Investigation on defects occuring in paper production process

A Six Sigma Black Belt project at SCA Edet mill

Master of Science Thesis in the Master's Degree Program Quality and Operations Management

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ABSTRACT

This study aims at understanding the related problems which affect the processes and quality of the final product during paper production. As an age-long problem in the paper production industry, web-flutter of paper and unwanted folding in the final product could be often seen, so steps towards managing these problems are continually developed. However, identifying and understanding the root causes of these problems has been a grey-area due to the complexity involved during paper production processes. This study adopted the Six Sigma methodology to try to identify what factors/parameters are influencing the occurrence of web-flutter during paper production processes at SCA Edet mill. It also highlighted other root causes for the unwanted folding in the final product of tissue paper at the paper mill.

Six Sigma is a methodology which can be used for root cause identification, problem-solving and improving processes in manufacturing/production. The methodology often follows the DMAIC (Define-Measure-Analyze-Improve-Control) framework in its application.

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List of Abbreviations

CCR	Critical Customer Requirement
CD	Cross Directional
CTQ	Critical To Quality
DMAIC	Define-Measure-Analyze-Improve-Control
KPI	Key Process Indicator
MD	Machine directional
MR	Mother Reel
PM	Papermaking Machine
QIS	Quality Information System
SEK	Swedish crown
VOC	Voice Of Customer

1 INTRODUCTION

1.1 Background

Edet paper mill was founded in 1881 by the Häger family. In 1927 the first paper machine was constructed, and in 1940 Edet paper mill started producing wrinkled toilet paper. The breakthrough came in 1967 as Edet paper mill became the first factory in Sweden to produce bleached toilet and kitchen paper. Being bought out by NCB in 1977, it later became a part of SCA Hygiene Products in 1996. Edet paper mill currently employs approximately 430 people, with a production of toilet and kitchen paper 24/7/365. Their main products are known as Consumer-Home and Away-From-Home (SCA, 2011).

A quality problem and a process disturbance have been observed by end consumers in form of "Tissue splitting", which is in practice unwanted folds in the final Edet Consumer-Home products. As the plant runs 24/7/365, a frequent occurrence of this problem leads to customer dissatisfaction, under-utilization of workforce and man-hours due to rework. With the high quality goals by Edet paper mill it is of utmost importance that this quality problem is corrected and solved.

1.2 Purpose

The purpose of this Master thesis is to trace the origins of a problem known as "Tissue splitting" and the process disturbance known as "Web-flutter" and generate an improvement hypothesis which would possibly solve the problem.

1.3 Problem Analysis & Research Questions

Through well-defined and structured processes, tissue rolls are produced at SCA, Edet paper mill. However, a quality problem has been identified sporadically in the final products by the end-consumers. There has not been any specific identification of where the problem could originate. In identifying where the problem possibly originates, key factors/parameters which affect or influence the problem occurrence will have to be discovered. The research questions stated below will structure and determine the focus of the project.

- What are the primary root causes for "Tissue Splitting"?
- What factors/parameters are influencing the occurrence of 'Web-flutter'?
    - What are the primary root causes of 'Web-flutter'?

1.4 Delimitations

This thesis will be limited to SCA, Edet paper mill, Sweden. Thus, the thesis project will follow a single case study approach. Due to scarce measurement resources, the measure and analyze phases in the study will be prioritized on factors which measurement resources are available for. It is also assumed that the components in the converting machine or used during the process are in standard working condition.

2 THEORY

The theoretical review will be divided into two sections where the first will look at the Six Sigma methodology which will be employed to carry out this project. Secondly, it will be followed by the theoretical review of theories, literature reviews on tissue splitting and other phenomena related to it.

2.1 Six Sigma Methodology

The Six Sigma methodology was selected to investigate the current situation at Edet paper mill, as the framework possesses a systematic way of problem-solving and critically due to the pre-knowledge already acquired in using this methodology. Six Sigma encompasses two problem solving methodologies named DMAIC and DMADV. The DMAIC framework is designed to be applied for improvement initiatives for existing organizational and operational processes. DMADV on the other hand is a framework aimed for product development initiatives used when no current process exists in the organization (McCarty et.al. 2005; Persse, 2006). The DMAIC framework will be the object of this theoretical review as the project carried out follows an improvement initiative on an existing process

A Six Sigma project is mostly carried out using the DMAIC framework. This approach functions for the improvement of all types of critical-to-quality characteristics and also can be functional to problem solving and general decision making. It is generally classified as an easy-to-use methodology through principles which are clearly defined with start and stop, formalized project team with roles and responsibilities, as well as a clearly defined sequence of activities, tollgates and deliverables (Magnusson et al. 2003).

The phases in the DMAIC framework include the *Define*, *Measure*, *Analyze*, *Improve*, and *Control* phases. Each phase is clearly defined using tollgates and action plans which help to achieve the efficacy of the whole methodology.

2.2 Define phase

The Define phase is considered to be the most critical, a well-defined project and boundaries is core for a successful outcome. The essential objective in the define phase is to focus on the right thing, that is, something that is important for the business itself (McCarty et.al. 2005). Persse (2006) concurs with the previous statement and adds that, in many cases processes are a corner stone of the business. Products and services are achieved through these leading to that company success is often based on these. The result is that any project focused on a particular process can have a big influence on the whole business itself in many dimensions, thus understanding why, how and what you want to achieve in a Six Sigma project is imperative. Magnusson et al. (2003) suggest using tools such as the affinity diagram and Pareto chart to help ensure that the right project is selected.

A well selected Six Sigma project should – according to McCharty et.al (2005) and Magnusson et al. (2003) – address certain organizational process factors. Following are some criteria encompassed from the authors.

- Impact a key business goal.

- Require analysis to uncover the root cause of the problem.
- Affect customer satisfaction.
- Focus on improving a key business process.
- Produce quantifiable results.
- Be scoped so that results can be achieved in 4-6 months.

2.2.1 Define Phase deliverables

With an appropriate Six Sigma project determined, researching and investigating deliverables for the Define phase is to be set in motion. There is no exact order in which these deliverables need to be achieved; it can depend on many different factors.

2.2.2 Project Charter

Like an organization, a project team exists for a reason and requires specific expertise and team members, with explicit communication channels within the team and to external parties (McCarty et.al. 2005). A project charter is a key document throughout the project. With a well-defined project scope and purpose this document will work as a communication tool for the team, contributing to a shared perspective of the projects key aspects as well as keeping focus on the deliverables in each phase (Magnusson et al. 2003; Persse 2006). Further aspects a charter could include are illustrated below:

Business Case: The business case serves the purpose of a communication mechanism for resources allocation and a means of project tracking for management and stakeholders (Persse 2006). It is also a way of showing clear application for why the project is important for the business as it encompasses a description of desired outcome of the project, also known as the big Y (McCarty et.al. 2005).

Mission statement: Creating a mission statement is a good way to assist the essential idea of the business case. It describes the opportunity or problem in focus, what outcomes that the organization hopes to derive from the project and the business benefits that can come from it. Having it present in the project will serve as a reminder of the project scope and be used as a tool to reinforce the team with resources (Persse 2006).

Goal statement: The goal statement should describe, as detailed as possible, the deliverables of the project. A well detailed goal will make sure that the project team precisely knows when the project is finished (McCarty et.al. 2005). Further, it is imperative that the goal has a clear link with the VOC, which is the motive behind initiating a Six Sigma project. If what is achieved doesn’t increase customer satisfaction, the project did not serve its purpose (Persse 2006).

Project Scope: The scope of the project will help keep the time plan and keep focus.

Project plan: A time plan where milestones are determined with desired date to keep track of the project, usually a Six Sigma project is carried out during 4-6 months.

Selecting team: As a part of the project definition, team selection is a core step that must be established. The Black Belt and Champion should be in charge of gathering member for the team that have the ambition, time, knowledge about the DMAIC framework and expertise in a specific field of concern.

Once a project charter has been established it should be revised and reviewed during the course of executing the project. As it functions as a living document it should be continuously updated and referred to in order to keep the project on right track (Persse 2006).

2.2.3 Big Y - Customer - Small *y*'s - Goal statement

A clear link between the business case, process requirements and goal must be established in the Define phase. After the business case has been determined acquiring the customers' needs and wants, the VOC is the next step. This task can be carried out in several ways depending on the specific case. However, there are designed tools that can help ensure that the team really understands the customer e.g. using a Kano survey. A central issue when capturing the VOC is to identify the true or most important customer.

The VOC is important because it will determine how the team sets its requirements. This is issued by first investigating the key customer issue (KCI) of their current dissatisfaction, and then translating the VOC with the help of the KCI into Critical to Customer Requirements (CCR), that actually state the VOC in a more detailed manner.

The next step is to translate the CCR into process requirements. This is accomplished by identifying measures of the process outputs that are important in order to meet the CCR. These measurements are referred to as Critical to Quality measures (CTQ), Key process indicators (KPI) or small *y*'s (McCarty et.al. 2005). CTQs' and KPIs' can be traits, features, benefits and other attributes that are essential to meet a specific dimension of quality that is important to the customer. From this a specific and realistic Goal statement can be generated (Persse 2006).

2.2.4 Process mapping

Another key deliverable in the define phase is the creation of process maps. Presumably the team members' knowledge of a full process will vary, therefore it is an essential element in getting the team a shared overview of the existing process and can also serve as a team-building exercise (McCarty et.al. 2005). A typical process map in a DMAIC project included activities, decisions, inputs, outputs, suppliers and customers (Magnusson et al. 2003). The SIPOC (Supplier, Input, Process, Output, and Customer) process map is commonly used in Six Sigma projects. In the SIPOC the process name is first established. Secondly, the team must define the starting and ending point of the process. Further, the inputs should be listed and who supplies them. Also state the top level process steps, the key process outputs and lastly the receivers of the outputs i.e. the customers (McCarty et.al. 2005).

Before leaving the Define phase, the project leader should control that all necessary steps have properly been executed.

2.3 Measure Phase

Following the DMAIC framework under the Six Sigma Methodology, the Measure phase follows the Define phase.

The Measure phase functions as a way of knowing how things are currently going on. McCarty, et al (2005) explains that data has to be collected to verify the current performance level. To achieve this, a data collection plan must be established where you map out what process elements and components will be measured (Persse, 2006). He explains that measuring is an ongoing and continual activity which follows three dimensions, prepare to measure, carrying out the measurement and organizing/protecting the data. Q. Brook, (2010) illustrates that the Measure phase aims to set a stake in the ground in terms of process performance (a baseline) through the development of clear and meaningful measurement systems.

McCarty *et al.* (2005) further explain that by making use of the KPI's and CTQ's, already established in the Define phase, the process and input variables that affect them known as Xs' are determined while base lining the small *y*'s concurrently. Operational definitions are a way of base lining and are developed to give clear and unambiguous descriptions of each KPI or CTQ (Q. Brook, 2010). McCarty, et al (2005) elaborates more on the operational definitions as precise definitions of the specific *y*'s to be measured. The purpose of the definition is to provide a single, agreed upon meaning for each specific *y*. This will help in the Analyze phase when studying the relationships between the *x*'s and *y*'s. A commonly used tool for determining process and input variable are The Cause and Effect Diagram, another tool with the same purpose is KJ-Shiba which can be used to compensate for each other. Further preparation before measurements can take place, includes determining variable characteristics, sampling, duration, how to collect data, who to be responsible, *etc*. Sampling of data also is a very critical process and proper sampling should be carried out so that the statistic is a good estimate of population parameters (Magnusson et al. 2003).

In conclusion of the measure phase, a concrete data collection plan should be developed along with the tools for manual data collection and then the data can be collected, and the process baseline can be established (McCarty et al, 2005).

2.4 Analyze Phase

Continuing the Analyze phase, the problem or problems of the project should have been determined in previous phases. The essential objective of the Analyze phase is to identify and validate the root causes of the process variation or defects. The process for finding the root causes is by subjecting all data collected in previous phases through a series of graphical and numerical tools. Essential is that a large enough quantity of data has been collected for statistical legitimacy; the amount is dependent on the nature of the project and problem studied, (McCarty *et al.*, 2005; Persse, 2006). Using a combination of graphical and numerical tools for the analysis is an advantage. The graphical tools will help understand the data characteristics, and ensure the legitimacy of the analysis. While the numerical tools provide means for determining if any variation detected is significant or of natural causes, (McCarty et.al 2005).

Examples of graphical and numerical tools to exploit during data analysis are; Pareto chart, Histogram, Box-whiskers plot, Dot Plot, Matrix Plot, Scatter Plot, Run chart, Multi-Vari

Chart, Hypothesis testing, Confidence Intervals, Regression analysis, Correlation analysis, DOE, and Time series analysis.

2.5 Improve Phase

The Improve phase follows after the Analyze phase. This phase works to improve the process, making changes to the process to make it more effective and efficient. All this comes from the insights provided by the analysis of the data in the analyze phase (Persse, 2006). This comes after there has been validation of the causes of the problems in the process and is ready to generate a list of solutions for consideration (McCarty *et al.*, 2005). According to Persse (2006), the improve phase should consist of six steps which are elaborated in details below.

The first step focuses on the analysis of the data in the previous phase. Focusing on the data collected earlier, there will be possible parts in the process which are unpredictable compared to others and will form the basis for improvement initiatives. With focus on the root causes of defect, very necessary in this step is to take options that suit the organizational culture, the budget for process improvement, schedule adopted for the project, and goals you have set in the project plan.

In the next step, there will be a few paths that can be taken to develop potential process improvement solutions. The main objective in this step is to develop ideas to a level where benefits are apparent, then make decisions to select the one with the greatest strategic potential and finally develop it for deployment. This basically entails three options of paths which can be taken when developing solutions. They entail refinement of process elements where it is seen that enhancement is possible without having to perform a lot of re-engineering, creating new work flow extensions to account for missing process components and possibly to define new processes or new components to reroute work flows towards greater efficiencies.

Select step focuses basically on choosing the solution to be developed. It involves studying and developing the options already developed earlier on whilst making cautious judgments to focus on the best one for the project. It involves the combination of maintaining the concept of practicality in mind whilst also placing the needs of the organization, proportions of the project, resources available and the capabilities of the Six Sigma team in consideration. Modify step involves improving the targeted process already selected by eliminating the root causes of the defects and by designing creative solutions to fix and prevent problems. These changes should reflect the constraints or trends reflected in the data.

The improvement phase finalizes with piloting and verifying the selected initiatives. Piloting involves running the process through real-life like situation and testing the pilot out in an environment as close to production as possible (online testing). Test the working of the process and then evaluate the results of the pilot. At the completion of the pilot and satisfaction is fairly achieved with results by the Six Sigma team then verification should be established with the rest of the organization through formal presentation of improvement deployment plan to the organization so as to keep them abreast of your proposed actions (Persse 2006).

2.6 Control Phase

The last and finalizing step in the DMAIC framework is the Control phase. The objective is to ensure that the modified process is rooted and that the established improvements are sustained. The main idea to achieve this is by setting controls in work that will help the organization to stay committed and not revert back to old ways of working.

To help with the transition and coordination of the new way of working, creating a Control plan is very useful as it covers several critical elements of maintaining the revised process; *A description of the adjustment of the process, a new or complementary process map, recognition of process owners, changes in the production, training plan intended for the individuals who will manage and use the process, a deployment plan for the improvements and formalization of the performances measures* (Persse, 2006).

The next natural step would be to present your Control Tools, consistent of documents, procedures and matrices' that will coordinate and communicate new process requirements, guidance, and monitoring and investment validation for the improvements.

Finally the project will reach a close-out which is a last set of activities which will put the project to rest. For this last task, all documentation should be organized and be dispatched the best way seen fit. Further reflections on the project should be made and ensure that this knowledge is exploited for further improvement initiations. Also identify how the project affected the business as a whole, to have a success story to share and motivate the organization. Conclude with a celebration of a successful project! (Persse, 2006; Magnusson *et al.*, 2003)

2.7 Tissue paper characteristics and related problems

To provide a description of paper constituents, a quote from Land (2010) is used "Paper is made from cellulose fibers that originate mainly from wood. The type of wood used influences the properties of the paper: softwood has long, strong fibers whereas hardwood has short fibers that provide the paper with a smooth surface. Fibers are composed mainly of fibrils, which consist of bundles of cellulose chains. The fibers are separated by mechanical means (e.g. grinding or refining) and/or by chemical means (e.g. kraft cooking) when producing pulp.

When making paper, the pulp is diluted with water to a fiber content of around 0.2÷1%, depending on the paper grade being made." See Figure 1for a description of the development of recycled fiber into tissue paper.

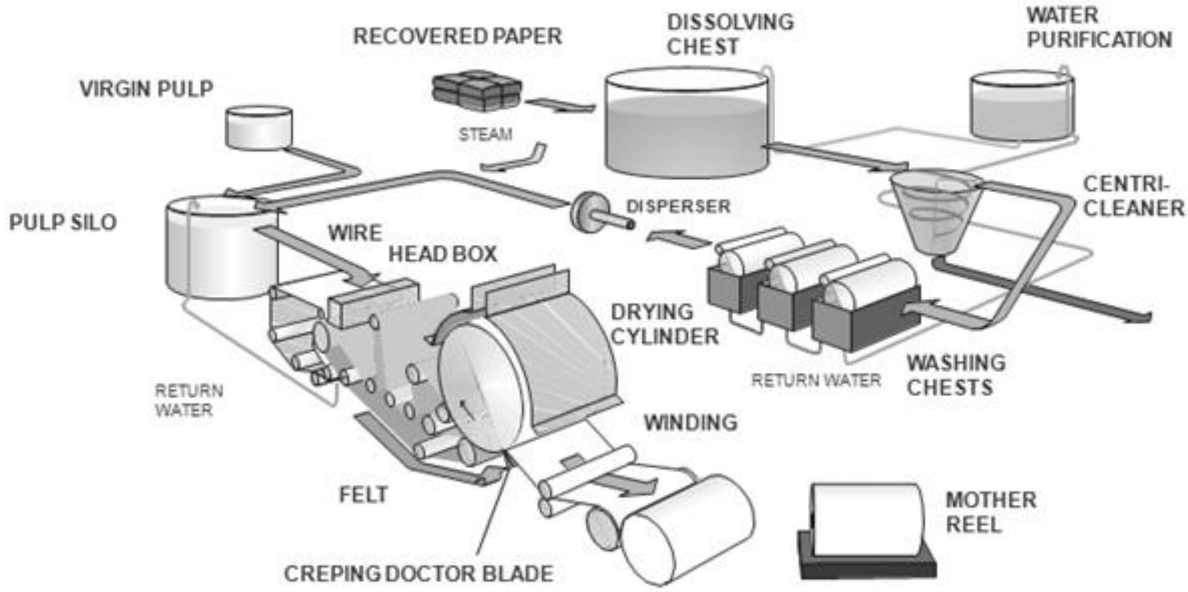

Figure 1. Overview of a papermaking machine, the process from recycled fiber into tissue paper, (source: SCA, 2011).

Proceeding after the papermaking process, is the converting process, where mother reels are developed into final tissue paper rolls. This includes the unwinding phase, where at least 1 unwind is required (mother reel diameter range 1.4÷3.0 m), embossing phase where ply bonding, decorating, softness and absorbency are applied to the paper, and then the re-winding phase which perforates, feeds-in-core, pick-up-laminates and finally re-winds. The last phases of the converting process are the accumulator and log-saw where the tissue rolls are cut into the right dimension according to product specifications. During both the papermaking and converting processes, the paper web is subjected to various types of machine tension and other wearing forces (SCA, 2011).

Several problems can result in the irregular development of the final tissue paper, which can be attributed to problems during the processes of tissue paper making. According to Roisum (1996; 2001) and Land (2010), several irregularities can be found in the paper properties during/after production. The term ”baggy web” is one of the most common paper irregularities which can be related to web fluttering and often leads to tissue splitting. Baggy web can be seen as both slackness and tautness in various parts of the paper web, however the slackness in a web usually appears at the same location in the cross direction (CD) of the web.

Variations in the web appearance can be traced back to differences in properties of: tension, length, strain, stress or flatness, which leads to an unstable web and produces difficulties in web-handling during the converting process. The unstable web could be seen as having slack parts of the web which do not tend to wind as well as the tauter parts, and if the bagginess is isolated to one edge of the web, the web will wander towards that side causing traction and web-path control issues. A continuous run of a web affected by bagginess, will likely result in web breaks or creases and folds when the web passes through nips. A case of “baggy web” during production can be seen in Figure 2. Kulachenko et al, (2006) explained that while considering the tension profile of the web which is mostly non-uniform, slack edges can be developed during the paper production. This combined with excitation vibrations at the edges often leads to web fluttering.

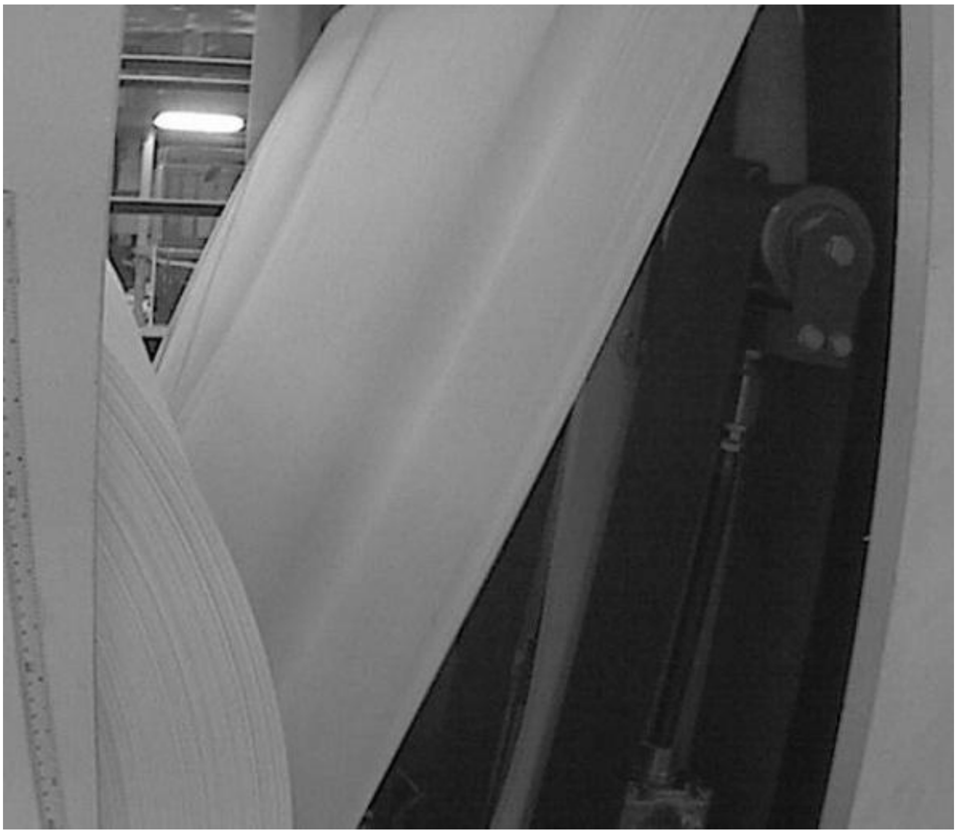

Figure 2.Visual slackness and tautness in the web (baggy web) during unwinding.

Land (2010) explains that the reason that these symptoms of fluttering show during the converting and not in the papermaking (PM) is due to a much higher web tension during winding in PM as compared to converting. Further (Webex Inc. 2008) suggests that the unsupported web length also influences “web-flutter".

Another irregularity that could be associated with tissue paper making is called “wrinkling”. Roisum (1996) defines wrinkling as “... any deviation from absolute flatness of the web”. Figure 3 shows a mother reel with wrinkles. He further explains that the severity of wrinkling during winding in the converting process can exist and be difficult to discern or lead to creases and folding of the web. When the web is exposed to external forces which try to make it expand beyond its original state, it tends to accommodate these forces by buckling out-of-plane which develops in the CD of the web. However, through these authors, there has been no consensus towards what causes the expansion of the web which leads to buckling (Roisum, 1996); (Kulachenko *et al*., 2006).

It can be seen that wrinkling is caused by external forces or irregularities on the web while bagginess is caused by internal irregularities in the properties of the web (Roisum, 2001).

Figure 3. Visible wrinkles on a mother reel.

Improper web tension could be a problem associated with wrinkling, stretching, creases or web breaks. Webex, Inc. (2008) explains that excessive web tension can contribute to web marking by pulling on the web. This pull invariably intensifies any irregularities that could exist on the web both internally or externally. According to Land (2010), the converting machine would be required to have uniformly shared winding tension to accommodate for any irregularities that could exist on the web.

Through experiments which have been carried out on web dynamics with focus on fluttering show a clear relationship with fluttering and air-flow externally or generated by the machines used. Watanabe et al, (2001) explains that the amplitude and frequency of the fluttering increases as wind speed increases however, there is no direct relationship between fluttering speed and web speed. In line with the latter statement, Kulachenko *et al.*, (2006) suggest that when studying web dynamics with reference to fluttering, it is important to not overlook the effects of air-flow on the web as it could have a direct impact on web-behavior during unwinding.

3 METHOD

Method will be divided into three sections. Firstly, Research Strategy, that will provide a brief background of the problem and the chosen strategy for carrying through. Secondly Literature Search and Review, that will explain how literature was gathered and screened. Lastly Empirical Study, which explains the research design and methods used during this thesis.

3.1 Research Strategy

SCA is interested in an approach to solve the quality problem that has been observed in some units of their final products. A Six Sigma project approach was selected in carrying out this thesis work based on previous education in the field and available resources at Chalmers University of Technology.

The research questions (see Section 1.3), will be defined through the first three steps of the DMAIC framework. Following the Six Sigma methodology, a deductive approach will be taken where the theory of Six Sigma will be tested against empirical settings (Bryman & Bell, 2007).

The DMAIC framework will provide the right platform for a mix method research approach through an empirical study. This will consist of both quantitative and qualitative data analysis methods, which will enhance the reliability of the study. It is necessary to emphasize that due to the peculiarity of the problem defined in the first phase, the degree of use of both types could vary on each phase.

3.2 Literature Search and Review

The literature search and review commenced from previously encountered and recommended literature through searching databases accessible at Chalmers University of Technology using keywords on search engines such as Chans, Science Direct and also independent ones e.g. Google Scholar. Published articles and e-books found were screened for their actual relevance to this study and then eventually applied.

For initial screening and reviewing of the literature, criteria were set for evaluating the large amount of literature the search generated. The criteria will aid in determine if the literature is relevant and trustworthy.

- The abstract needs to suggest that the article/book encompasses interesting information that may be of relevance.
- Author/publication/citations will determine the validity of the source.

3.3 Empirical Study

The empirical study will be divided into two sections; research design and research methods, and will elaborate on tools and approaches which are considered to be appropriate to use in carrying out this project.

3.3.1 Research Design

The Master thesis was performed as a Six Sigma Black Belt project, as a single case study. The project focused on a detailed analysis of certain process/es at SCA, Edet paper mill. The thesis set as a Six Sigma project, followed the DMAIC framework, where the criteria of reliability and validity was critical. Therefore, a mix methods research approach was utilized which is facilitated on a Six Sigma platform with its extensive use of qualitative and quantitative research methods.

3.3.2 Research methods

Through observations, semi-structured or open interviews, the evaluation of the current state of the paper mill was established to develop a platform for the acquisition of necessary data. This was followed by using the DMAIC framework where relevant tools which adapt to the problem definition and solution were applied. The interviews were conducted mostly with shop floor and management employees at Edet paper mill, focusing on personnel who were most knowledgeable of the processes or problems.

The following terms or methods defined below were used in the course of this project to collect and analyze data.

Semi-structured interviews

This is a term that covers a wide range of instances. It typically refers to a context in which interviewer has a series of questions that are the general form of an interview schedule but is able to vary the sequence of questions. The questions are frequently somewhat more general in their frame of reference than that typically found in a structured interview schedule. Also, the interviewer usually has some latitude to ask further questions in response to what are seen as significant replies (Bryman & Bell, 2007). See Appendix G for interview guide.

KJ- Shiba

The KJ-Shiba method employs the affinity technique in the collection of large quantities of verbal data (ideas, customer demands, opinions etc.) and in the organization of this data into different groups according to some form of natural affinity. The resulting affinity diagram illustrates associations rather than logical connections (Alänge, 2009). This method is suitable for creating a consensual understanding of a problem with diffuse and contradicting initial perspectives. Through semantics methods, underlying facts are determined from language data, finding relation between language and reality (Shiba et al., 1993).

Ishikawa

The Ishikawa diagram also known as the fishbone diagram is usually adopted as an effective tool to facilitate brainstorming sessions. There are many different versions of fishbone diagrams – with different classification methods (e.g. People, methods…), see Figure 13.The versions used are as appropriate to the project or could be created to suit your project. (Brook, 2010).

3.4 SCA Data Bases

The following section will briefly describe different databases used at SCA, Edet mill. The databases are used to store and follow important production data.

ABB – Control system

Edet Mill is utilizing an ABB control system for process control in pulp processing, paper making and in the steam producer. The control system monitors all signals picked up from measuring equipment and sensors in the machines. The signals are controlled to keep specific levels that will ensure stable running processes. The system is key for the production as it is the main tool for the operators to manage the processes.

TS – Fagus paper

This is an internal traceability system that tracks and stores data on production and transportation of MRs. By assigning each MR an ID number, it is possible to keep track of the MRs from production at paper machine via transportation and storage till converting lines. Additional data gather from the production is also embedded in each MR files. TS also have a mediate role where it receives input data from the ABB control system, which it distributes to other database systems.

PLAIN

PLAIN acts as a production follow-up system, where various data on quantity of production, production orders and production stop are registered. In PLAIN a logbook is also accessible, it serves as a communication tool between the different shifts and employees.

QIS – Quality Information System

QIS is a system used at Edet Mill for quality control that allows for offline analysis of quality and process outcome. The internal quality controls carried out by operators are directly inputted into the QIS system in a systematic way. Data input from ABB control system via TS is also acquired and embedded in the systems storage. This allows for follow up and control on the outcome of paper qualities and articles. The simplicity of QIS provides easy access to information on specific MRs or statistical production data, which can be exported to Microsoft Excel©.

4 DMAIC
The following section will describe the work made in this case study through the DMAIC framework.

4.1 Define
Edet paper mill manufactures and produces tissue paper in two major market segments; Away-From-Home products and Consumer-Home products. Through an external complaints claim system at the marketing department, various types of problems on the final products provide feedback to SCA to help improve the quality of their products. The problem called "Tissue splitting" was identified as the second biggest external claim during 2010. The problem was then analyzed both externally (marketing) and internally (converting process) to determine its value in terms of losses to the company (SCA, 2011).

4.1.1 Problem description
According to the marketing department, "Tissue splitting" happens to be the second biggest complaint cause at Edet paper mill on the Consumer-Home products segment. Statistics from the external claim system shows that this problem held for [redacted] complaints, about 14.4 % of the total amount of complaints during the year of 2010. For the "Tissue splitting" problem, the marketing department estimated that it will cost SCA [redacted] in coupons for the year of 2010 excluding administration cost for handling the complaints and the cost of franked envelopes that are sent to consumers to get a sample of the defect product back to be investigated (SCA, 2011). Losses were also accounted due to "Tissue splitting" by losses in machine efficiency at the converting lines where the final productions of these tissue papers were made. This propelled investigations into the problem internally.

The loss incurred in machine efficiency reduction was the major catalyst to develop a taskforce to combat this problem. This taskforce included members from various departments that were familiar with the problem. As defined by the taskforce "Tissue splitting" occurs during the embossing in the converting process of tissue paper production, see Figure 12. It happens when the paper/web folds and causes a crease. One reason suspected for causing the folds and creases are due to excessive "web-flutter". When these crease/folding is noticed in the final products it is referred to as "Tissue splitting" (SCA, 2011). To manage this problem, there is usually a reduction in optimum speed performance during the converting process.

Since June 2011, there have been [redacted] internal claims of speed reduction during converting due to "Tissue splitting". This has resulted in losses of about 20% in average speed corresponding to [redacted] MRs less produced. The calculated value of this lost production is estimated at [redacted] SEK/MR and the cost for the mill [redacted] SEK/MR in added work-time. This loss amounts to an estimated figure of [redacted] SEK from January-June, 2011 (SCA, 2011). It was also discovered that in the internal claim system only [redacted]% of losses due to "web-flutter" where entered into the system, this would have increased the value of the losses due to "Tissue splitting" if entered. Also, the claim "web-flutter" in the internal claim system has only been active from January-June, 2011, so it is estimated the value of this claim would be doubled considering it on a yearly basis (SCA, 2011). Other losses incurred were due to waste cost on un-run able MRs due to over-excessive web-flutter at the converting lines which were then rejected as waste. So far, [redacted] kg has been rejected from January-June, 2011 at an estimated cost of 10,000 SEK/ton which corresponds to an estimated cost of about [redacted] SEK/year (SCA, 2011)

Due to the combined value of the losses and costs (known and unknown) experienced both externally and internally, SCA, Edet paper mill decided upon carrying out an improvement initiative towards the problem. This improvement initiative followed a Six Sigma project approach with the aid of the authors of this thesis report from Chalmers University of Technology.

4.1.2 Business case/ Big Y

The desired outcome of this Six Sigma project is to increase the efficiency of current converting lines, which will lead to reduction in waste costs and loss of production.

4.1.3 Team Charter

A team charter was created with and shared between involved leaders of the project, as to provide a common perception of the project in areas of business, customer impact, scope, resources and project support, see Appendix A.

4.1.4 Define the defect

"Tissue splitting" is the given name by marketing to this quality problem which is seen in the end products on the Consumer-Home segment. The actual defect is characterized by either a crease/folding in the tissue paper rolls, see Figure 4. The tissue crease/folding becomes permanent after the embossing phase in the converting process.

Figure 4. Tissue splitting as seen in Consumer-Home products.

"Tissue splitting" can be caused by various types of problems namely; incorrect adjustment of the web or MR, defect MR, static charges at the converting line, "web-flutter", mechanical failures and human error. For the purpose of the case study it was necessary to determine which of these problems were the most probable in causing "Tissue splitting". Further investigation was carried out through interviews with the problem owners, and "web-flutter" was suspected as the primary cause to "Tissue splitting".

"Web-flutter" is visible first during the unwinding phase in the converting process, see Figure.11. As discussed in Section 4.1.1 (problem description), "Tissue splitting" can occur when the edges of the web flutters, and when this fluttering becomes too severe, the edges will fold, causing creases. If not properly managed during the unwinding phase these creases will become permanent in the next converting phase (embossing), and can be seen in the end product.

Apart from causing "Tissue splitting", "web-flutter" can also cause web-breaks, which leads to production stop. The only way for converting operators to manage the problem is by reduction of the process speed or increasing web-tension, which might lead to web-breaks. All these come at a cost in loss of production, and excess waste (SCA, 2011).

4.1.5 Customer

As (McCarty et.al. 2005) and (Persse 2006) states, it is essential to identify the true customer. In this case study the customer could be both internal and external. The internal customers are the main benefactors to this project as they will get the direct benefits from less rework and higher utility of workforce and man-hours. The most critical internal customers are personnel representing the converting process for those lines which are producing Consumer-Home products. The external customers who are mostly the end consumers will benefit from consistency quality in the final products. The impact of improvements will be felt in different degrees between internal and external customers. Therefore, the converting representatives were determined as the true customers and the following information was collected from them.

Voice of the Customer (VOC)

By conducting semi-structured interviews with process engineers and operators assigned to converting lines producing Home-Consumer products, the VOC could be identified as: "run stable productions in converting without stops or reduction of speed to accommodate for the "web- flutter" issues".

Key Customer Issue

Having to accommodate for a high degree of "web-flutter" is the main customer concern. If no actions are taken during fluttering of web, it will eventually lead to web-breaks or "Tissue splitting".

Critical Customer Requirements CCR

To keep the “web-flutter” to a minimum degree that will not lead to web- breaks or “Tissue splitting” without reduction of process speed or manage the” web- flutter” without it causing any quality problems.

Critical to Quality/ Key process indicators CTQ/KPI

The degree of “web-flutter” was determined as a KPI.

4.1.6 Goal statement

The goal of this project is to investigate into the current process disturbance of “web-flutter” and to identify the root cause behind it and other likely causes resulting in “Tissue splitting” following the purpose of this Master thesis already stated above.

4.1.7 Collection and analysis of historical data

Currently Edet paper mill uses both internal and external claim systems for storage of customer complaints. The procedures unto how the claims are collected differ and this section will briefly explain this, continuing with details about analysis of the historical data.

External claim system

When an external customer finds a defective product and wants to report this, they may contact a SCA consumer contact. During this procedure, a reclamation form is filled out containing details of the defect. The consumer is asked to send a sample of the product together with the barcode, which allows for internal tracking of the original MR from which the tissue was produced. This information from the reclamation form is typed into the SAP system, where all external claims are stored. This information can be later accessed by anyone who has the clearance. One important thing to note is that, Edet paper mill produces tissue paper for other companies, restricted to converting line 14. Any claims made for tissue, traced back to this converting line, would have gone through a different reclamation process, and SCA does not receive any samples to verify the defect claims.

Internal claim system

The internal claims are restricted to the converting lines where the symptoms of various defect are often visible. The claim “web-flutter” in the internal claim system has existed as from January 2011 and any visible defects detected during operation are required to be reported by the operator present at the time. This can be understood that the internal claims is in contrast with the external and do not report “Tissue splitting”, but “web-flutter”.

Analysis of historical data

Data from both the internal and external claims were extracted, however the external claims were a collection of a random sampling throughout Sweden and with further investigation into both data sets it was determined as the more reliable data source. Several graphs and models were created from the data set for the purpose of detecting indications towards where the problem was most critical, and if any patterns or relations could be distinguished as seen in Figures 5-8.

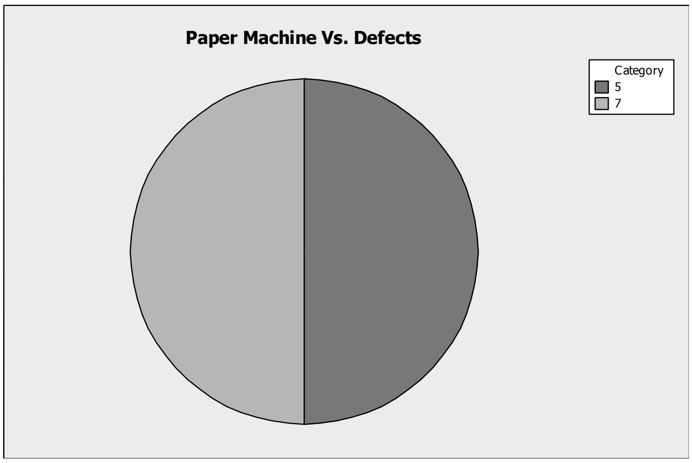

Figure 5 Distribution of defects produced by paper machines 5 and 7.

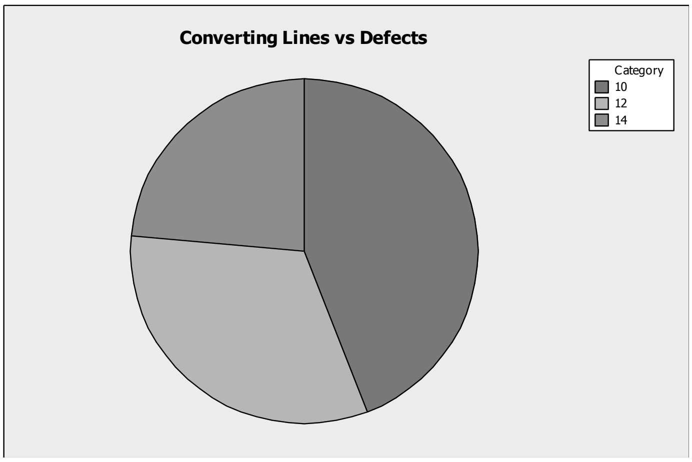

Figure 6 Distribution of defects produced by converting lines 10, 12 and 14.Coverting line 10 appears to be the major converting line responsible of defective products.

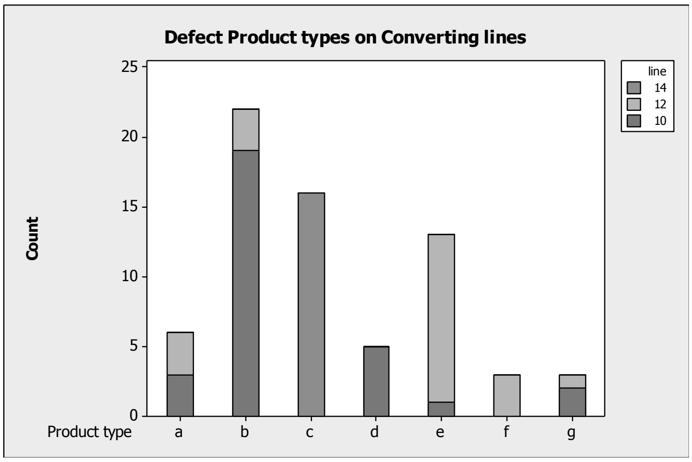

Figure 7 Distribution of defects over product groups and converting lines. Product type b can be seen as the most critical and has its majority produced on converting line 10.

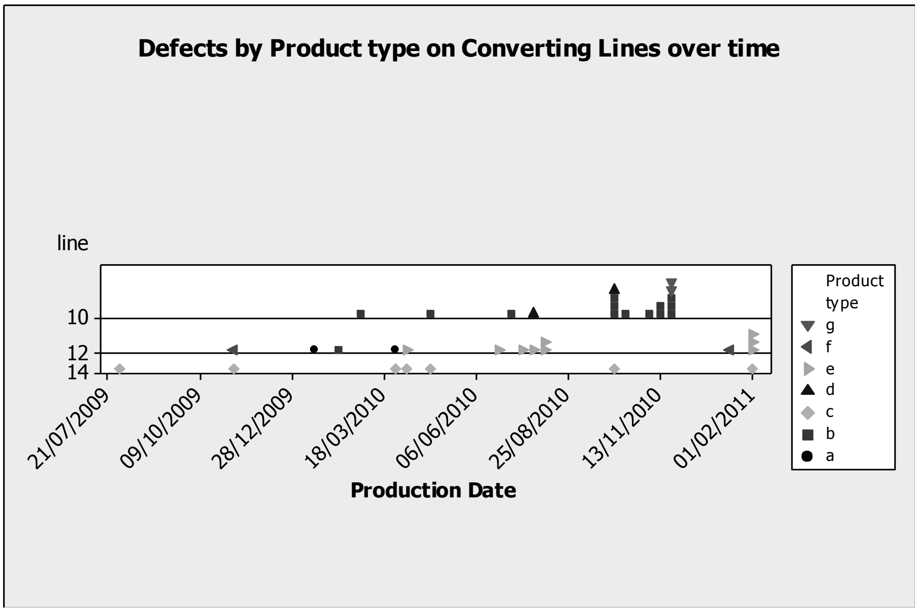

Figure 8 Defective products distribution over time and by converting line. A cluster of defects from product group *b* on converting line 10, can be seen during the months of October till November 2010.

The results of the analysis came to play a major part as to where and on what to focus on during the measure phase. A table of the product groupings can be seen in Appendix B.

4.1.8 Process map

The process of creating tissue is a long and complex process and can be split into several sub-processes. A holistic mapping of the full process was created and also process maps of the most critical sub-process, to untangle the complexity and provide a shared understanding of where focus is needed. Further, these process maps would also facilitate the generation of *y*'s and *x*'s.

Analysis of historical data pointed towards converting line 10 as the most critical line. However, it showed an equal distribution of defects between paper making (PM) machines 5 and 7. Therefore, it was determined that process maps were to be created for converting line 10 and also PM 7 which is the main supplier of paper to converting line 10. Flow charts were created for both process and a SIPOC map for converting line 10, seen in Figures 9-12 and Table 1. In addition the mechanics of the unwinding phase in converting line 10 were studied in-depth, since the symptoms were seen there first.

The crucial steps in the process that determines the characteristics and uniformity of the web, begins at the head box until the web is wound. These steps of PM 7 are shown in the flow-chart below, see Figure 9.

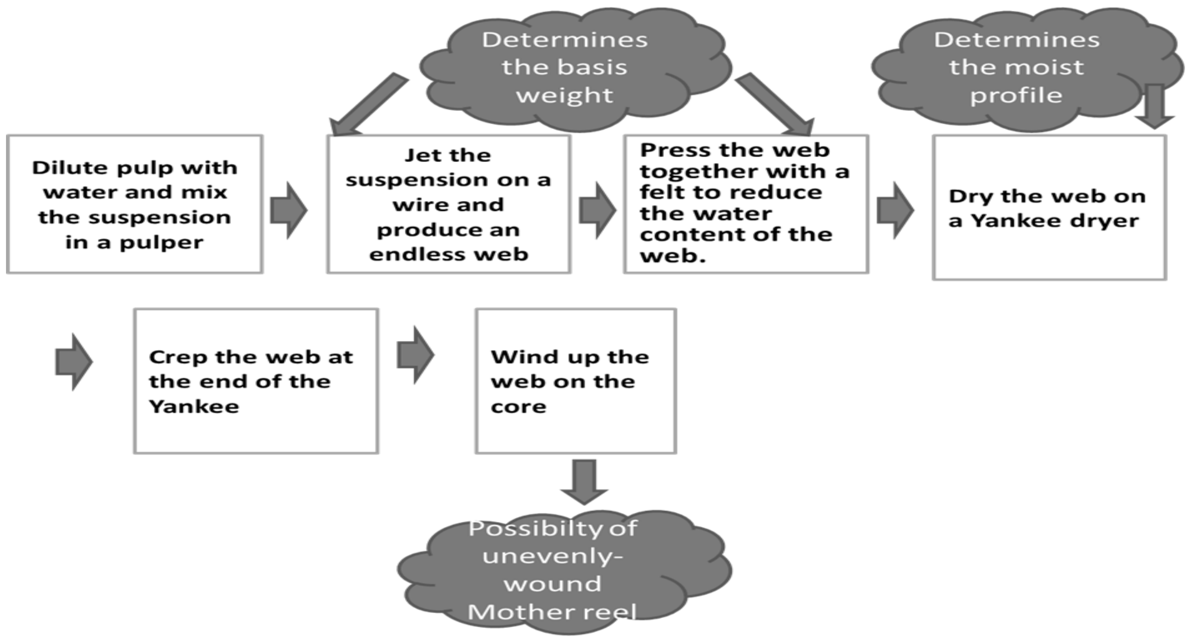

Figure 9 Process map showing the crucial steps in PM 7.

Table 1 SIPOC map of Converting Line 10

Start: Mother reel of paper **End: Tissue toilet rolls**

Suppliers	Inputs	Process	Outputs	Customers
Paper Making Process	Mother reel of paper	**Preparation** **Unwind** **Embosser** Rewind Tail-sealer Accumulator Log-saw Packaging Palletizing	Tissue paper	Warehouse

In relation to the problem, the most critical process phases during converting are preparation, unwinding and embossing. The preparation phase is presented below, this is the only screening of the MRs before they are utilized and are heavily influenced by human factors, see Figure 10.

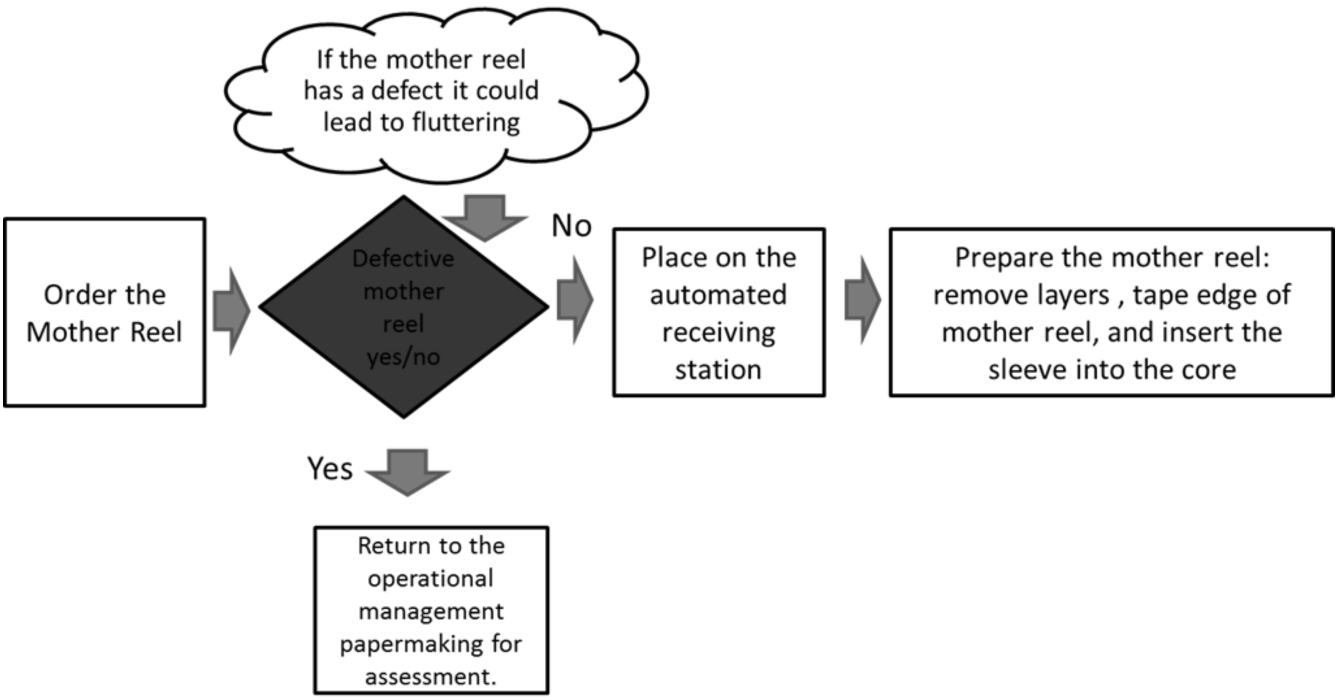

Figure 10 Flow chart of the preparation phase in converting.

The next flow chart displays the unwinding phase, during this phase the first symptoms of fluttering are visual, see Figure 11.

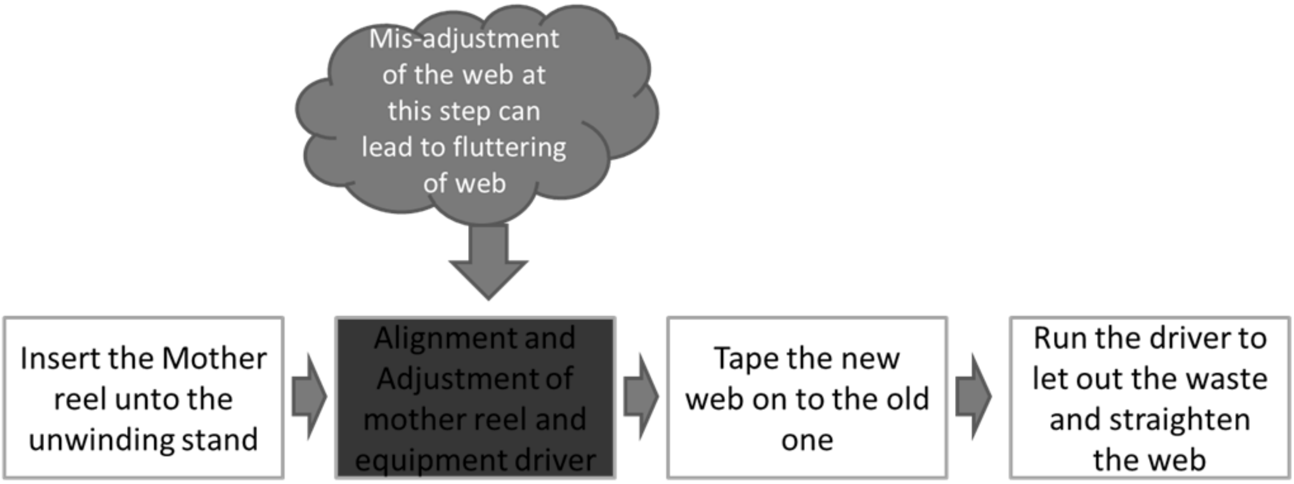

Figure 11 Flow chart of the unwinding phase of converting.

This last flow chart represents the embossing phase, after this phase any defect will become permanent in the final product, see Figure 12.

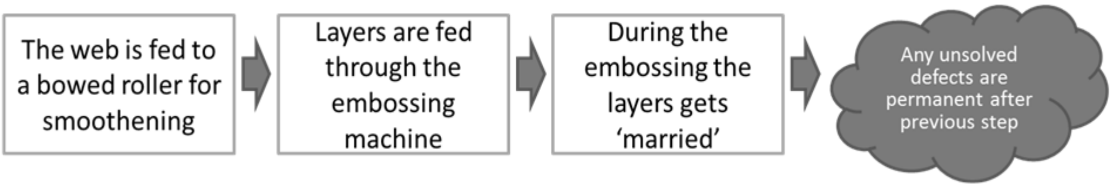

Figure 12 Flow chart of the embossing phase of converting.

4.2 Measure

As identified in Section 4.1.7, converting line 10 was the most critical in terms of defects produced. In addition product type B could be isolated as the most critical product produced on converting line 10. Product type B is a 3-ply product consistent of two-ply of paper quality 2067 and one-ply of 1067. From these conclusions, it was decided that any measurement would have to take place with focus towards converting line 10, in particular product type B and other products using a combination of paper qualities 2067 and 1067.

4.2.1 KJ SHIBA session and Ishikawa diagram

The following is a summary of a KJ-Shiba session performed at Edet paper mill with ten participants all with knowledge about the problem working in various functions and positions. Following is an Ishikawa diagram produced from the results.

Problem Title: What is the cause of “web-flutter”?

Identified Causes as variables:

- Uneven formation of the pulp on the wire
- Variations during drying on the Yankee
- Uneven Moisture profile
- Pressure difference in the driver and operator side
- Improper Pope winding
- Mother Reel transportation and storage
- Wrong Settings during unwinding(Converting)
- External Disturbances during unwinding (Converting)

The results reflect the analysis from all the participants. From the session, it was discovered that the focus of the problem was centered between the (uneven formation on the wire) going through the (MR transportation and storage issues) to the (converting Rewinding/Unwinding process).

Voting: According to the votes, the uneven moisture profile was seen as the most important variable associated with the “web-flutter”. The Uneven formation of the pulp on the wire and improper pope winding were voted as the second and third most important variable associated with “web-flutter” respectively.

Cause-Effect relationship: The Cause-Effect relations between the variables show that the *uneven moisture profile* was a consequence of three variables which are; *uneven formation of the pulp on the wire, Mother Reel transportation and storage* and *Variations during the drying on the Yankee*. Also, the *Wrong setting during the unwinding* (Converting) was a consequence of the *improper pope winding, Mother reel transportation and storage, uneven moisture profile* and *External Disturbances during unwinding* (Converting).

The results from the KJ-Shiba brainstorming session were reflected upon and translated into Ishikawa diagram where priorities were finalized and x measurements clarified, see Figure 13.

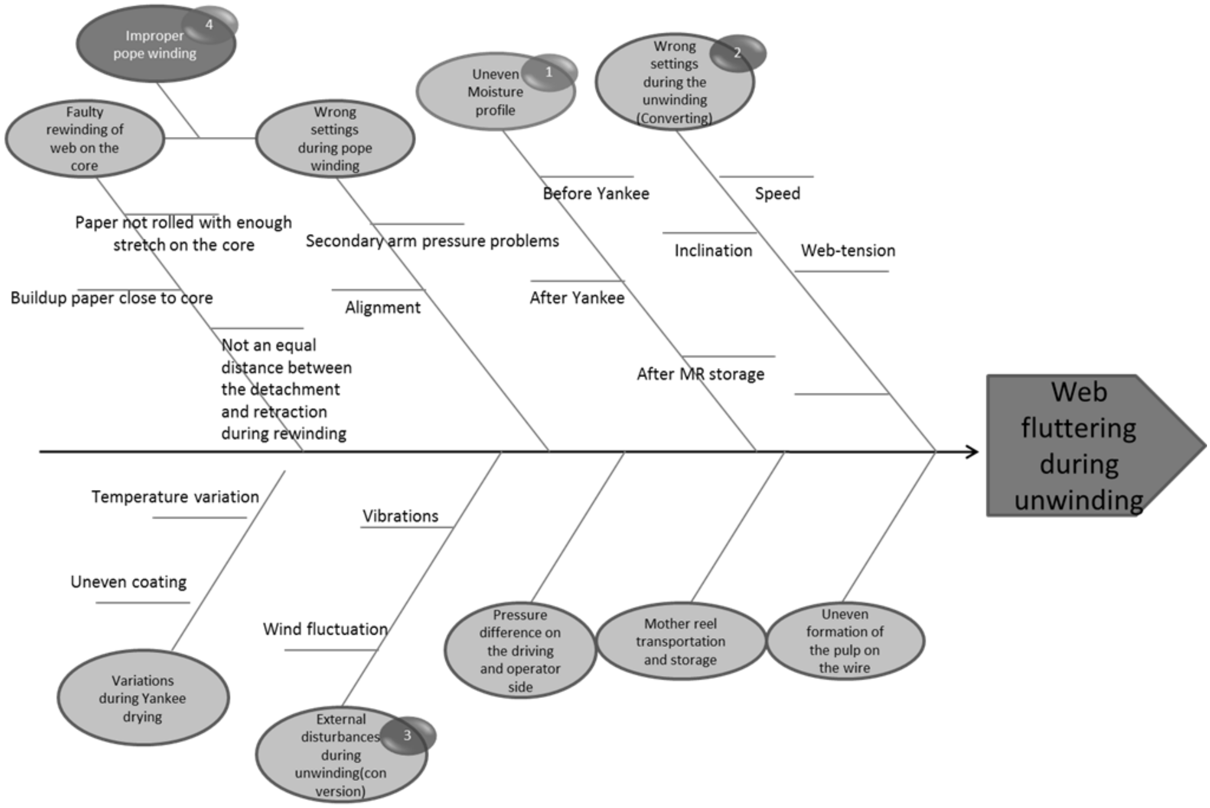

Figure 13. Ishakwa diagram displaying measurement priorities on; uneven moisture profile, wrong settings during unwinding, external disturbances during unwinding and improper pope winding.

4.2.3 Data collection plan

This section is divided into three parts; **Data preparation plan** that describes how the measurements were initially planned to be carried out, **Data collection plan** that describes how the database system was exploited to acquire the right data measurements, **Focused measurement report** that elaborates on the separate set of data collected.

Table 2 Preparation for data Collection

y measure	Web characteristics	Converting (Unwinding settings)
Operational Definitions	Cross sectional variation in the moisture content and surface weight of the web. Difference of radius on operator and driver sides of the MR. On paper qualities 2067 and 1067	The measurement will focused on a particular paper quality 2067 and 1067, where defects have been seen to be imminent most often through analysis of the data (see Appendix X).
Data source and location	Paper making QCS system (PM7), Manual measurements of the MR (PM7)	Converting line 10, PLAIN, QIS (Centerline), Internal Claim system, Video recordings
Sample size	Approximately 20 mother reels produced a day	Every production of paper qualities 2067 and 1067.
Who will collect the data	Representatives of PM7	Representatives of Converting line 10 and project analysts
When will data be collected	Every day from the 5th July, 2011 - End of August (On each MR produced)	Begins by end of week 31. Focused measurements in week 34. Frequency of data collection depends on planned scheduling accessed through PLAIN system.
How will data be collected	Through the IT report system (ABB control system) and manually by operators	Through automatic and manual measurements and video coverage - Speed data from plain system, web tension from QIS (Centerline), and Fluttering data will be collected through video recordings, supported by internal claim system. MR ID will be collected by operators manually.
x data should be collected at the same time	Cross-sectional moisture content after the paper making and surface weight, radius of MR from the core	Unwinding speed and speed differences, Web-tension, Angle of attack of first bowed roll Width and side of web fluttering. Frequency, date and time of web-fluttering.

Table 3 Data Collection Plan

COLLECTION OF THE DATA	STEP 1	STEP 2
Internal Claim System	Through the internal claim system. Locate the fluttering complaints that have been entered into the system.	Extract the MR ID and time the complaint was perceived to have happened. Also extract information about the fluttering, the width, the unwind stand it occurred on and what side it. Check for the run ability of the MR if it was still used or not.
VIDEO	Use to verify physically when the reported claim says fluttering occurs and to locate claims on fluttering that are not entered into the internal claim system	Collect web-fluttering date, time and unwinding stand side of web-fluttering. Also use as a base for collecting speed, web-tension and to identify MR.
CENTRELINE	Collect information on the MR IDs and web tension.	
PLAIN	Collect information on the speed difference. Planned production schedule for paper qualities 2067 and 1067. Further logbook information can be accessed to verify claims	
PM Measurement	Check the fluttered MR ID through the previous systems and then collect information about the MR when it was produced at the PM7	Collect information on Basis weight, Moisture content, Diameter of the FS and DS and the difference between both sides. Also look at the graphical undulations which have documented.

Focused measurements

The measurement was conducted so as to observe the characteristics of the MR after storage before consumed on the converting lines. As specified earlier in the data collection plan, the focused measurement followed on the paper quality and converting line already identified and selected for the measure phase.

Firstly, the cross-sectional diameter of each of the MRs before loaded into the unwind stands were taken on both the driver's and operator's side of the MR. This is collected for the purpose of investigating the MR symmetry and oval-ness.

Full length cross-sectional of 3.41m and specified vertical samples were collected on 10 MR's at each interval before these MR were loaded into the unwind stands at converting line 10. These samples were then carefully cut and sized at the SCA laboratory so as to carry out measurements on them. Two samples were collected for the specified vertical samples, on the driver's and operator's side of the MR. Each of the specified vertical samples were firstly placed in containers and then weighed to determine their moist weight while also having the standard weight of each of the containers without any content. The vertical samples were then placed in an oven of 102c for duration of 3hours after which they were then placed back into a container for an hour. Each of the samples was then weighed to determine the weight after this process. All data and information was collected and recorded for later analysis of difference of the moist content on the different sides of the MR.

The full cross-sectional samples were cut and sized, focusing 6 of 8 samples mainly on the edges of the driver's and operator's side of the samples and 2 in the middle area of the cross-sectional samples. These 8 samples were then sorted into layers of 4 plies where they were then further cut and sized for measurements on their stretch strength on both the machine length (MD) and cross-directional length (CD). For the basis measurement, using the same 8 samples earlier on in this measurement, samples were cut into layers of 8 plies for each cross-sectional sample and then weighed and measured to determine each sample thickness. All this data was carefully collected and recorded for later analysis so as to determine any variation in the stretch, strength, weight and thickness across the 3.41m cross-sectional length of the MR. The focused measurement for strength and stretch samples were replicated collecting data on an additional 9 MRs. The sample size collected for each measurement is presented in Table 4.

Table 4 Sample size collected on each measurement

Variables	MR (ID)	Strength MD/CD (N/m)	Stretch MD/CD (%)	Moist (%)	Thickness (µ m)	Weight (g)	Diameter (cm)
Sample size	10+(9)	160	160	20	80	80	20

4.3 Analyze

Based on data carefully collected in the earlier phases, in this phase they were subjected to systematic analyses using several graphical and numerical tools. The aim of this query was to develop, eliminate, and validate inferences towards the root causes of the problem focused on during the measure phase of the project.

To help validate the analysis, several measurements were taken especially in successive processes so as to have fluidity and continuity in the measurement system. However, some variables could not be pursued in the analysis due to resource limitations.

The focus of the analysis was to give inferences on where and what influence the occurrence of “Tissue splitting”. These analyses include the following below.

- Occurrence of MR “web-flutter” during unwinding (converting).
- Variations of the MR symmetry before and after storage.
- Variations in the weight, thickness and moisture profile of the MR web with respect to “web-flutter”.
- Variations in the MR stretch at break and tensile strength with respect to “web-flutter”.
- Speed behavior during fluttering (converting).
- Physical observations on converting line.

Using Minitab® and Microsoft Excel® as software, graphical analyses of the data are shown below with descriptions.

Occurrence of MR "web-flutter" during unwinding (converting)

Through video coverage of the unwinding phase during converting, observations towards the occurrence, location and frequency of "web-flutter" was collected across the three different unwind stands. The graphical data analysis is presented below, see Figure 14.

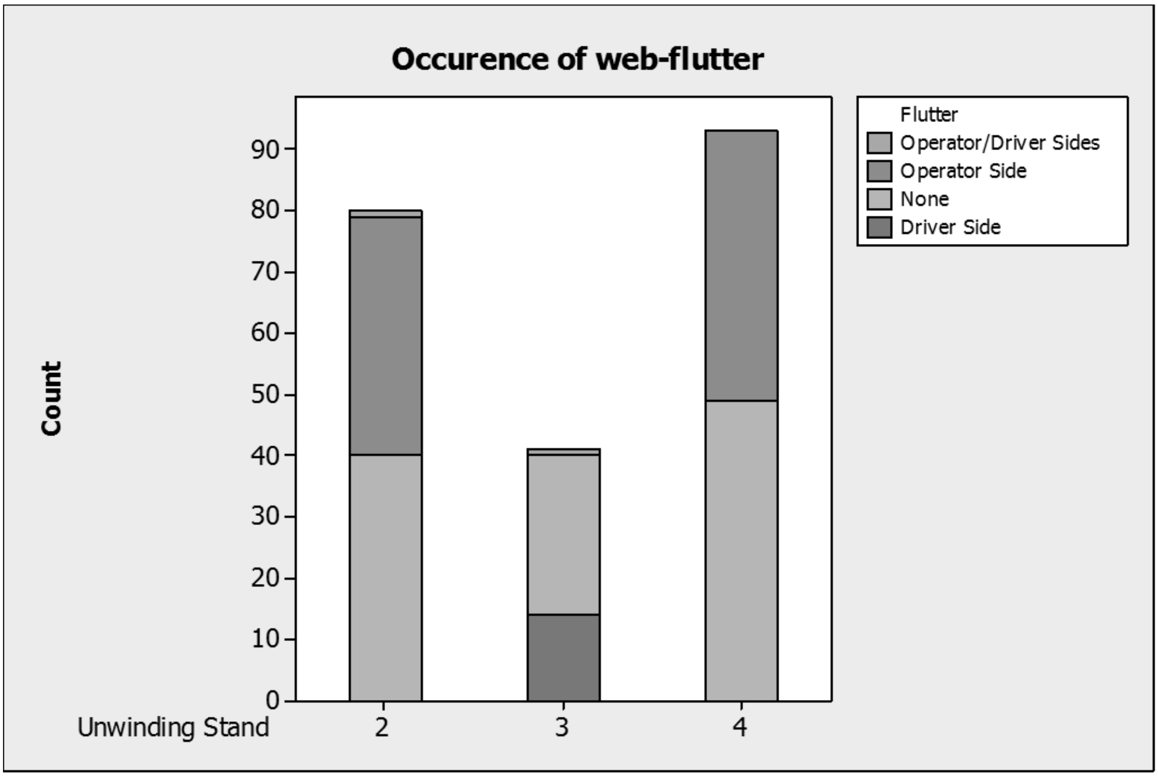

Figure 14. Frequency of fluttering on the three different unwinding stands on converting line 10.

Since unwinding stand 3 is reversed the "web-flutter" as seen in the graph can be isolated to one side of the MR during unwinding. The frequency of "web-flutter" is of equal value across unwinding stands 2 and 4 with a 50% occurrence of "web-flutter", while having approximately 35% "web-flutter" on unwind stand 3.

Variations of the MR symmetry before and after storage

Measurements were taken to analyze any variations as to the diameter of the MRs on both operator's and driver's sides before and after storage. 501 MRs were measured before storage, the operator sides had an approximate average of 162.1 cm and 160.7 cm on driver side, excluding MR core. The results from the analysis of the data showed an average difference of 1.4 cm between the driver side and operator side of the MRs' before storage, the operator side being the larger side. 10 MRs were measured after storage. The operator side had an approximate average of 185.5 cm and 186.2 cm on driver side, including MR core. This results in a 0.71 cm difference, the driver side being the larger side. See Appendix C and G for data tables.

Variations in the weight, thickness and moisture profile of the MR web with respect to "web-flutter"

Through a focused measurement, cross-directional variations in the thickness and weight of samples taken from MRs were analyzed. The cross directional variation in thickness differed between 90.6÷101.5 µm, and in weight between 1.3÷1.4 g. The moisture profile difference between operator and driver side of the MRs were analyzed to check for any variation. It differed between 6.62÷8.03 % on operator side and 6.75÷8.92 % on driver side. The average value of the moisture samples for the MRs was calculated to 7.4 % after storage. These variations were also analyzed with respect to the MRs which experienced "web-flutter" during unwinding to determine any patterns towards its occurrence. The results showed no trends in variation in thickness, weight or moisture profile towards "web-flutter". See Appendix C and E for data tables.

Variations in the MR stretch at break and tensile strength with respect to "web-flutter"

The variations of the tensile strength and stretch at break of the MR web in both MD and CD were analyzed. At stretch at break both paper qualities have the same specification limits, thus the average of all samples could be shown as one graph. As for the tensile strength, the paper qualities have different specification limits and are separated into two graphs, see Figure 15 and 16. A skewed web tension can be discerned, with lower values on the operator side increasing towards the driver side. Also noticeable is that the values in stretch at break are very close or falling below the lower control limit on the operator side and in the middle area of the web.

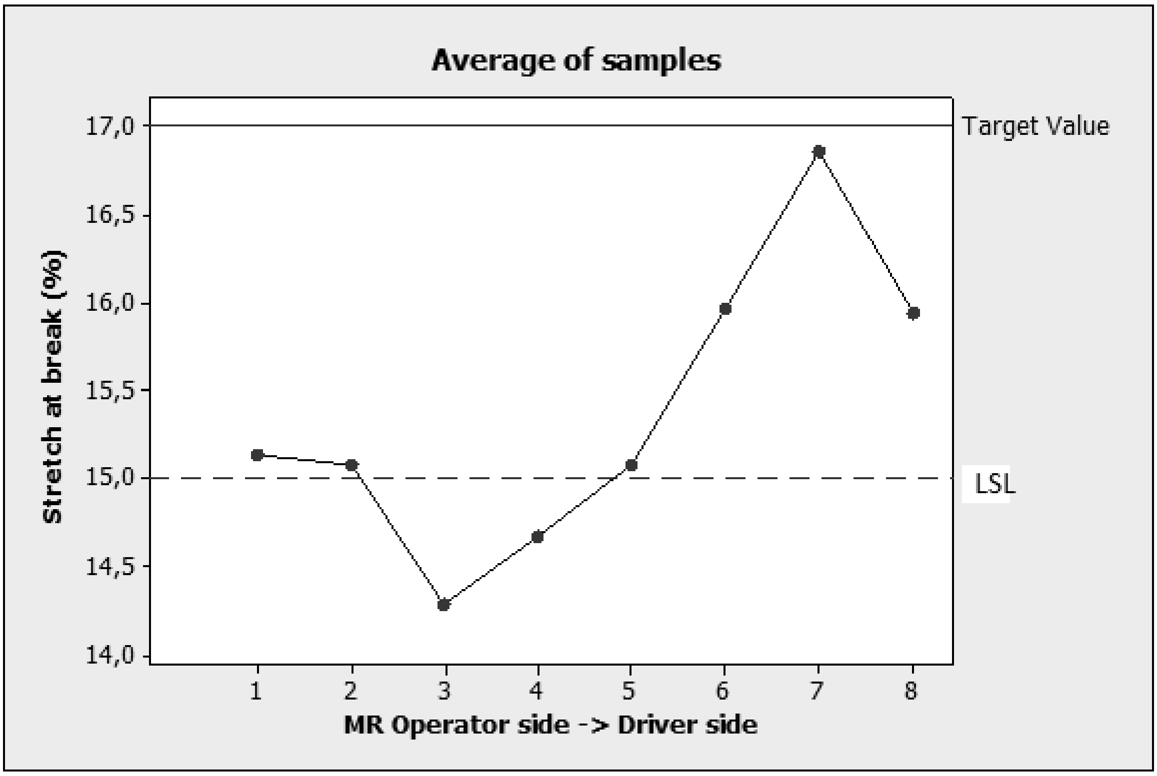

Figure 15. Average of all samples in stretch at break, measured in MD. Lower values can be seen from samples taken from operator side.

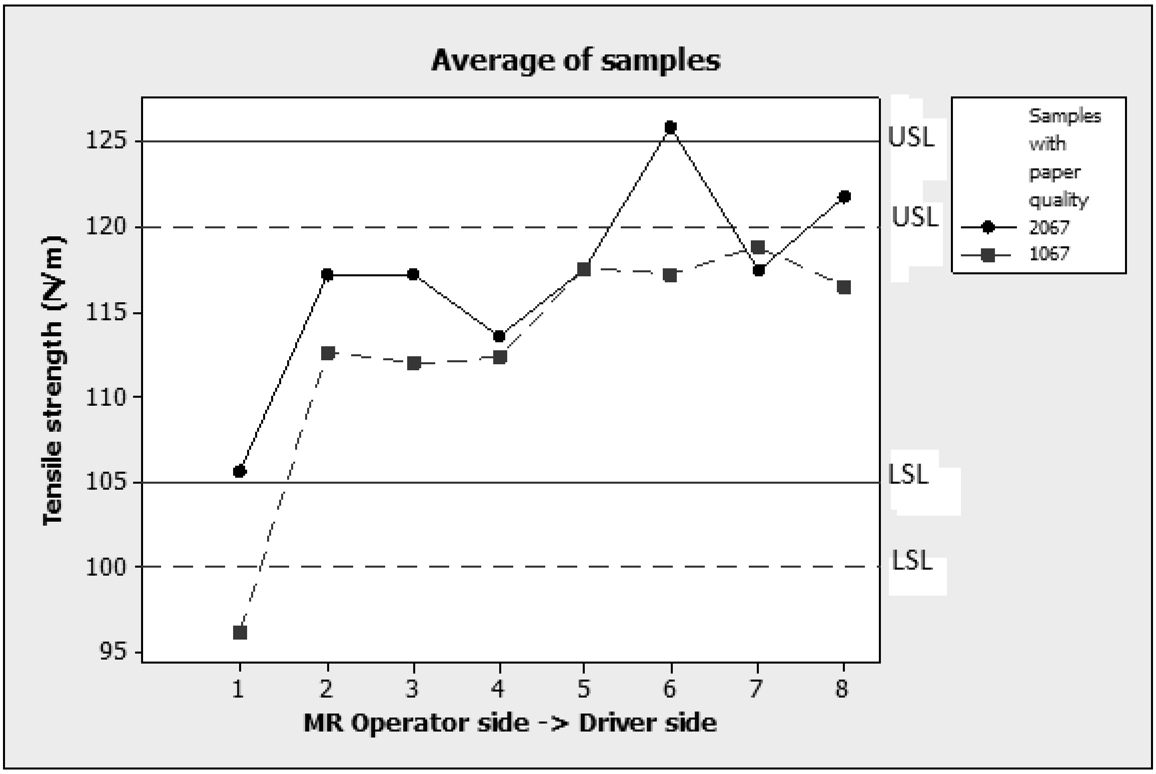

Figure 16. Average of all samples in tensile strength, measured in MD. Paper qualities 2067 and 1067 are viewed in two different graphs.

A similar trend can be seen in tensile strength in the CD, see Figure 17. However looking at the values in stretch at break, no apparent trend could be discerned, see Appendix D for data table.

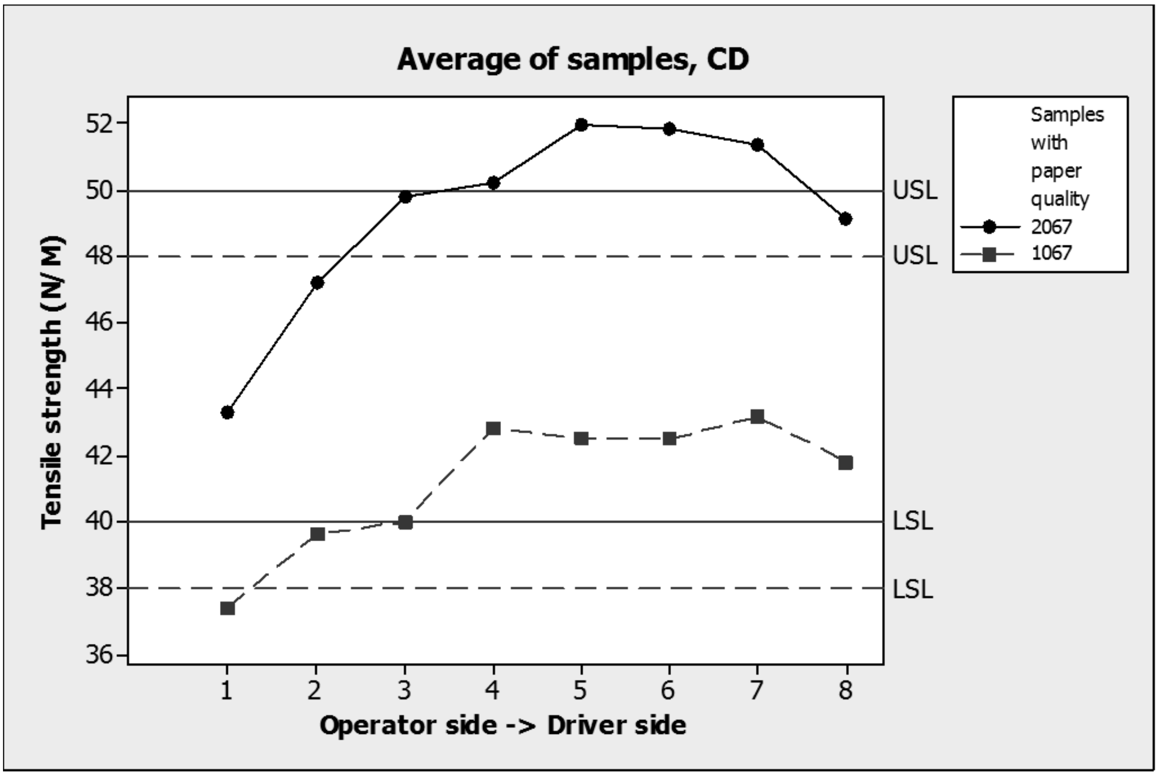

Figure 17. Average of samples in tensile strength, measured in CD. Paper qualities 2067 and 1067 are viewed in two different graphs.

Speed behavior during "web-flutter" (converting)

The speed behavior when the MRs fluttered was analyzed so as to determine any trends. The results from the analysis of the data show that fluttering occurred at both low and high speeds. It was also noticed that fluttering occurred at stable, accelerating and decelerating speeds with no particular trends, see Appendix F.

Physical observations on converting line

Other observations were established through physical assessment of the web and analyses of the video recordings during unwinding in the converting phase. It was noticed that there was a baggy-nature on the operator side on unwind stands 2 and 4 of the web when it fluttered and conversely on the driver's side of unwind stand 3 which is mirrored see Figure 19 and 20 as compared to Figure 18 showing a straight running web.

It was also noticed that there were wrinkles which could be observed on several MRs before and during unwinding in converting, see Figure 21.

Figure 18 Pictures a straight running web, during unwinding.

Figure 19 Web-flutter during unwinding on Driver side, Stand 3.

Figure 20 Web-flutter during unwinding on Operator side, Stand 4.

Figure 21 Wrinkles in web while running during unwinding.

4.3.1 Discussion

As could be seen from the physical observations and data analysis, the operator side of the MRs was seen to be the side which fluttered exclusively. It was also observed that almost 50% of the MRs fluttered which is significantly of a high value and probes for more investigations. Following below will be comments on several variables that were considered during the analysis.

Stretch at break and Tensile Strength

Figure 22 depicts the distribution of values collected for each MR in stretch at break. The figure includes all MRs tested during the focused measurements and is displayed as a box plot. The MRs with IDs; 0211, 1384, 1380 and 1585 were determined not to flutter during the physical observations. In the box plot three out of four have median values that fall below 14% and have a distribution of 1.7% or less between their 1st and 3rd quartiles. As compared to the other MRs which in general are above the 14% mark and have a wider distribution between their 1st and 3rd quartiles. From the paper-making process, the target value of the stretch at break for the paper quality 1067 & 2067 in the MD is 17% with an upper specification limit (USL) of 19% and Lower specification limit of 15% and specification limit of 12%. It is also necessary to emphasize the instability of this process with big variations in the values across the MRs produced, where 85% of the mean values fall below the target value and 36.8% below the lower control limit. Similar in CD for Tensile strength, the samples from paper quality 2067 tends to fall above the USL on the driver side of the MRs as seen in Figure 17.

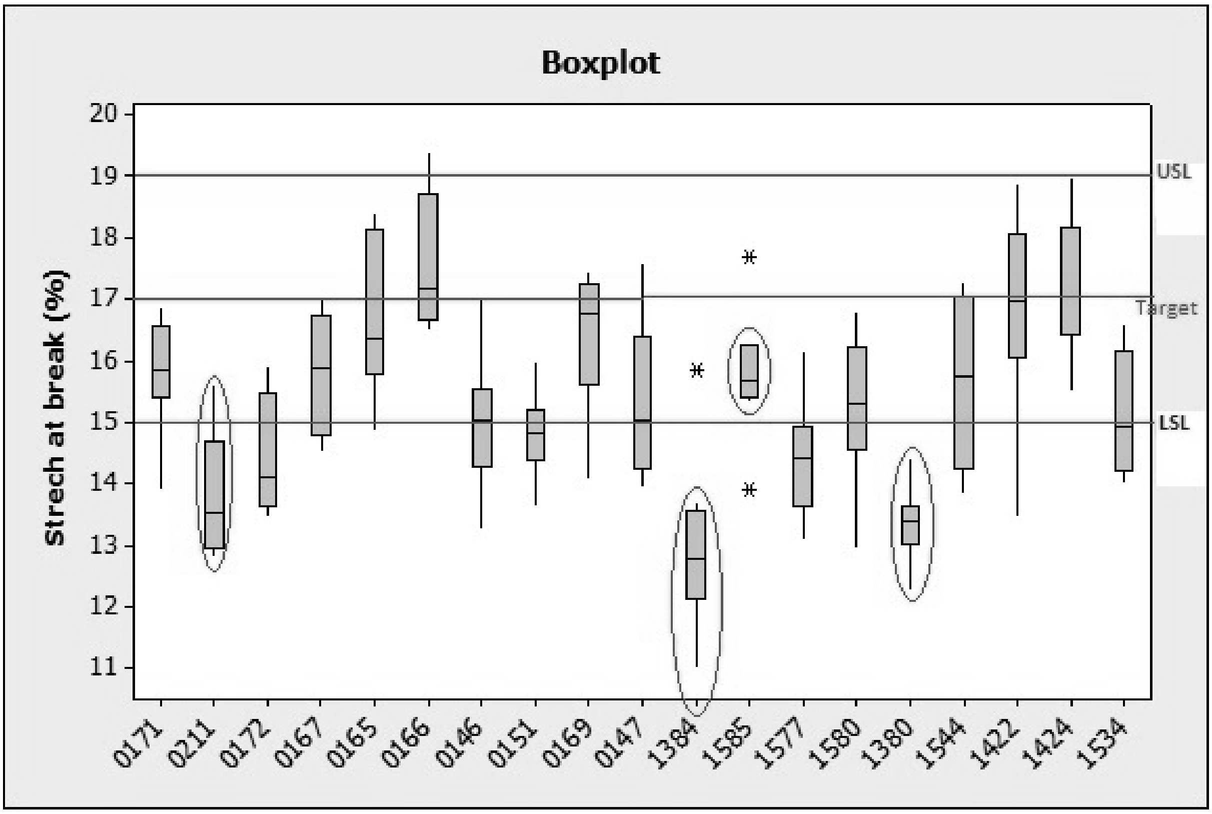

Figure 22 Distribution of the stretch at break values in MD. Samples collected from produced MRs on PM 7, the circled staples represent MRs that did not show "web-flutter" during unwinding.

Taking into consideration the results from the analysis of the data and looking at previous literature on the same subject, similarities can be seen. With reference to the physical observations made, different levels of tautness were seen on the web in the cross direction of the MRs, with a high level of slackness focus in the areas of the edges that were observed to have fluttered. Similar observations had been made in studies on the same subject by authors Land (2010), Roisum (2001) and Kulachenko *et al.*, (2006) see Section 2.1.

Furthermore, considering the trends noticed with the stretch at break and tensile strength, results can be related to a similar study by Roisum (2001). He reasons that the variation of the stress and strain across the cross-direction is one reason for these areas of slackness and tautness. In particular, he highlights the case of the web exhibiting one slack part and terms this occurrence as "Pure Camber". In this case, the web will show a linear trend from one side to the other causing the end with the lower values to become looser than the part with higher values which can be seen in Figure 2 and be compared with Figure 23. Roisum (2001) example of "Pure camber" coincides with the findings from analysis which shows a similar regression trend in stress and strain, see Figure 24.

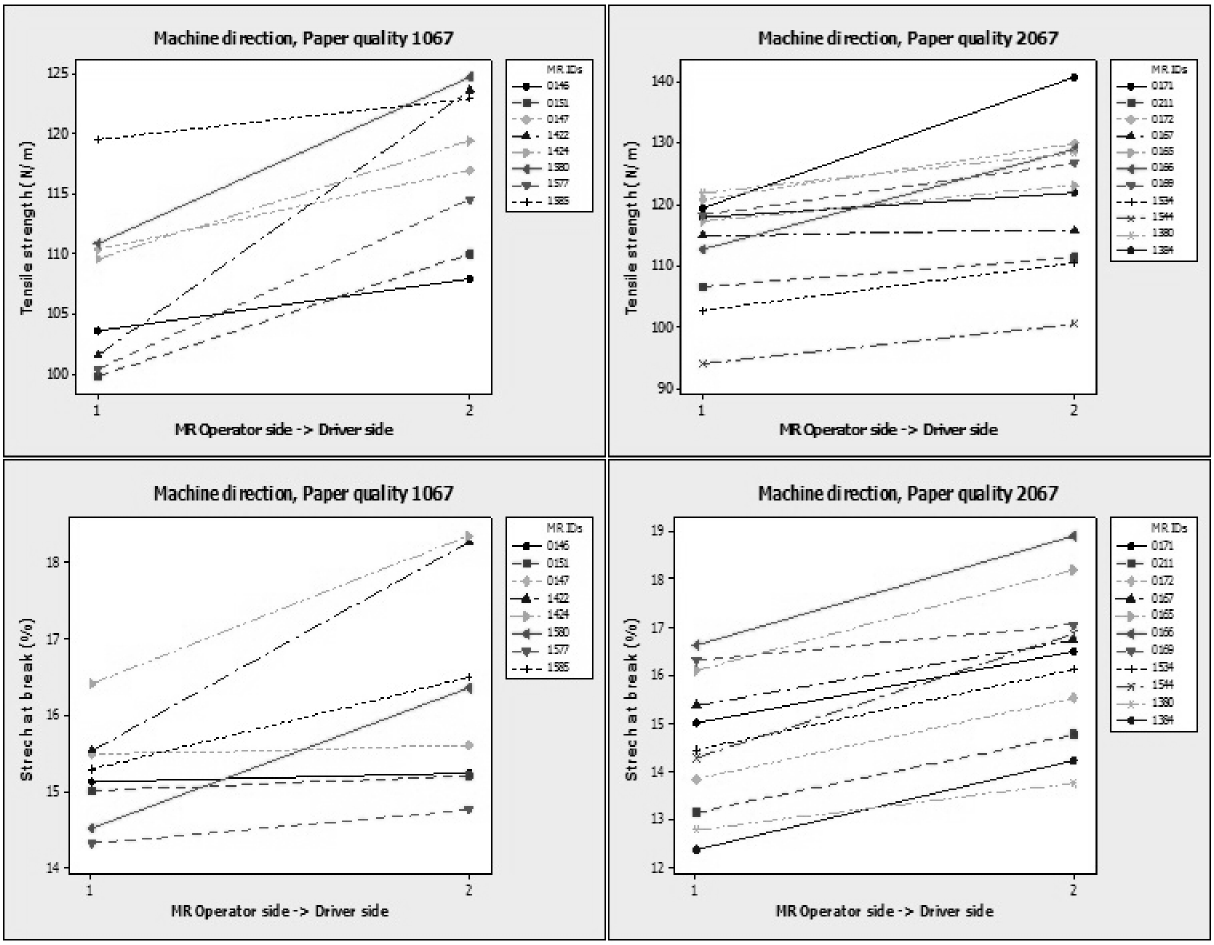

Figure 23 Scatter plot distribution of MRs in stretch at break and tensile strength.

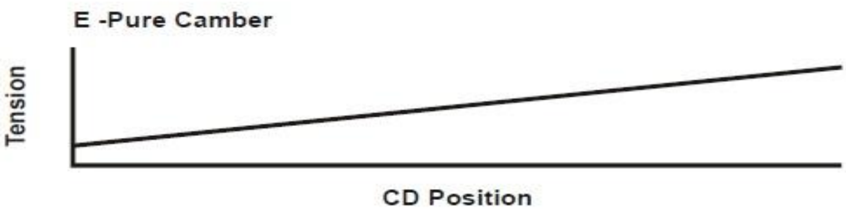

Figure 24 Graph of a linear trend in stress or strain in paper web. Roisum (2001).

Due to the fact that only a few samples of the MRs produced at the Edet mill were considered during this project as a result of production constraints and time. Recommendations on further tests to be carried out on more MRs with more samples cross-directionally across the web so as to further understand the trends and variations of the stretch at break and tensile strength. Also to make more concrete conclusions on the variation in papermaking process a substantially larger sample size would have to be required. Looking at other PMs and converting lines with similar paper quality production as focused on during this project will be a good area to also develop inferences towards the trends and variations of the stretch at break and tensile strength.

Finally, these variations of the stretch at break and tensile strength could be directly a result of irregularities in the paper making process. An extensive research on the variables and factors which influences the stress and strain properties of paper during the paper making process would be a good step in uncovering the root cause of this variation.

Wrinkles

Conversely, looking from the physical observation during the analysis, wrinkling in the MRs could be observed as a fact, see Figure 2 and 21. This has also been highlighted in studies from Roisum (1996) and Kulachenko et al, (2006). They relate wrinkling as a major contributor to “Tissue splitting” as the wrinkles folds when the web passes through the nips in the embossing phase during the converting process. They argue that wrinkles appear when a MR is exposed to environments which make it want to expand beyond its equilibrium state. Roisum (1996) identified the causes of such constrained expansion to; moisture increase, solvent increase, temperature increase or tension drop.

Connecting this back to the empirical environment at Edet mill, it is very likely that one or more of these potential causes vary in the factory. Seeing as the wrinkles first appeared on the MRs after they had been transferred to the converting lines from the storage. The environmental conditions of the storage room are likely to be affecting the MRs equilibrium.

Also Kulachenko *et al*. (2006), suspect that external pressure can cause the same phenomenon. Observing as the MRs are transferred in and out of storage by a heavy automated lift which grabs the whole MR surface area. Substantial pressure is applied to the MRs, thus making this another likely cause of wrinkles.

Therefore, wrinkles on MRs can be seen as a direct cause of “Tissue splitting” which does not necessarily influence “web-flutter”. More study on the effects of wrinkling in the empirical settings of Edet mill, is an area for further research.

Variations of the MR symmetry before and after storage

The symmetry results before and after storage on MRs turned out inconclusive. Before storage measure shows an approximate average difference of 1.4 cm, where the operator’s sides were larger compared to the driver’s sides. This is a reverse in the10 MRs that was measured after storage that showed 0.71 cm difference, where the driver sides were the larger sides. These disputable results can be attributed to different measurement techniques used before and after storage.

The set target for a MR produced at PM 7 is 190 cm. During these measurements, including the MR cores places the measurements taken before storage close to the target values, while the after storage measures fall a few centimeters short of it. Also, before storage measure had substantially more measures collected. Therefore, before storage measure of MRs diameter can be considered a more reliable source.

Accepting the before storage measures suggests that PM 7 were producing uneven MRs. The roughly 1% larger operator side could in theory affect run-ability during converting. It is difficult to determine if the 1% difference across sides are of any significance. Seeing as the MRs produced generally suffer from skewed web tension that is argued in this report to be a probable cause of baggy web. An increase in length of the baggy parts of the web would be a natural outcome. Furthermore considering paper exposed to unstable environments, it is likely to change in its state of equilibrium which can cause a potential difference in the symmetry of sides in the MRs.

Air flow

An important variable which affects “web-flutter” also is the effects of external disturbances. Air flow during the unwinding process has been found to have influences on “web-flutter”. Chang & Moretti, (2002) study looked at the interaction of air with the web which they presumed can cause the free edges to vibrate violently. Paper web being a very wide, thin and non-uniform material when exposed to axial velocity creates forces in different directions, which directly affects the surrounding air flow as well as the paper characteristics itself (Kulachenko, et.al. , 2006). When the paper web interacts with the surrounding air flow, it tends to get dominated by the surrounding air. This alters the web making it deflect out-of-plane (Chang & Moretti, 2002).

An experiment created by Chang & Moretti (1992), on cross-air-flow influence on the moving paper web could disregard that “web-flutter” was caused by random turbulence. They rather suggested that it was the result of the velocity of web and air. Later Watanbe & Sueoka (2001) confirmed these results, writing that “web-flutter” amplitude increases gradually with increased wind speed. Chang & Moretti (1992) also showed that the waves created by the cross-air-flow increased in amplitude toward the edges of the web.

Discussing airflow influence on web-flutter is important to underline that airflow is a three-dimensional issue, which is hard to replicate. Most of the experiments carried out on the phenomenon have been made with two-dimensional experiments.

However due to inadequate resources in physical measuring equipment and time, this variable was not researched in this study. It was not possible due resource inadequacy to measure the flutter amplitude and frequency and also the physical diagnosis/observations of “web-flutter” were subjective. Therefore, “web-flutter” behavior could not be related directing to the measurement data collected. This relates also directly to the process speed effects on “web-flutter” which cannot be eliminated until objective measurements can be carried out. The area of air flow is recommended to be further studied at Edet mill.

4.4 Improve

As no improvements were carried out during this project, this chapter will be dedicated to recommendation areas. Also criticism towards the measures that were carried out will be presented.

4.4.1Recommendations

Suggestions or recommendations have been drawn out towards improvements that will facilitate better operations in terms of traceability and problem solving in the future. These recommendations can be explained as long term solutions of: improving the databases used presently so as to increase traceability for problem solving; addressing the current state of the quality control system; and a short term solution of adopting the use of video coverage to monitor processes.

Long-term Suggestions

Improved databases to increase traceability

There have been several databases analyzed during the course of this project to collect, manipulate, verify and draw out conclusions according to the peculiarity of the problems encountered during this project. Based on mostly observations and problems encountered due to continuous operations of these database systems, it has been observed that there is lot of duplication information, incorrect or in some cases insufficient information entered into them. A few suggestions will be presented as recommendations towards procuring solutions to the afore-mentioned problems. These suggestions will be presented as immediate and long-term suggestions.

Continuous synchronization of the databases with real-time events which they track is an immediate issue that should be addressed. As observed through analysis during the project, problems were encountered when the TS database system was used for tracing MRs ID to MR stands during the converting process. This was evident as a video coverage system was installed so as to validate the collection of this information. It was noticed that there was a mismatch between the information in the TS database system and real-time events.

Suggestions towards the standardization of the routines and information which are entered into the database system manually. It was observed that there were variations in silimar information entered into the database systems by shop-workers individually and by shifts. This invariably created problems in terms of an objective description and view on problems and routines towards enetering these information (problem codes) into these databases. Also noticed was poor traceability between the external claim and internal claim system due to little or no standardize form of collection of information in the internal claim system. Creating standard procedures and trainings towards the description of common problems will help maintain fluidity towards understanding the effects of these problem and problem-solving.

A suggestion for the future is the creation of a central system where all necessary information is entered into a single database system. This will help centralize information, keep consistency, reduce errors, and keep a centralized view on the information entered especially across functions or processes that work together (converting and paper-making). An initial step towards this proposition is by identifying common information which is duplicated across the various databases and brainstorming across the various users of these databases as to which information is relevant, commonly or functionally used.

Finally, one of the purposes of creation of database systems is to help in the traceability of problems to their origins of development during the whole production process. Synchronization, ambiguity, and traceability of information in these systems should be a grounded thought when applying these improvement suggestions.

Quality control

There is a routine and well defined manual for the internal quality control currently at Edet mill. This explicitly states how and where controls should take place and are reported back to QIS. However, for unknown reasons very few defects are detected and entered into QIS, which does not reflect the true value of defects. Instead, the external claim system has become the most reliable source. This way of receiving feedback on defects has two major issues. Firstly, it can safely be assumed that only a fraction of the defective products are shown in the claims, since it is a low cost product. Secondly, it is a very slow process that can take months in between production until claims are received. Thus, there is not any certainty of the quantity of the defective products, namely Tissue splitting, on the external market.

If any improvement initiatives were to be carried out directly towards Tissue splitting it would be very hard to track the immediate progress. It would require a more reliable quality control, where sigma levels can be assured before and after any improvements are initiated.

Short-term Suggestion

Measurements system

Video coverage and monitoring was adopted for processes that were particularly focused on during measurement and analysis on this project. This adoption was a relevation as it showed a lot of details which were often missed by operators. It also served as a good validation system for problem-solving as a complement to the other database systems. The acquistion and installation of these video coverage and montoring systems is relatively cost-effective and could be adopted in a lot of other systems where problems are encountered or perceived.

4.4.2 Criticisms of measures

In this investigation, “web-flutter” was treated subjectively. It was measured through video coverage and analyzed by physical observations. Therefore no concrete measures on web-flutter could be made such as ‘flutter amplitude’, ‘flutter frequency’ or ‘flutter speed’. With such variables available a much more in-depth analysis could have been carried out. Correlation might have been found between different factors in “web-flutter” and the factors measured in this project. Unwinding speed during converting is one of these factors that are perceived to require more concrete measures of “web-flutter” in order to find any correlation.

4.5 Control

The control phase usually commences with setting controls towards sustaining the improvements suggested and implemented in the previous phase of the DMAIC framework. This represents creating guidelines, manuals, new techniques and control plans so as to maintain and continuously sustain improvements implemented. On this project, this phase was not fully arrived at due to some unforeseen circumstances and constraints however; proposed actions to be carried out and benefits with respect to this project will be elaborated in this chapter. In that respect, recommendations towards upgrading the use and performance level of statistical process control techniques will be presented.

Statistical Process Control (SPC) charts graphically represent the variability in a process over time. They are usually used to monitor processes, where control charts can uncover inconsistencies and abnormal variations. In cases where there is no special-cause variation found to be present in the process, SPC helps define the capability of the stable process to evaluate whether it is operating at an acceptable level. As a result, SPC charts are used in many industries to improve quality and reduce costs (Wheeler & Chambers, 1992).

As could be seen in the discussions of the results arrived at during this project, see Section 4.3.1, there was a lot of variation in some processes in the tissue paper production. This was evident with a lot of inconsistences and deviations of processes from set target values, control limits and specifications.

Recommendations on applying statistical process control so as to understand and reduce these variations and manage them during production.

5 CONCLUSIONS

The primary defects investigated during this thesis were the issues of “Tissue splitting” and “web-flutter”. Quantifying the resulting financial impact due to these defects occurrence demonstrated large economic losses for the mill on a yearly basis.

From the analysis conducted, it could be discerned that the paper web are being produced with a skewed cross directional profile in stretch at break and tensile strength. As discovered through the results of the analysis, the paper web had inherently different properties after production at the papermaking process. This unevenness of its properties resulted in differences in length across the paper web. This gave the appearance of a baggy web, where slack and taut areas of the web could be discerned. Running the unwinding operation with paper web with this defect, will lead to “web-flutter”, where the slack parts of the web will suffer. Also, “web-flutter” was discovered to have a great risk of causing “Tissue splitting”. The root cause behind “web-flutter” was traced back to the papermaking machines and its processes at the mill and a solution to the problem would have to be sought there. These conclusions were made through in-depth analysis and research which are highlighted in this report.

Another issue that is attributed to “Tissue splitting” and was eminent at Edet mill was wrinkling on the MRs. Visible wrinkles on the paper web often results in folds during the converting process as the web passes through nips which in-turn results in permanent folds or creases in the output products. The origin of the wrinkles was traced back and isolated to the transportation and environmental differences which the MRs were exposed to at the mill.

On a concluding note, the investigation conducted in the master’s thesis has presented interesting and valid results that can be utilized as a solid platform for proffering solutions to defects in the paper production mill. However, more study by other researchers should be carried out so as broaden and concretize findings and results on this area.

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Appendix A

Project Charter

Project Title: Investigation on defects in paper production process, a Six Sigma Black Belt project at SCA Edet mill.

Company/Organization	SCA Hygiene Products, AB	**Unit/department**	Edet paper mill
IT Champion		**HR Champion**	**Göran**
Sponsor & Process owner	**Jonas Pihlström, Johan G.**	**Site or location**	**Lilla Edet, Sweden**
Project start date	**2011-04-27**	**Project completion date**	**2011-10-21**
Expected impact level		**Expected financial impact**	

Element	**Description**	**Charter**
Project description	A short description of the project.	A quality problem has been observed by end consumers in form of tissue splitting with the final products. This could be attributed to several parts of the process, and it is paramount to pinpoint the source of the defect in the process. Over-excessive web-fluttering was identified as cause to the tissue splitting problem. As the plant runs 24/7/365, a frequent occurrence of this problem leads to customer dissatisfaction, under-utilization of workforce and man-hours due to rework. This evidently leads to increase overhead cost.
Impacted process	The specific process/es involved and where opportunity exists	Key processes where the quality problem could be attributed to presently are: Paper-making process and converting process.
Benefit to customers	Define internal and external customers (most crucial) and their requirements.	Representatives of the Home-consumer products converting lines To keep the web-fluttering to a minimum degree that will not lead to web- breaks or tissue splitting without reduction of the process speed. manage the web- fluttering without it causing any quality problems
Benefit to business	Describe the expected improvements in business performance.	Short term benefits: Maximum utility of workforce and man-hours and process efficiency. Reduction waste Cost efficiency Increase customers satisfaction (internally) Long term benefits: Solving the quality problem can increase the market share probabilities. Increase customers satisfaction (externally)
Project delimitations	What will be excluded from the project?	This thesis will be limited to SCA, Edet paper mill, Sweden. Thus, the thesis project will follow a single case study approach. During the measure and analyze phase of this project, external wind which influences the term called “web-flutter” which consequently could cause “tissue splitting“ will not be considered during these phases due to scarce measurement resources. It is also assumed that the components in the converting machine or used during the process are in standard condition.
Required support	Support in term of resources (human and financial) required for the	Representatives of Paper-making, Converting process, Marketing, IT and Human Resources.

	project.			
Team members	List names of Master students.	Robbie Hällås Henry Savage Olugbenga		
Specific goals	Define the Baseline, your realistic goals for the project and the best case target for improvement.	Actual value (Baseline)	Realistic goal by project end date	Best case goal
		To identify parts of the process where the problem could be seen.	To identify the root cause of "web-flutter" and other likely cause resulting in Tissue splitting.	To reduce the degree of web-flutter.

Appendix B

Paper qualities sorted into product groups

Paper Machine	Paper quality 1	Paper quality 2	Paper quality 3	Product type
7	251134100	251134100		a
7	251134100	251134100		a
7	251134100	251134100		a
7	251134100	251134100		a
7	251134100	251134100		a
7	251134100	251134100		a
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
7	106734100	206734100	206734100	b
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171316700	171316700		c
5	171334100	171334100		d
5	171334100	171334100		d
5	171334100	171334100		d
5	171134100	171134100		d
5	171134100	171134100		d
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
5	176034100			e
7	251134100	191134100		f
7	251134100	191134100		f
7	251134100	191134100		f
7	206734100	206734100	206734100	g
7	206734100	206734100	206734100	g
7	206734100	206734100	206734100	g

Appendix C

Moisture content and after storage diameters

Mother Reel ID	Diameter of MR Measurement after storage			Moisture level after storage (%)			
	Diameter OperatorSide	Diameter DriverSide	Diff. OP-DS	PM Operator side	PM Driver Side	Average	Diff.
2671110165	186,69	189,23	2,54	7,62	7,34	7,48	0,28
2671110166	189,23	191,135	1,91	7,18	6,93	7,06	0,25
2671110167	189,23	190,5	1,27	7,31	7,25	7,28	0,06
2671110171	186,69	188,595	1,91	7,23	7,17	7,2	0,06
2671110172	189,865	189,23	0,64	7,21	6,75	6,98	0,46
2671110147	189,23	188,595	0,63	[redacted]			
2671110146	189,23	189,865	0,64	8,03	7,74	7,89	0,29
2671110151	189,23	189,23	0,00	6,62	8,62	7,62	-2
2671110211	186,055	186,69	0,63	7,34	7,27	7,3	0,07
2671110169	159,385	159,385	0,00	7,23	7,5	7,36	-0,27
Avarge	185,4835	186,2455	-0,76				

Appendix D Stretch at break and Tensile strength data

	MR ID	171		211		172		167		165	
Sample	**MD**	Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch
1		106,3	15,3	96,1	13,4	109,6	13,9	106,6	15,5	109,2	15,8
2		124,9	15,8	114,0	13,2	120,7	13,5	126,3	16,1	119,6	15,8
3		126,8	13,9	109,6	12,9	132,1	14,1	111,7	14,5	122,9	16,7
4		141,7	15,7	106,3	12,8	131,0	14,1	106,0	14,6	109,1	16,0
5		141,5	16,3	123,9	13,8	113,6	13,5	112,3	15,6	123,7	14,9
6		133,5	15,9	115,6	15,0	135,8	15,9	118,5	17,0	129,2	18,0
7		129,7	16,7	108,0	15,6	125,1	15,6	112,5	16,3	120,8	18,4
8		159,2	16,9	110,5	13,7	128,8	15,0	116,5	16,9	119,5	18,2
	CD										
1		43,3	2,0	41,1	2,8	43,6	2,5	44,4	2,7	43,5	3,2
2		48,4	3,2	37,5	2,8	49,2	2,5	51,2	2,4	46,7	3,0
3		49,9	2,7	41,8	2,7	48,5	3,0	54,1	3,0	56,8	3,3
4		57,8	1,6	44,4	2,8	52,6	2,1	49,6	2,4	53,6	2,9
5		54,7	2,1	48,9	2,8	52,2	2,1	54,1	2,3	56,3	3,0
6		55,1	2,2	48,8	2,9	50,5	2,3	51,0	2,8	53,3	3,0
7		72,3	2,6	43,4	3,1	50,1	2,8	47,9	2,9	50,3	2,9
8		47,7	2,5	43,3	3,0	52,5	2,4	50,2	2,8	53,6	3,0
	MR ID	**146**		**151**		**147**		**1585**		**1577**	
	MD	Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch
1		98,2	14,8	88,2	15,2	102,5	16,8	105,0	16,3	89,3	14,9
2		99,0	15,3	102,5	14,6	114,8	15,0	126,5	15,7	108,2	14,9
3		113,4	15,2	108,6	15,2	113,7	14,6	127,1	13,9	103,6	13,1
4		116,0	13,3	118,5	13,6	114,9	13,9	110,8	15,7	94,6	14,2
5		115,4	15,6	108,7	14,3	129,4	15,1	128,2	15,3	102,2	14,1
6		101,6	14,2	107,7	14,8	129,4	15,1	112,2	15,7	120,2	13,5
7		113,1	17,0	109,8	14,8	112,6	17,6	126,5	17,7	114,6	16,1
8		109,0	14,4	112,5	16,0	108,9	14,1	130,1	16,1	108,8	14,7
	CD										
1		33,3	3,0	33,0	2,8	49,1	6,0	40,9	4,2	37,0	3,5
2		36,6	3,7	34,3	2,3	35,9	3,8	47,0	3,5	40,2	3,2
3		30,4	3,6	38,9	2,6	37,6	4,0	44,4	3,2	40,4	3,2
4		35,8	2,5	44,3	2,5	51,5	5,2	49,4	3,4	39,9	3,2
5		40,8	3,3	43,7	2,6	43,4	3,1	49,5	3,1	43,1	3,4
6		43,5	3,7	42,0	2,6	43,4	3,1	46,8	3,0	45,0	3,9
7		40,7	3,5	40,4	2,8	42,5	3,7	45,8	3,8	42,6	3,4
8		40,4	3,8	41,2	3,0	39,9	3,3	47,2	3,8	40,8	4,0

166		169		1384		1380		1544	
Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch
109,9	16,7	113,4	16,0	116,1	12,7	112,1	13,0	88,4	14,0
112,8	16,5	125,1	17,5	120,7	12,1	122,2	12,3	96,0	15,0
115,3	16,7	116,6	15,5	116,6	12,4	131,5	13,1	97,9	13,8
123,7	16,7	105,4	14,1	103,0	12,8	115,7	13,5	96,0	16,4
133,5	17,6	120,1	16,8	100,8	11,0	123,9	13,7	93,5	15,5
130,9	18,5	126,3	17,2	125,7	13,1	128,0	13,6	107,8	17,3
123,2	18,8	125,6	17,3	120,8	15,8	122,7	14,4	99,2	17,3
133,2	19,4	128,2	16,7	119,1	13,7	134,5	13,2	94,6	16,1
38,6	3,4	46,1	3,3	49,7	3,5	50,4	3,2	35,0	2,7
44,1	2,9	49,2	3,1	51,8	3,7	51,4	3,4	45,1	2,6
48,0	2,9	51,0	3,3	51,3	3,7	51,5	3,3	43,2	2,9
47,8	2,5	54,9	2,9	47,3	2,4	53,8	3,5	40,3	2,7
51,7	3,3	54,0	2,8	53,8	3,0	56,5	3,4	42,4	3,0
50,3	2,9	56,8	3,5	53,1	2,7	53,8	3,2	46,3	3,6
55,0	3,2	48,1	3,8	47,7	2,9	55,4	3,4	43,5	3,5
		55,3	3,3	46,0	3,5	55,5	3,8	39,1	3,4

1580		1422		1424		1534	
Strength	Stretch	Strength	Stretch	Strength	Stretch	Strength	Stretch
96,6	15,2	91,2	17,0	98,7	16,7	93,7	14,4
119,6	15,4	113,7	16,1	116,9	17,0	106,9	14,8
116,4	13,0	99,9	13,5	113,2	15,5	107,5	14,2
119,8	15,1	109,2	16,0	114,7	16,3	110,9	14,0
124,4	14,4	114,2	16,9	117,9	17,1	106,2	15,1
124,9	16,3	122,4	17,8	119,2	17,8	132,4	16,6
123,4	16,8	125,5	18,9	125,0	19,0	103,7	16,4
125,8	15,9	123,0	18,2	114,0	18,3	95,3	15,3
38,9	3,7	38,7	3,1	28,6	2,5	40,3	2,2
46,6	3,7	38,0	3,1	38,5	3,2	44,9	1,6
44,6	3,3	46,3	2,8	37,3	2,6	51,4	2,8
45,8	3,6	41,8	3,1	34,1	3,1	50,2	2,5
45,9	3,8	39,2	3,2	34,5	2,8	46,7	2,3
39,8	3,0	38,3	3,2	41,1	3,2	51,3	2,7
46,9	3,9	39,4	3,3	47,0	3,5	51,1	3,1
44,5	4,2	40,3	2,6	40,2	3,3	43,5	1,9

Appendix E

Thickness and weight data

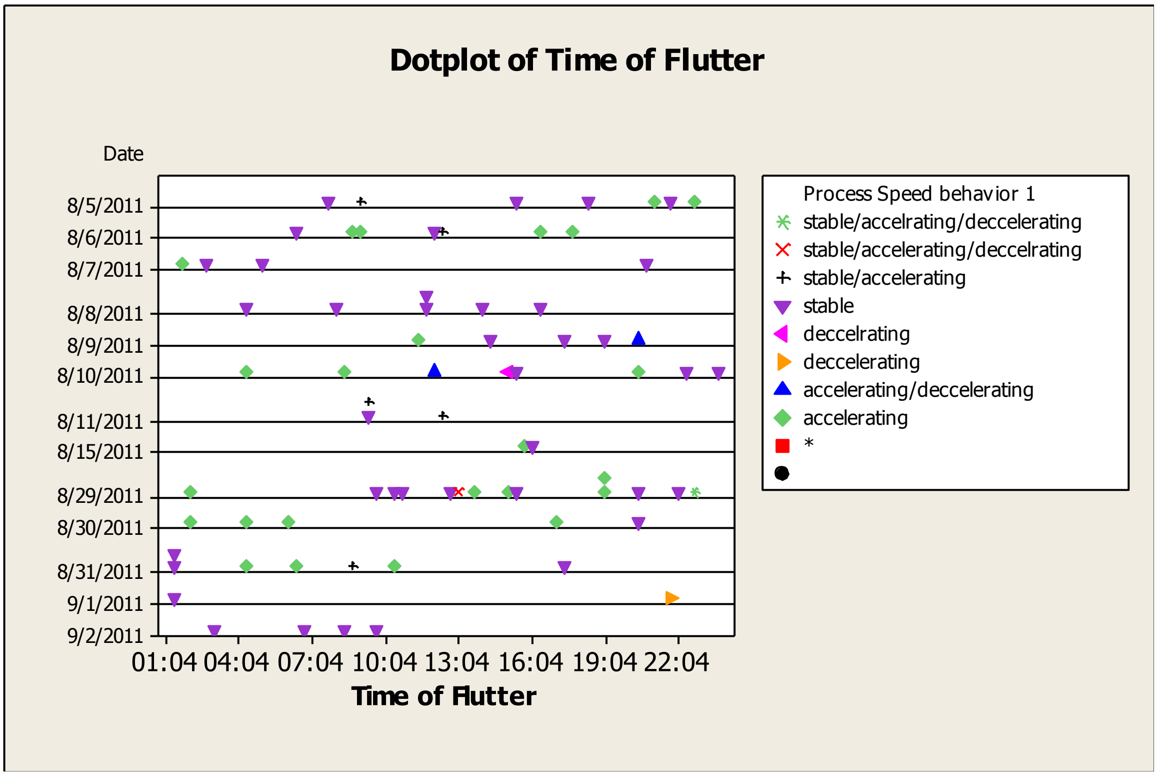
THE CROSS-SECTIONAL SAMPLE OF THE MR - THICKNESS AND WEIGHT

Mother Reel ID	267110146		2671110169		2671110165	
Sample	[redacted]					
	Thickness(µm)	weight(g)	Thickness(µm)	weight(g)	Thickness(µm)	weight(g)
1	103	1,26	96	1,3	96	1,34
2	103	1,33	96	1,37	95	1,34
3	101	1,33	96	1,41	94	1,36
4	101	1,41	90	1,43	95	1,36
5	100	1,31	94	1,38	94	1,33
6	101	1,34	93	1,42	94	1,37
7	103	1,36	95	1,36	95	1,35
8	100	1,35	95	1,39	93	1,26
Mother Reel ID	2671110166		2671110147		2671110171	
Sample	[redacted]					
[redacted]	Thickness(µm)	weight(g)	Thickness(µm)	weight(g)	Thickness(µm)	weight(g)
1	94	1,3	105	1,3	95	1,36
2	93	1,37	103	1,34	98	1,4
3	94	1,37	99	1,36	96	1,43
4	91	1,28	101	1,3	95	1,43
5	93	1,36	101	1,32	95	1,4
6	93	1,38	101	1,42	95	1,37
7	91	1,32	103	1,35	96	1,4
8	93	1,34	103	1,37	94	1,37

2671110172		2671110151		2671110167		2671110211	
[redacted]							
Thickness(µm)	weight(g)	Thickness(µm)	weight(g)	Thickness(µm)	weight(g)	Thickness(µm)	weight(g)
96	1,26	101	1,28	90	1,36	96	1,32
95	1,35	101	1,28	91	1,33	95	1,44
96	1,28	98	1,38	90	1,4	95	1,35
96	1,27	98	1,34	91	1,32	96	1,33
96	1,32	100	1,36	90	1,34	99	1,42
95	1,34	100	1,33	90	1,32	98	1,4
96	1,33	100	1,35	93	1,35	98	1,33
93	1,27	100	1,33	90	1,32	96	1,35

Appendix F

Dotplot of time of flutter with respect to speed behavior



Appendix G

Measurement data of MR diameter before storage

	Measurement of MR diameter at PM7				
Samples	**MR ID**	**Paper Quality**	**Diameter OS**	**Diameter DS**	Diff.
1	2671108297	1713	165.4	164	1.4
2	2671108402	1067	164.8	164	0.8
3	2671108403	1067	165.2	163.4	1.8
4	2671108404	1067	168	167.2	0.8
5	2671108405	1067	169	167	2
6	2671108406	1067	164	161	3
7	2671108407	1067	166	167	1
8	2671108408	1067	164	166	2
9	2671108409	1067	163	162	1
10	2671108410	1067	162.8	164.8	2
11	2671108411	1067	161.4	160	1.4
12	2671108412	2067	162	164	2
13	2671108413	2067	162	162.6	0.6
14	2671108414	2067	165	163	2
.	.	. .	.	.	.
.	. .	. .	.	.	.
444	2671110614	1067	163	161	2
445	2671110615	1067	164	161	3
446	2671110616	1067	164	162	2
447	2671110617	1067	163	161	2
448	2671110618	1067	163	161	2
449	2671110619	1067	164	161	3
450	2671110620	1067	163	162	1
451	2671110621	1067	161	160	1
452	2671110622	1067	162	161	1
453	2671110623	1067	164	162	2
454	2671110624	1067	163	161	2
455	2671110625	1067	164	164	0
456	2671110626	1067	164	163	1
457	2671110627	1067	162	162	0
458	2671110628	1067	162	161	1
459	2610100010	2067	143	141	2
500	2671110688	2067	162	161	1
501	2671110689	2067	160	158	2

Appendix G

Semi-structured interview questions

Interview guide

The purpose of this research to trace the origin of a problem known as "Tissue splitting" and the process disturbance known as "Web-flutter" and generate an improvement hypothesis which would possibly solve the problem.

- Have you heard of the term "Tissue splitting" and how do you interpret it?
- Have you heard of the term "web flutter" and are you aware where it occurs in the process of tissue paper making.

Tissue Splitting (External Claim system)

- How does SCA, Edet mill establish final products have experienced "Tissue splitting"?
    - Who contacts who (SCA>Customers, Customers> SCA or which other ways) when "Tissue splitting" occurs?
    - How is it confirmed and validated that is actually "Tissue splitting"?
    - What types of claims are paid as compensation when "Tissue splitting" is established?

- How is this claim tracked or traced back to production?
    - Which traceability systems exist?
    - What information is included in them (if it exists)?
    - Who is responsible for this information?
- How is the problem "Tissue splitting" managed by SCA, Edet mill?

Web-flutter (Internal Claim system)

- In what part of the issue paper making process does "Web flutter" occur?
    - In General, what are the physical characteristics when it occurs?
    - Is it a subjective or objective decision, when it does occur?
    - Who makes these decisions?
- What types of claims are used to represent "Web flutter"?
    - What system is responsible for handling the claim, "Web-flutter"?
    - Who enters these claims into the system?
    - How often or when exactly is it entered into the system?
- What are the likely causes of "Web-flutter"?
- What are the likely outcomes of "Web-flutter"?

- How is "Web-flutter" managed by SCA, Edet mill?