may take months to do, but after the project is finished and a process improved, no monitoring is given and the process goes back to where it was. It is important to give track to the implementations, specially during the first months so we can get an idea if these improvements are working.

According to Pande (2004), the objective of the Control phase is to continue measuring the yield of the process in a continuous way, adjusting the operation when data indicates to do so or customer requirements need to be changed.

The Control phase is divided in four steps:

- Discipline
- Document improvements
- Metric registration: establish metrics for the process
- Advance to the next phase: design a process management plan

##### **4.3.5.1 Visual Factory**

At Philip Morris International the philosophy of a visual factory is very important. We took advantage of this to display what was done with the project and to show the progress the project was having and if the solutions were being effective.

Basically, a visual factory system is used to display schedule boards, production boards, tool boards and many other devices in the production floor. The idea of this is to provide management and workers an idea of what is happening in the plant.

Some reasons for using visual management tools are:

- Helps make problems visible to everyone
- Workers stay in direct contact with the floor

- Clarifies targets for improvement

Every progress done with the project will be shown in the production boards, this will help keep workers informed about the project and what is being done to reduce the cigarette reject rate. Figures 27, 28, 29. show an example of the production boards used to control and inform about projects.



Figure 30. Visual Factory example



Figure 31. Visual Factory example



Figure 32. Visual Factory example

## 5. Summary and Conclusion

This project was intended to support Philip Morris International in their quest of trying to reduce cigarette wastage for all their production lines. This has been a challenge for the company since many variables that cause waste affect the process.

For the realization of the project, a Lean Six Sigma approach was implemented. The use of the DMAIC methodology for the different phases of the project helped eliminate some causes of waste in the process.

Defining the project and what was intended with it was the first step done. The creation of the project charter helped the team know where to focus in the process. Putting together a cross functional team for the project was important to get different ideas and opinions on how to resolve the stated issue. Measuring the data helped the team to focus on the biggest causes of waste and try to reduce them. Calculations such as the sigma level, process capability study and machine breakdown, helped the team understand which causes were more critical to the process. Analyzing these results was important for the team to get an idea on the possible root cause of the problems, the action plan to attack the causes was created in this phase. In the Improvement phase, the best solutions proposed were selected and implemented. New measurements were taken to check if the improvements were having an impact on the process. The Control phase of the project was set to monitor that the improvements made were continuous through time.

It was satisfactory for the team to know that the improvements done were having an impact on the performance indicators, although the goal was not completely reached by the end of this thesis, with time and patience that goal can be reached. For this, the control phase of the project is important, this phase will help the team follow actions and keep the project on track until the end.

Even though this was a small project with a small impact on the company's finances, we can give proof that Lean Six Sigma is really a tool that can be used to obtain positive results in process improvements. If we apply the methodology through all the production lines, it would be very beneficial for the company as they would save a lot of money in resources. In the case of Philip Morris, I believe it is important to create a process improvement

department that can carry out different continuous improvement projects that will help them improve process performance and offer the customer a better quality product.

Several objectives conquered with the realization of the project were

- The objective of the project was almost achieved, thanks to the planned use of the DMAIC methodology.
- The statistical validation of data helped the team focused on the major causes of waste to get to the root cause of the problems.
- It helped create an organizational change on continuous improvement projects, as more projects like this one will be carried out in the future.

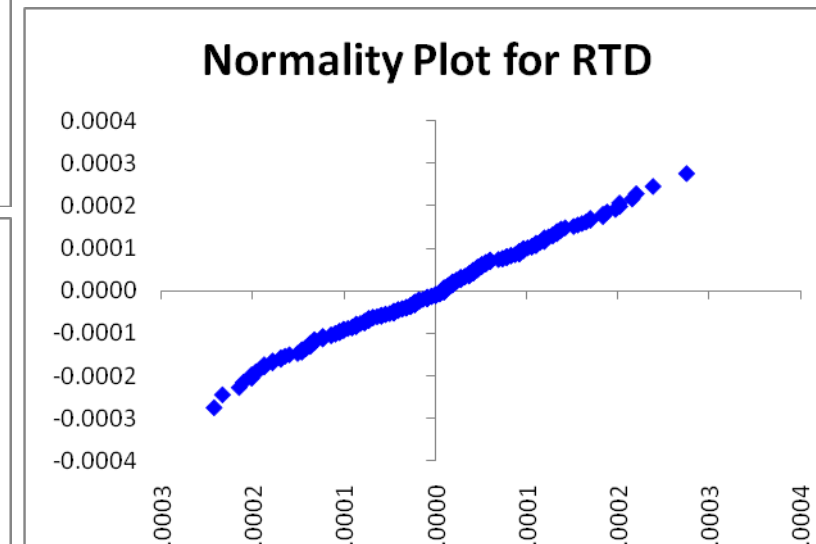
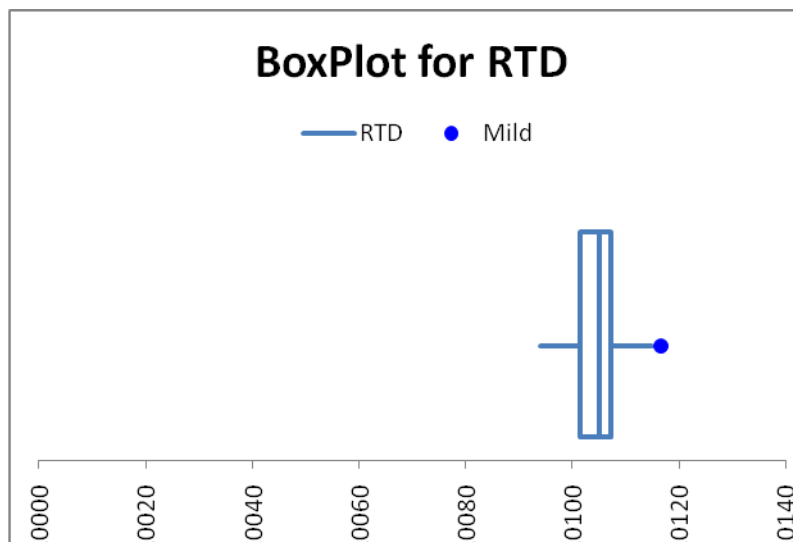
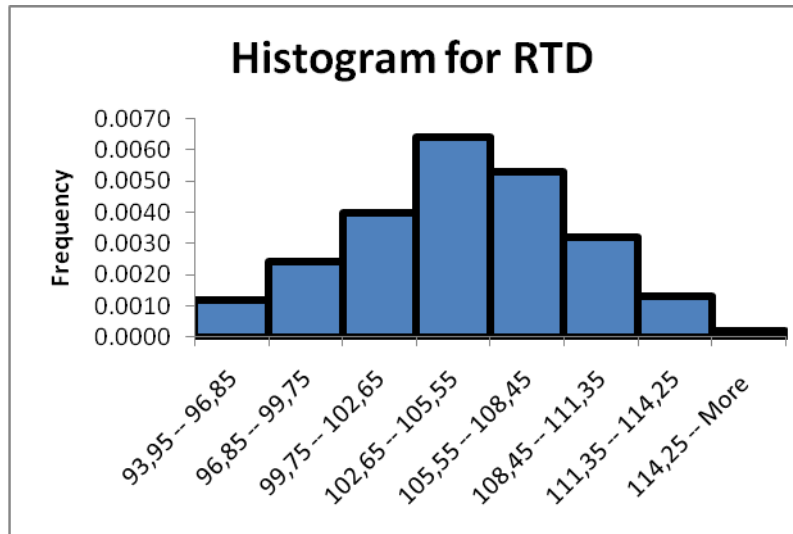
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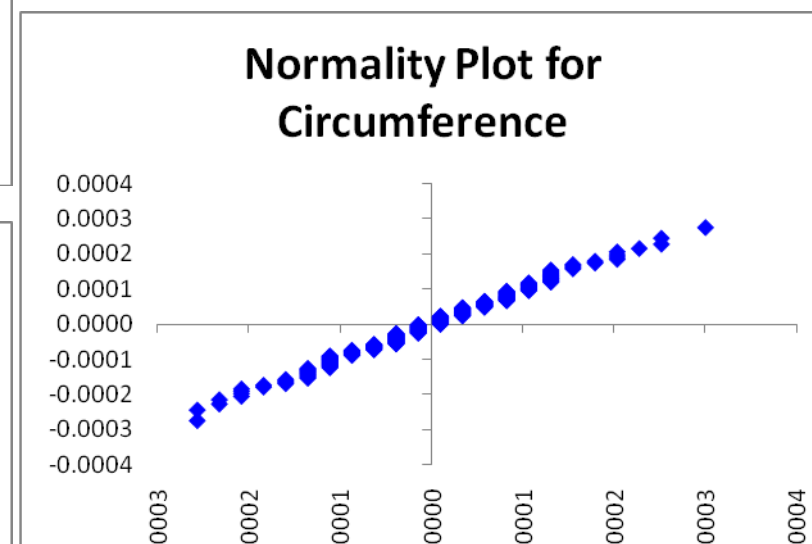
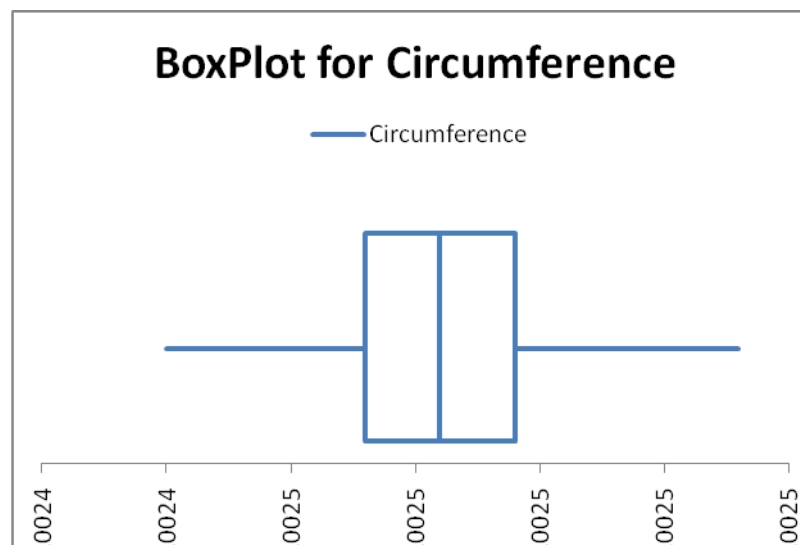
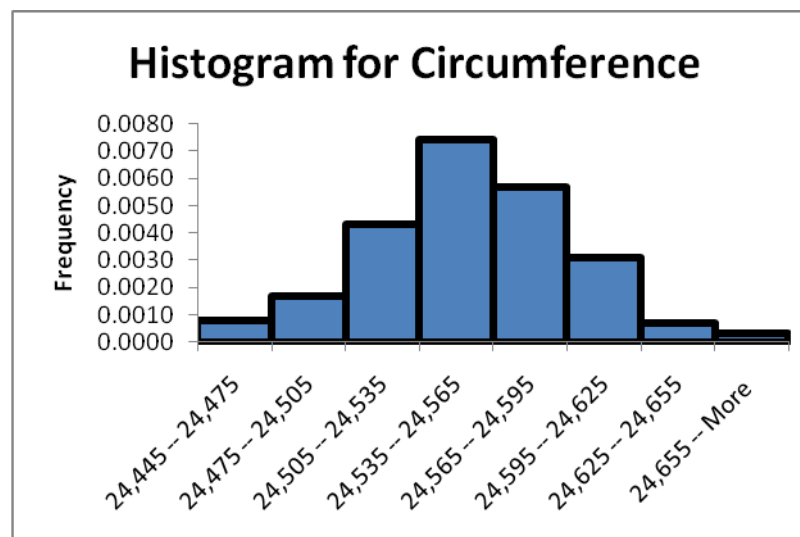
## Normality Analysis for RTD Characteristic

Basic Statistics for RTD	
Anderson Darling Test	
AD Statistic	0,5177
AD Critical Value	0,7496
AD p-Value	0,1870
Mean	104,5717
Standard Deviation	4,3656
Variance	19,0583
Kurtosis	-0,2481
Skewness	-0,0361
n	240,0000
SE Mean	0,2818
Mode	105,0000
Minimum	94,0000
First Quartile	101,4000
Median	105,0000
Third Quartile	107,1500
Maximum	116,6000
95% Confidence Intervals	
For Mean	104,0165
	105,1268
For Median	104,4000
	105,4000
For Standard Deviation	4,0068
	4,7954



# Normality Study for the Circumference Characteristic

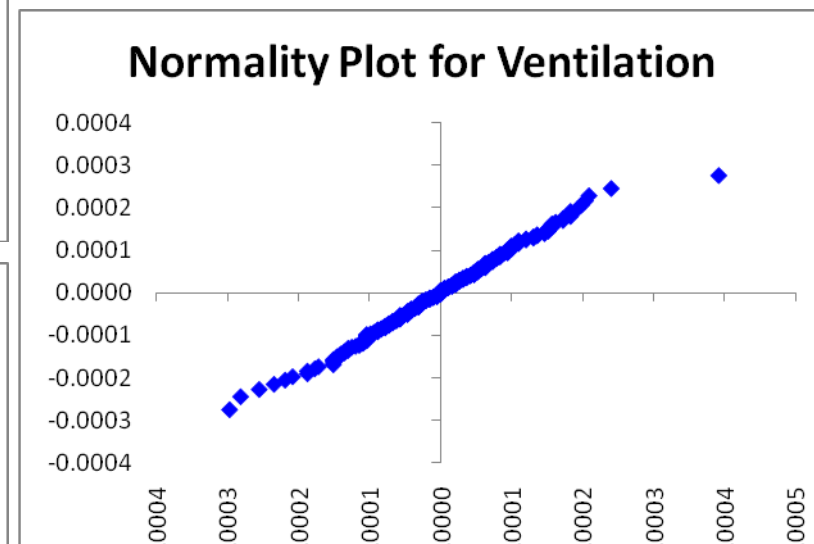
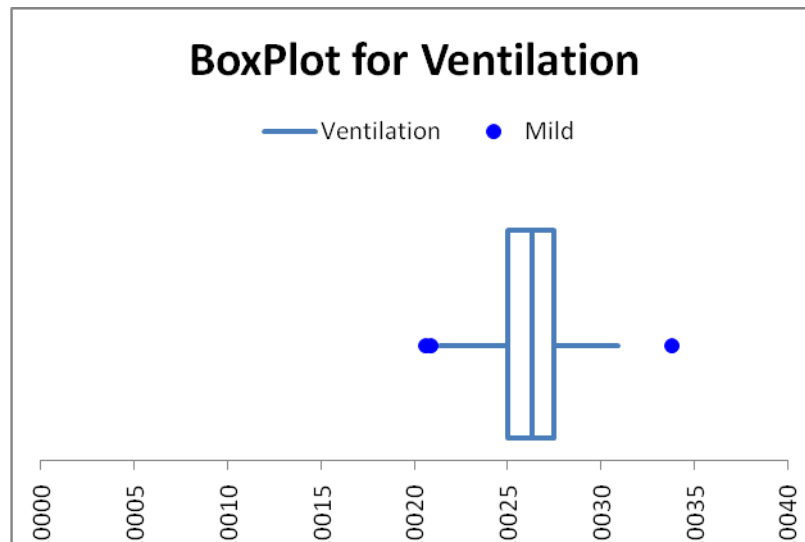
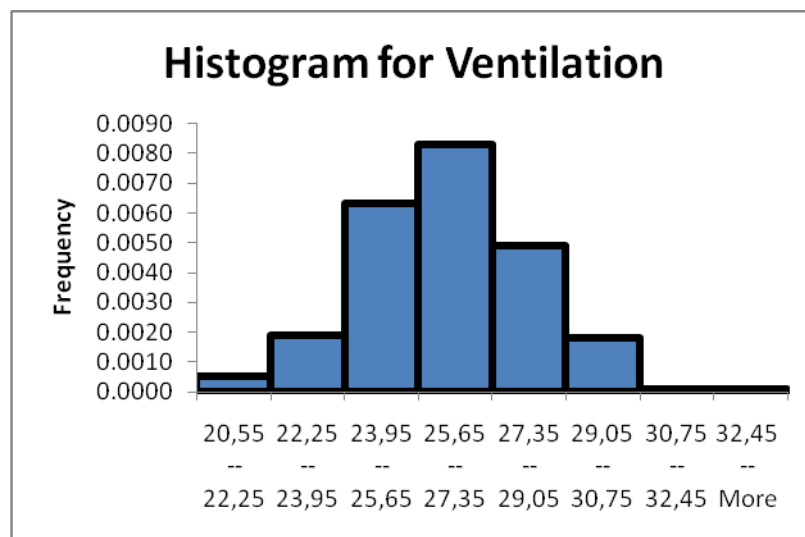
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Anderson Darling Test	
AD Statistic	0,7760
AD Critical Value	0,7496
AD p-Value	0,0433
Mean	24,5559
Standard Deviation	0,0414
Variance	0,0017
Kurtosis	0,0097
Skewness	0,0224
n	240,0000
SE Mean	0,0027
Mode	24,5400
Minimum	24,4500
First Quartile	24,5300
Median	24,5600
Third Quartile	24,5900
Maximum	24,6800
95% Confidence Intervals	
For Mean	24,5506
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For Median	24,5500
	24,5600
For Standard Deviation	0,0380
	0,0454





# Normality Study for the Ventilation Characteristic

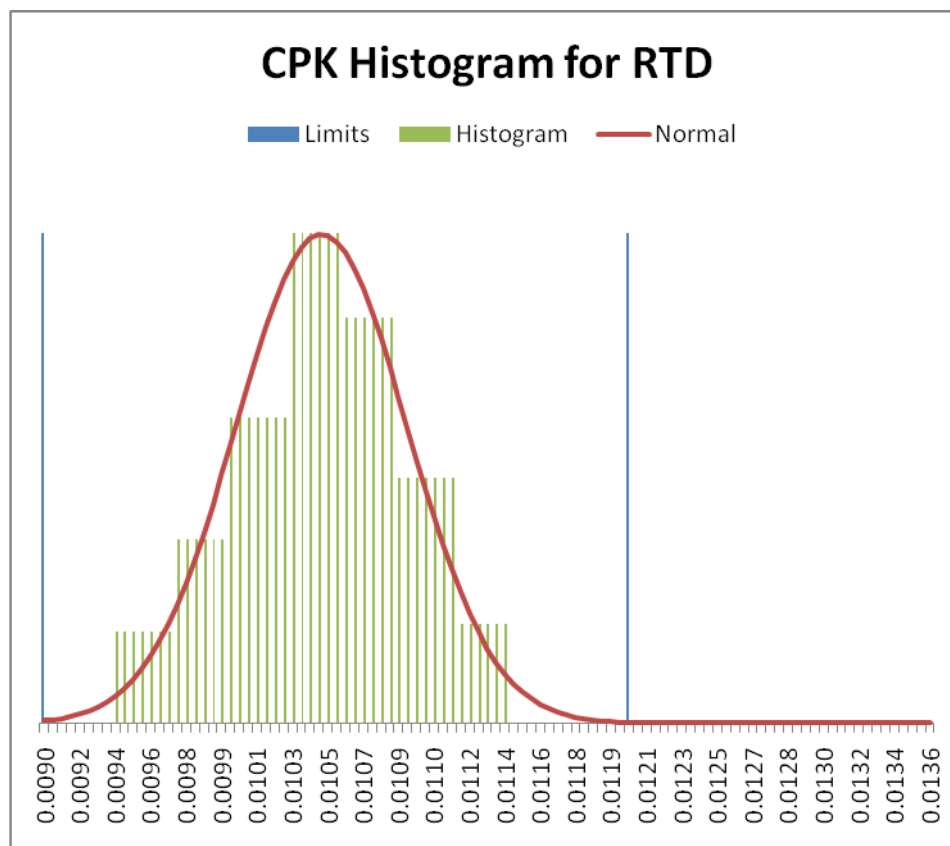
Basic Statistics for Ventilation	
Anderson Darling Test	
AD Statistic	0,2000
AD Critical Value	0,7496
AD p-Value	0,8830
Mean	26,2925
Standard Deviation	1,9159
Variance	3,6705
Kurtosis	0,6906
Skewness	0,0687
n	239,0000
SE Mean	0,1239
Mode	26,3000
Minimum	20,6000
First Quartile	25,0000
Median	26,3000
Third Quartile	27,5000
Maximum	33,8000
95% Confidence Intervals	
For Mean	26,0483
	26,5366
For Median	26,0000
	26,5000
For Standard Deviation	1,7581
	2,1049



# Capability Study for the RTD Characteristic

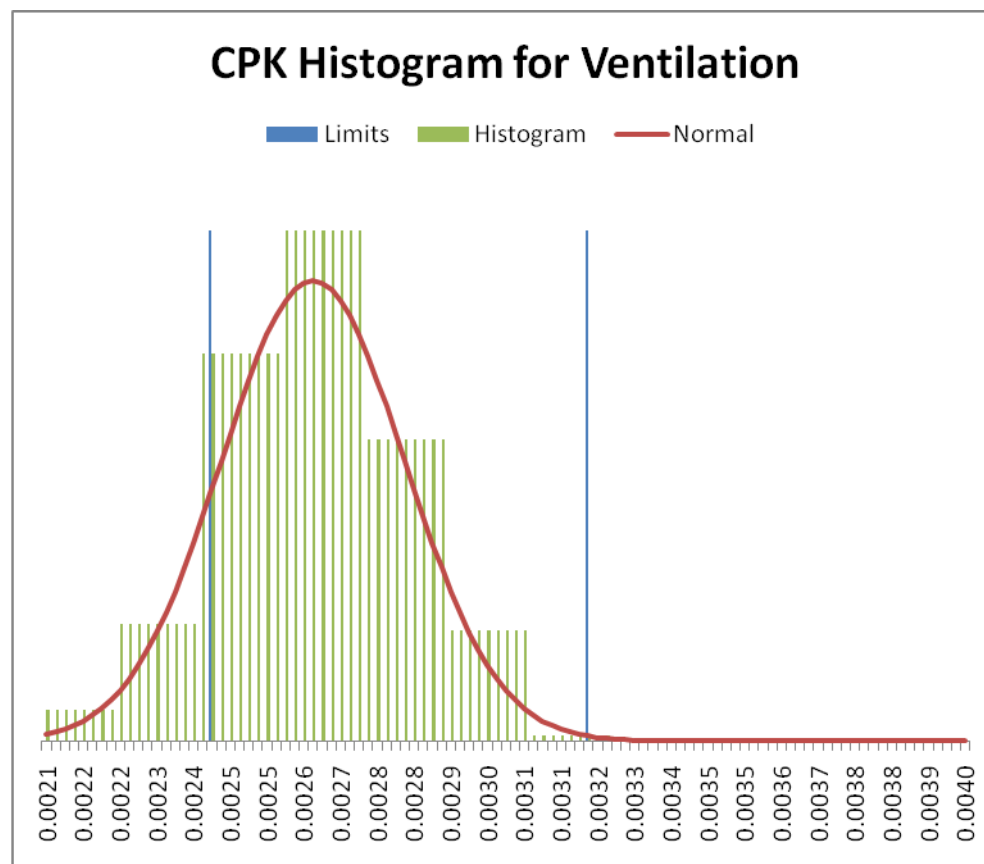
Capability Analysis for RTD	
Number of Classes	8,0000
Max	116,6000
Min	94,0000
RBar	3,4402
Mean	104,5717
StDev	4,3656
Skewness	-0,0361
Upper Spec Limit	120,0000
Lower Spec Limit	90,0000
Ppl	1,1126
PpU	1,1780
Pp	1,1453
Ppk	1,1126
Cpl	1,5926
Cpu	1,6863
Cp	1,6395
Cpk	1,5926
Upper 3s limit	117,6684
Lower 3s limit	91,4749
Observed Performance	
Upper % out	0,00%
Lower % out	0,00%
Total % out	0,00%
Exp Within Performance	
Est Upper ppm out	0,2109
Est Lower ppm out	0,8856
Est Total ppm out	1,0965
Exp Overall Performance	
Est Upper ppm out	204,5932
Est Lower ppm out	422,1391

## Appendix 2



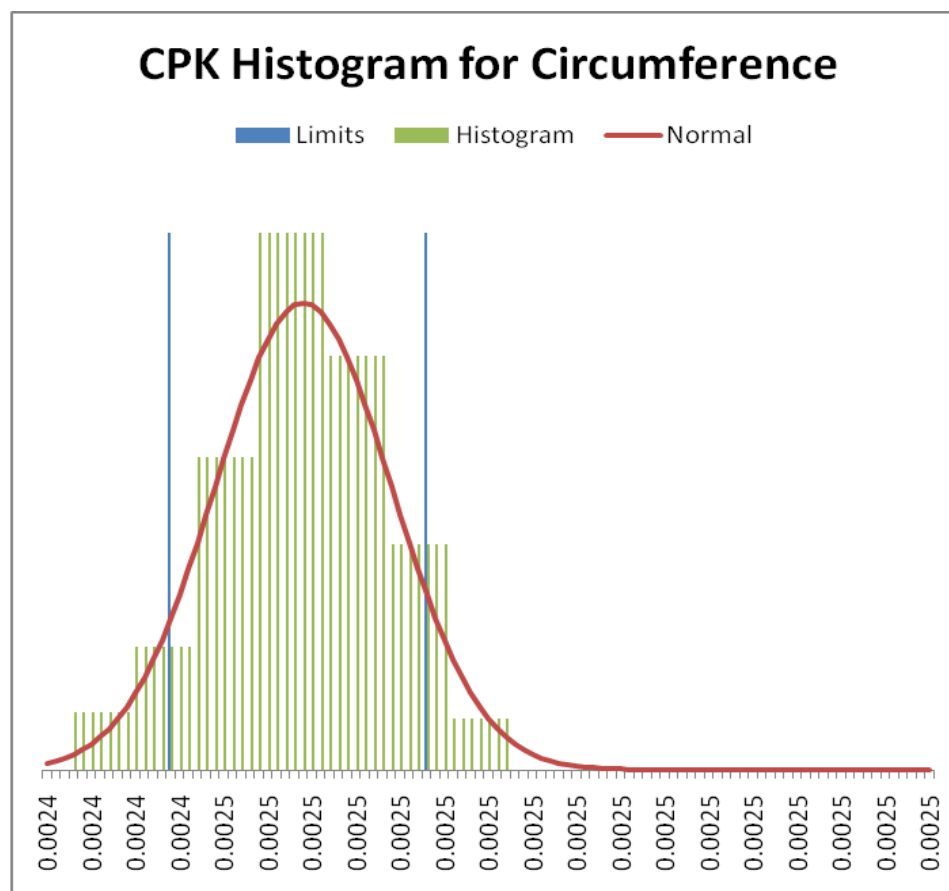
# Capability Study for the Ventilation Characteristic

Capability Analysis for Ventilation	
Number of Classes	8,0000
Max	33,8000
Min	20,6000
RBar	1,5828
Mean	26,2925
StDev	1,9159
Skewness	0,0687
Upper Spec Limit	32,0000
Lower Spec Limit	24,0000
Ppl	0,3989
PpU	0,9930
Pp	0,6959
Ppk	0,3989
Cpl	0,5446
Cpu	1,3559
Cp	0,9502
Cpk	0,5446
Upper 3s limit	32,0401
Lower 3s limit	20,5449
Observed Performance	
Upper % out	0,42%
Lower % out	10,04%
Total % out	10,46%
Exp Within Performance	
Est Upper ppm out	23,7494
Est Lower ppm out	51152,4237
Est Total ppm out	51176,1731
Exp Overall Performance	



# Capability Study for the Circumference Characteristic

Capability Analysis for Circumference	
Number of Classes	8,0000
Max	24,6800
Min	24,4500
RBar	0,0411
Mean	24,5559
StDev	0,0414
Skewness	0,0224
Upper Spec Limit	24,6100
Lower Spec Limit	24,4900
Ppl	0,5309
PpU	0,4362
Pp	0,4836
Ppk	0,4362
Cpl	0,6022
Cpu	0,4948
Cp	0,5485
Cpk	0,4948
Upper 3s limit	24,6800
Lower 3s limit	24,4318
Observed Performance	
Upper % out	5,83%
Lower % out	4,17%
Total % out	10,00%
Exp Within Performance	
Est Upper ppm out	68851,2151
Est Lower ppm out	35408,4064
Est Total ppm out	104259,6215
Exp Overall Performance	


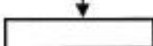
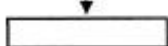
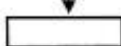




### Checklist created for the maintenance of the circumference

61

## Appendix 4

Return trial document to reduce empty rods in the MK9 machine

	<b>Documento del Sistema de Calidad</b> <b>Tabacalera Costarricense S.A.</b> <b>Prueba de retorno MK9</b>		Efectivo desde: 24/02/2009
	Documento No.T0117-S32	Tipo de documento: Registro	Versión 1.0
<b>PRUEBA DE RETORNO</b>			
Elaboradora <span style="border: 1px solid black; padding: 0 20px;"> </span> (O)perador <span style="border: 1px solid black; padding: 0 20px;"> </span> (A)sistente <span style="border: 1px solid black; padding: 0 20px;"> </span> (T)écnico <span style="border: 1px solid black; padding: 0 20px;"> </span>			
PASO		RESPONSABLE	
1.	Permita que la elaboradora produzca al menos por 20 minutos de forma regular.	O / T	
2.	Tome de la especificación de cigarrillos colocada en la elaboradora el peso de NTM's (en mg)	A	
3.	Pese una bolsa limpia (en kilogramos)	A	
4.	Tome el peso de 100 cigarrillos tomados de la banda con la elaboradora produciendo de forma continua (en g).	O o T	
5.	Inmediatamente, coloque un cartón sobre el flujo de tabaco que se encuentra en la parte posterior de la máquina elaboradora y retire todo el tabaco con una aspiradora limpia durante 1 minuto.	O y A	
6.	Retire el tabaco de la aspiradora, deposítelo en la bolsa y péselo (en kilogramos)	O y A	
7.	Anote la velocidad de máquina en cigarrillos por minuto y calcule el porcentaje de retorno con las fórmulas dadas.	O o T o A	
<b>Peso de tabaco atrás:</b>			
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">             6. Peso bolsa con tabaco   </div> <div style="text-align: center;">             3. Peso de la bolsa limpia   </div> </div> $  \begin{array}{ccccccc}  \boxed{\phantom{000}} & - & \boxed{\phantom{000}} & = & \boxed{\phantom{000}} & \times 1000 & = & \boxed{\phantom{000}} \\  & & & & & & & \downarrow \\  & & & & \boxed{\phantom{000}} & & & \swarrow \text{ } \searrow \\  & & & & & & & \boxed{\phantom{000}} \times 100 = \boxed{\phantom{000}} \\  & & & & \boxed{\phantom{000}} + \boxed{\phantom{000}} & & & \downarrow \\  & & & & & & & \boxed{\phantom{000}} \text{ \% Retorno}  \end{array}  $			
<b>Peso de tabaco adelante:</b>			
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">             4. Peso de 100 cigs                100           </div> <div style="text-align: center;">             2. Peso de NTM's                1000           </div> </div> $  \boxed{\phantom{000}} - \boxed{\phantom{000}} = \boxed{\phantom{000}} \times \boxed{\phantom{000}} = \boxed{\phantom{000}}  $ <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;">             7. Velocidad de elaboradora   </div> </div>			
El porcentaje de retorno recomendado para cada una de las elaboradoras es el mostrado:			
Elaboradora	%	Si el porcentaje de retorno no es el recomendado, se debe ajustar el mismo hasta se encuentre en el punto medio del intervalo recomendado.	
101	20-25		
102	25-30		

## Appendix 5

### Yield and Sigma Levels

YIELD	DPMO	SIGMA	YIELD	DPMO	SIGMA
6,6807%	933.192,77	0,000	99,8650%	1.349,97	4,500
8,4566%	915.434,22	0,125	99,9111%	889,09	4,625
10,5650%	894.350,16	0,250	99,9423%	577,09	4,750
13,0295%	869.705,44	0,375	99,9631%	369,13	4,875
15,8655%	841.344,74	0,500	99,9767%	232,67	5,000
19,0787%	809.213,09	0,625	99,9855%	144,52	5,125
22,6627%	773.372,72	0,750	99,9912%	88,44	5,250
26,5985%	734.014,53	0,875	99,9947%	53,33	5,375
30,8538%	691.462,47	1,000	99,9968%	31,69	5,500
35,3830%	646.169,71	1,125	99,9981%	18,55	5,625
40,1294%	598.706,27	1,250	99,9989%	10,70	5,750
45,0262%	549.738,27	1,375	99,9994%	6,08	5,875
50,0000%	500.000,00	1,500	99,9997%	3,40	6,000
54,9738%	450.261,73	1,625			
59,8706%	401.293,73	1,750			
64,6170%	353.830,29	1,875			
69,1462%	308.537,53	2,000			
73,4015%	265.985,47	2,125			
77,3373%	226.627,28	2,250			
80,9213%	190.786,91	2,375			
84,1345%	158.655,26	2,500			
86,9705%	130.294,56	2,625			
89,4350%	105.649,84	2,750			
91,5434%	84.565,78	2,875			
93,3193%	66.807,23	3,000			
94,7919%	52.081,27	3,125			
95,9941%	40.059,11	3,250			
96,9604%	30.396,30	3,375			
97,7250%	22.750,06	3,500			
98,3207%	16.793,25	3,625			
98,7776%	12.224,43	3,750			
99,1226%	8.774,46	3,875			
99,3790%	6.209,68	4,000			
99,5668%	4.332,49	4,125			
99,7020%	2.979,82	4,250			
99,7980%	2.020,20	4,375			



## Appendix 6

### Cigarette definitions

Cigarette reject rate: Is a measure of the percentage of the cigarette throughput in the make/pack groups that is rejected. These values should be used in conjunction with the secondary cigarette yield and cut filler weights per cigarette to judge the performance of cigarette production as opposed to pure machine production capability.

Gut: Tobacco strand and cigarette paper created in the MK9 machine

Rod: The column of the cigarette without the filter

Filter: Is made out of cellulose fibre known as tow. The fibres are bonded together with a hardening agent, triacetin plasticizer, which helps the filter to keep its shape.

Tipping paper: Paper combined with adhesive to glue the rod with the filter

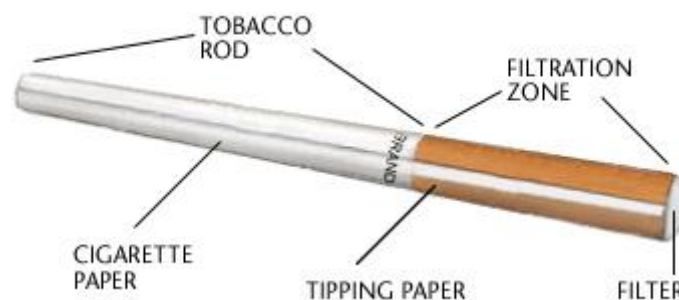


Figure 33. Parts of the cigarette

MK9 machine: Part of the machine that creates the gut (cigarette paper and tobacco strand)

MAXS machine: Part of the machine that glues the rod to the filter using the tipping paper

Disengage: Disarrange the clutch in the machine to free the MK9 and MAXS machines for proper maintenance.

Empty rod: Defective cigarettes that are rejected in the process due to lack of strand, this can be caused by the humidity of the strand, the materials or improper machine calibration



Figure 34. Empty rod cigarette



Return trial: Test done to the MK9 machine to establish how much tobacco is returned to the beginning of the process, the range of returned tobacco has to be between 25% and 30%.

RTD: The pressure required to force air through the full length of a cigarette at the rate of 17.5 ml/sec. The RTD value is expressed as mm or inches of water.

Suction chamber: Is the chamber where the tobacco strand passes to the MK9 machine, coming from the Primary process.