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Call, Celina A. ***Increasing Rolled Throughput Yield in Optical Films Using Six Sigma Methodology***

Abstract

Product X2, an optical film, was created in 2010 to enhance electronic displays. During the new product introduction process, the team faced low rolled throughput yield issues. Due to poor quality, the team was unable to pass a management review that would allow the product to be mass produced without the help of corporate resources. This study was created to increase rolled throughput yield from 39% to 55%.

Within this research, Six Sigma methodology was utilized to define, measure, analyze, improve, and control the process to generate a solution to this problem. Pareto charts, cause and effect diagrams, and control charts were utilized within these stages. With these tools, edge mottle and streaks were identified to be the top two quality issues causing low rolled throughput yield. The team then used the cause and effect diagrams to narrow down root causes and brainstormed an improvement plan for reducing edge mottle and streaks.

As a result of the improvement plan, edge mottle was eliminated by modifying the original formulation while streaks were reduced by implementing machine die repair procedures and optimized process conditions. With these implementations, the team estimated rolled throughput yield to be 60%. These improvements will allow the team to pass the next management review, scheduled for February 2012.

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Chapter I: Introduction

Company DEF's (real name not given due to confidentiality) C Division creates and manufactures optical film that is sold globally for liquid crystal display (LCD) electronic displays. In order to stay competitive in this fast paced market, DEF has established programs to create several new products every year. The program to create product X2 was started in 2010. Product X2 provided an energy savings solution to laptop manufacturers by increasing the brightness to their display. This enabled the laptop manufacturers to use less light emitting diodes (LEDs). With fewer light emitting diodes in a visual display, less energy is used to power the laptop and thus increases the time between battery charges. Like every new product, X2 had to go through the new product introduction (NPI) process.

The new product introduction process was established to assist management by increasing their ability to make better business, marketing, and resourcing decisions. It includes six stages (in chronological order); concept, feasibility, development, scale-up, launch, and post launch. Each stage in the new product introduction process is presented through gate reviews to internal stakeholders, also known as gate keepers. The presentation during the gate review contains information regarding the team's requirements, timeline, and current progress. Requirements include achievements such as production yield, product sales milestones, and percent attachment rates in the market.

For a gate review, the team declares the status of their project prior to giving their presentation. Project statuses include green, yellow, red, and black. Green means the team has passed all requirements and is ready for the next stage. Yellow signifies that most requirements are met, but there is a slight delay in reaching others. Often times, teams with a yellow status will propose that they are moved to the next stage with the agreement of fast improvements and additional reviews. Red signifies the team's inability to reach their goals due to issues that may require more time for them to overcome. In this case, the team suggests resources that are needed to support their improvement efforts. Lastly, black status means that the team advises the project should be cancelled in the interest of the division. After each presentation, the stakeholders will decide whether they agree with the team's status or if it needs to be changed. They will also make any resourcing changes needed to help support the success of the project.

The X2 project was in scale-up and preparing for the launch phase in the new product introduction process. Scale up is when the final product design has been chosen to go into mass production. The corporate lab and manufacturing teams are then responsible for establishing process and product procedures to ensure good product capability. A product transitions to the launch phase when scale up has been completed, and the manufacturing responsibilities are transferred from the corporate development team to the local manufacturing team. This transition is agreed upon during a gate review.

Project X2 had been declared a red status for its gate review to transition into launch phase. One of the main requirements for the transition was to have a 55% rolled throughput yield across all converting sites in Asia. Rolled throughput yield refers to the percentage of the input product rolls that were successfully converted into the final product parts. Converting sites refer to manufacturing locations that take rolls of the product and convert them into individual parts for placement into electronic displays. In collecting monthly yield information from Asia, they encountered several months of low yields. These yields averaged 39%. As volume increased it was assumed that the rolled throughput yield would improve, however, this was not the case.

Statement of the Problem

Low rolled throughput yield in the converting process prevented the new product introduction project from meeting the requirements. These requirements allowed product X2 to transition into the launch phase.

Purpose of the Study

The goal of this study was to determine the root cause of low rolled throughput yield in order to improve the overall quality of the film. Thus an action plan was presented to increase rolled throughput yield, and thereby allow the project to progress into the launch phase

Assumptions of the Study

Several assumptions have been made for this study. These assumptions involve commonly accepted yield losses, independence of the machinery design in connection to the rolled throughput yield, and part design optimization to maximize rolled throughput yield.

For rolled throughput yield, it is commonly accepted that there will be quality and process losses. Quality losses include raw material, coating, and roll formation defects. Achieving less than or equal to 15% loss due to these causes is considered good. Process losses include product scrap created due to starting the process machinery and equipment issues caused by maintenance problems. Process losses typically account for less than 5% of the rolled throughput yield reduction. The assumption for this study was that since rolled throughput yield was only 39%, there were causes outside of the standard process and quality losses leading to the poor rolled throughput yield.

Another assumption for this study was that the machinery used to convert the X2 product was not the cause of the reduced rolled throughput yield. This assumption was made on the basis of two factors. First, the X2 product was made with several different types of machines with no significant difference in rolled throughput yield. The second factor is that the equipment from these lines is used to convert other products that achieve high rolled throughput yield.

The final assumption is that the part design has been optimized to maximize rolled throughput yield. Since the X2 product is converted from rolls into individual pieces, there is an expected of amount of material lost due to the geometry of the pieces not exactly matching the dimensions of the roll. Prior to the scale-up phase, the part design was optimized to maximize rolled throughput yield.

Definition of Terms

Design Loss – Material is produced in rolls, and certain products are cut out of the rolls at an angle. When the material is cut out at an angle, there are certain sections across the width of the roll that are no longer usable, since they are smaller than the desired product dimensions. Only a certain number of product cut-outs fit across the width of the roll, and the excess material is considered a design loss.

Gate Reviews – A gate review is a meeting held by managers where the team developing a new product presents the current status of it being introduced to the market.

New Product Introduction (NPI) – It is a six stage process that all new products go through to assist management in making better business, marketing, and resourcing decisions.

Pareto charts – A graphical tool for ranking causes from most significant to least significant. The principle, named after 19th century economist Vilfredo Pareto, suggests that most effects come from relatively few causes; 80% of the effects come from 20% of the possible causes. (Summers, 2006, pg. 790)

Percent attachment (attach rate) - Percent attachment is a rate in the market referring to customer acceptance of a new product over a current product being sold to them.

Plastic Substrate – A plastic material that is later processed with a coating. (Yoshihara et al, 2002)

Rolled Throughput Yield (RTY) – The overall process yield that is determined by multiplying all of the sub-processes' yields together. (Watson, 2000)

Six Sigma – A methodology consisting of quality management and statistical tools used to improve a process. ("Six Sigma", n.d.)

Limitations of the Study

The research covered in this paper will only include analysis on rolled throughput yield loss due to poor product quality. It will not include any yield improvement opportunities dealing with equipment problems.

Additionally, this study is limited to the improvement analysis for a particular optical film. Results from this study may not be relevant to other products due to its unique construction. However, the methodology utilized in this research can be applied to solve problems in many situations.

Methodology

This study includes the following: a literature review, the methodology behind the study, the results of the study, and the conclusions and recommendations of the study. In the next chapter, the literature review covers information regarding optical films, such as its uses, its main construction, and common defects created in the manufacturing process. The literature review then further explains quality tools that are often used in manufacturing to help improve product quality.

The study continues to chapter three where the methodology chosen to resolve the low rolled throughput yield issue is explained. This section describes Six Sigma, as well as the define, measure, analyze, improve, and control (DMAIC) stages of the method.

Next, in chapter four the study progresses by explaining the results of the methodology used to improve the rolled throughput yield and how the improvement can be sustained. This includes solutions discussed in the literature review as well as best practices in quality control procedures.

Finally in chapter five, the paper concludes by discussing the solutions determined from the study. Recommendations derived from the knowledge gained through this study are also provided to help guide further process improvements.

Summary

This chapter discussed a brief introduction to product X2 and the new product introduction process that had to undergo. Terms were also defined including the rolled throughput yield which was the main focus of this study. The chapter was concluded with the methodology used to outline the remaining parts of the study.

The next chapter details the review of other studies completed on optical films, the process problems which are encountered when making films, and quality tools that are used in manufacturing process to improve quality.

Chapter II: Literature Review

To aid in the study of low converting process rolled throughput yield, a literature review was completed to discover and analyze what other researchers have recorded regarding optical films and quality improvements. This chapter discusses the reviewed literature with respect to the applications that optical films are used in, the main construction of these films, and the manufacturing processes for these films. Next, it provides a better understanding of optical films and their benefits within electronic displays. The chapter continues with information regarding common defects found in each manufacturing process, and it introduces quality techniques and methodologies used within manufacturing. Furthermore, the literature review discusses how others have used quality tools to help them succeed in improving their manufacturing processes.

Optical Films for Electronic Displays

According to 3M, MacDermid, and General Digital companies ("Energy Efficient Displays", n.d.; "Flat Panel Displays-Optical films", n.d.; "Optical Enhancement Tuturial", n.d.) optical films are high performance films that contain essential features for a variety of electronic display applications. Such applications are televisions, computer monitors, cell phones, laptops, tablets, and hand held gaming devices. Optical film properties are constructed using a plastic substrate and coating.

Substrate extrusion. The plastic substrates are created through an extrusion process. The extrusion process melts plastic pellets into a thick continuous web. The web is then stretched to a desired thickness and width. Depending on the required optical properties and machinery available, there are many methods of extruding and stretching the films. Wellen (1969) invented a technique that first stretches the film in one direction (most commonly in the machine direction) and then stretches it again in its perpendicular direction. Another approach was discovered by Funk and Gross (1993) and Sturken (1962) that controlled width and thickness by sending melted pellets through a slot creating a thick continuous web. This web is sent through a set gap between two rollers. The smoothness created in using the rollers provided the film with specific characteristics such as thickness, haze, and roughness.

Additionally, several patents about extrusion processes have stated the importance of creating substrates through the heating and cooling of the plastic using machine rollers. This helps to achieve high quality film. For example, Wellen (1969) stated that “If the temperature of the rollers 37 and 38 are not maintained at the critical values above set forth, the film will not be usable in the manner contemplated in the invention.” (p. 4) Funk and Gross (1993) also stated that the required surface roughness, thickness, curvature, and shrinkage properties needed for an optical performance are created by heating and cooling certain machine rollers throughout their process.

Substrate coatings. In addition to substrates, coating is another important element in optical films. Like the extrusion of substrates, there are several methods used in coating film. Cohen (2010) reported seventeen different types of coating processes being used industrially by a collection of surveys, blog queries, and literature searches. One of the more popular methods being used is over 100 years old.

Furthermore, the coatings put on substrates help enhance the substrate features. For instance, hardcoats add features such as scratch resistance, reduced warping and curl, and resistance to cracking and peeling. (Yoshirhara et al, 2002) These are desired traits in films to mitigate the risk of damaging electronic displays through daily use. Matte finish coating delivers improved display uniformity while masking minor cosmetic defects in the application. (“Vikuiti™ DBEF-M”, n.d.) Other coatings such as anti-reflection, anti-glare, and prism coatings increase the display performance. (“Energy Efficient Displays”, n.d.; “Flat Panel Displays-Optical films”, n.d.; “Optical Enhancement Tuturial”, n.d.)

Uses for optical films. Optical films can be used to enhance properties of different display technologies such as liquid crystal displays (LCD), organic light emitting diodes (OLED), and plasma displays. (“Optical Enhancement Tutorial”, n.d.; “Energy Efficient Displays”, n.d.) The utilization of these films in the display is beneficial because they improve the brightness, provide a moisture barrier, provide antiglare properties, and reduce the energy needed to operate the display. 3M company reports that their prism films can increase the brightness of an electronic display by 120%. (“Prism Films”, n.d.) This is achieved by focusing the light in the display towards the users with prism structures. More importantly, their studies have shown that using reflective polarized films enables the light in the display to be recycled. This helps increase the energy efficiency of the electronic device and reduces the power usage. (“Energy Efficient Displays”, n.d.)

In addition to brightness and energy savings, optical films are also used to reduce the nuisance of reflected images that make it hard to see electronic displays. These are created by ambient lighting. Anti-glare and anti-reflection films have been created to reduce the amount of reflection back to the user. (“Optical Enhancement Tutorial”, n.d.; “Optical Film Enhancement”, n.d.; “Flat Panel Displays-Optical films”, n.d.) For example, General Digital has developed an anti-reflection film that reduces the reflection of sunlight down to 0% -0.2% reflection at certain angles. (“Optical Enhancement Tutorial”, n.d.) The anti-reflection technology enables the electronic display to be more readable.

Common Optical Film Defects

In making high performance films, numerous defects can be created causing the film to have low quality. There are a total of five common defect categories that are caused from the substrate and coating process.

Common substrate defects. There are three categories of substrate defects; point defects, continuous defects, and winding deficiencies. (Collen, 2011; Gamage & Xie, 2007; Mount, 2011; Steinberg, 2000) Point defects can be defined as random spots across the entire web. Continuous defects are constant non uniformities seen repeatedly throughout areas of the film and are commonly located in the same area of the web. Winding deficiencies are defects created in winding the film into rolls.

First, point defects can come from deposits on the machine rollers. (Mount, 2011; Gamage & Xie, 2007) These deposits can build over time and release themselves onto the film. In some occurrences, these deposits can be burnt, leaving a dark spot called gels. According to Gamage & Xie (2007), their study found that these deposits were unacceptable in their application when it reached a size larger than 500µm. In addition, any film product can be susceptible to environmental debris causing point deformities.

Secondly, one continuous non-conformity is known as a streak or coating void in the film. (Steinberg, 2000; Roisum, 2008) This can occur by an object physically disturbing the surface of the film and making visible lines in the machine direction. Steinberg (2000) also discovered other defects such as skew (substrate curving left or right instead of being straight), corrugation (buckling in the machine direction), edge buckles (wrinkles in the transverse direction starting at the edges), and center buckles (film buckling in the transverse direction located in the center of the web) due to variations of thickness in the film. These defects can be easily observed when the film is unwound.

Lastly, major defects in winding quality are caused by wrinkles. (Roisum, 2008) Roisum states that as the film is being wound into a roll, it is very critical to eliminate wrinkles created by routing the web through the machine. These wrinkles can be continuous in the machine direction or a repeated diagonal line throughout the roll. Wrinkles can be so severe that they could cause the entire roll to be destroyed.

Common coating defects. Defects in the coating process can be categorized into two main groups: point defects and continuous defects. Cohen (2011) claims that one cause of point defects can be bubbles in the coating process. These bubbles can be created in the solution delivery system or through the mixing of the coating before it is applied to the substrate. Again, point defects can also be caused by environmental debris as the film is being coated and dried.

Similar to continuous substrate defects, streaks can also be created in the coating process. According to Cohen's (2010) research, he found that streaks are the most prevalent coating defect in the industry. For many years, coating experts have tried to eliminate this problem. An apparatus was invented by Spengos and Fegley (1970) to help reduce streaks, but it is still an issue. Furthermore, research has found that streaks are caused by several things. These sources include coating non uniformity, solution flow instability, non uniform air flow in the drying of the coating, and physical disturbances by particles, bubbles, gels, and dirt. (Cohen, 2010; Spengos & Fegley, 1970)

Another continuous coating defect found is a consequence of not having a flat substrate. (Steinberg, 2000) As stated previously, some flatness issues are the film being skewed, corrugated, or buckled. Non-flat film can cause the film to flutter and scrape against machinery as it passes through tight spaces. This causes the coating to be damaged or even removed. Wrinkles can also be caused by non-flat film. As films have less flatness to them, it becomes harder to steer with line tension causing wrinkles to form in various areas.

Quality Improvement Tools

Quality improvement principles have evolved over the years to help improve processes and overall customer satisfaction. According to Summers (2006) quality has advanced through the stages of artisan, inspection, quality control, statistical quality control, statistical process control, total quality management, continuous improvement, and finally to the current principle of Six Sigma.

Six Sigma. In 1986, Bill Smith from Motorola developed Six Sigma. According to ("Six Sigma", n.d.), "Six Sigma was heavily inspired by six preceding decades of quality improvement methodologies such as quality control, TQM, and Zero Defects, based on the work of pioneers such as Shewhart, Deming, Juran, Ishikawa, Taguchi, and others" (p. 2)

There are a total of thirty two methods that are used. Some of these include quality tools that the pioneers created to help shape the Six Sigma methodology. ("Six Sigma", n.d.) Six Sigma consists of five major stages; define, measure, analyze, improve, and control (DMAIC).

Define. The first stage of the DMAIC process, define, is meant to identify and understand the issues in a process. Pareto charts and Pareto analyses are visual representations of defect data, and are commonly used to identify problem areas. This data is created using histograms that are arranged from highest to lowest importance. A study done by Murugaiah, Benjamin, Marathamuthu, and Muthaiyah (2010) used Pareto charts to help them identify material scratches as the number one defect mode in their process. The charts helped them see that this mode accounted for 48.15% of total scrap weight recorded.

A similar Pareto analysis completed by Kumar and Sosnoski (2009) showed that Wilson Tool's top quality issues were wrong size (approx. 50% of total issues) and cutting tool breakage (approx. 20% of total issues). Their analysis was completed by collecting data of categorized defects and errors entered by employees. From this analysis, they were able to identify that they needed to further investigate the causes of wrong size defects.

Even though the Kumar and Sosnoski (2009) data showed top issues by volume, it may not have been as significant to the company as the cost association with the defects. By applying cost per defect, the Pareto analysis can have different results. For instance, the wrong size defects could cost $0.50 per defect, but another defect that only accounts for 5% of total defects could cost $1000 per defect making it the number one issue. There can be exceptions to using cost though, as seen in the Murugaiah, Jebaraj, Marathamuthu, and Muthaiyah (2010) research. They decided not to look at total cost because the price of the material fluctuates throughout the year. In conclusion, there are many ways to look at the data, but improving the process to bring the most benefit to the business is most relevant.

Measure. The second stage, measure, takes the issues identified in the define stage and studies the current process capability with regard to the machinery or procedure involved. (Aruleswaran, 2008; Kumar & Sosnoski 2009) Measurements and data are collected and analyzed to identify the baseline performance of the process. Understanding the current capability reveals gaps between process performance and the requirements needed to satisfy customer specifications. Hargreaves agreed (as cited in Holmes, n.d.) with Eva Holmes, a Six Sigma deployment manager at Tube Lines company, that 'defining, measuring, and understanding the process is the only way to improve them.' (p. 44)

Some common tools in measuring the process are control charts, process capability analysis, analysis of variance, and histograms. Murugaiah, Benjamin, Marathamuthu, and Muthaiyah (2010) used control charts, histograms, and statistical analysis. Control charts are used to monitor a process by plotting data points with calculated upper and lower control limits, and were developed by Shewhart to understand the variations of a process (Summers, 2006). The process is said to be in control if all the data points are within the upper and lower control limits. The data analysis completed by Murugaiah, Benjamin, Marathamuthu, and Muthaiyah (2010) showed the process was out of control. In addition, their statistical analysis resulted in a defects per million (DPM) value of 1,350. According to Six Sigma methodology ("Six Sigma", n.d.), the goal is to be less than 3.4 DPM.

Analyze. With the information collected from the define and measurement stages, the third part of the investigation is to find the root cause of the main issue ("Six Sigma", n.d.). Methods that can be used are cause and effect diagrams, '5 whys' analysis, root cause analysis, SIPOC analysis (Suppliers, Inputs, Process, Outputs, Customers), and process maps. These tools are used to analyze the connection between the inputs and outputs to the process. (Aruleswaran, 2008)

Murugaiah, Benjamin, Marathamuthu, and Muthaiyah (2010) chose to use the '5-whys' analysis to find the root cause in their research. The '5 whys' method is done by asking why the original problem exists five consecutive times, with each why addressing the answer of the previous one. By asking why 4 times (Figure 1.), Murugaiah, Benjamin, Marathamuthu, and Muthaiyah (2010) were able to ask why the last body sheet of every bundle had scratches, allowing them to see that they needed to implement a maintenance schedule.

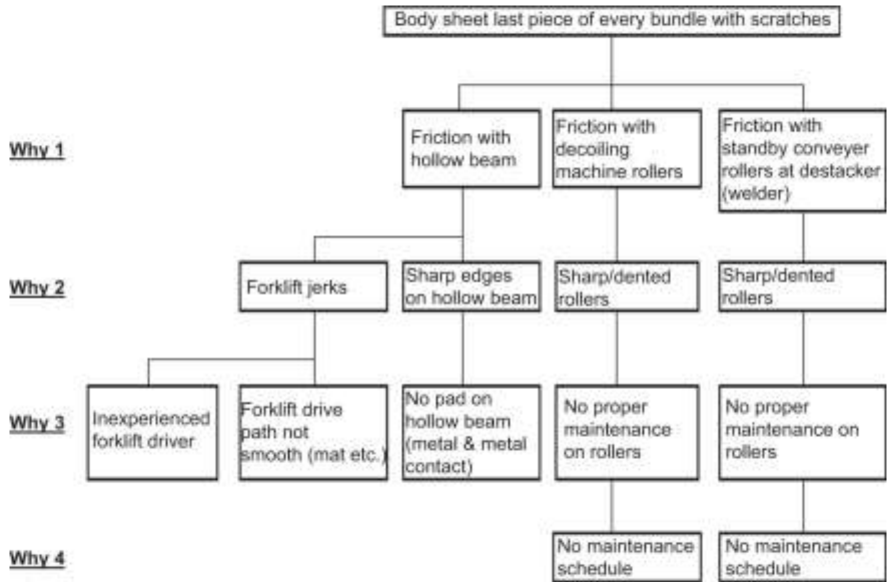

Figure 1. 5-whys analysis (body sheet). This figure illustrates the paths created in finding the root cause of an issue by simply asking the question why. Adapted from "Scrap Loss Reduction Using the 5-Whys Analysis" by Murugaiah, Benjamin, Marathamuthu, and Muthaiyah, 2010, *The International Journal of Quality & Reliability Management, 27(5), 527-540.* 2010. Adapted with permission.

Though this analysis worked well for this issue, it is not ideal in every situation. Kumar and Sosnoski (2009) uncovered their root cause by using process maps and cause and effect diagrams. The process map was used to narrow down the area of the problem. Then a cause and effect diagram was used. This diagram, also known as a fish-bone diagram because of its shape, was developed by Kaoru Ishikawa. (Summers, 2006) The diagram begins with the nonconformity (effect) on the right side, and on the left side it lists all possible causes of that issue. The causes are divided into five categories: environment, material, people, methods, and equipment. In using this diagram, Kumar and Sosnoski (2009) indentified two major causes to their non-conformity.

Improve. Once the causes have been identified, the next step is to create ways to improve the process through experimentation. (Aruleswaran, 2008; Kumar & Sosnoski 2009) Aruleswaran believes that the improve stage is a crucial part of the DMAIC process where ideas become solutions. Some tools that are used include design of experiments (DOEs), mistake proofing, risk analysis, or implementing standard work processes. Methods that were used to measure the current process in the measurement stage are often used to analyze improvements following process experiments.

Kumar and Sosnoski (2009) did not follow a traditional design of experiment process, but they experimented with different designs to help improve their warp issue. In doing so, they discovered a particular design that reduced their defect per million of 1350 to 9.

Murugaiah, Benjamin, Marathamuthu, and Muthaiyah (2010) improved their process using another approach. In their findings noted above, they found that there were no scheduled maintenances done on the machine rollers. To mitigate this risk, they implemented a preventative maintenance schedule that resulted in eliminating the defects with which they were concerned.

Control. Lastly, once an improvement method has been proven to work, it is necessary to control it. (Aruleswaran, 2008) This means that the process needs to have documented procedures in order to ensure that the implementation is sustainable and managed. This will lead to achieving the desired process improvement. In addition, the process must be monitored to confirm that the process does not return to a problematic state. Again, process analysis tools used in the measurement phase are commonly used to oversee the progress. Kumar and Sosnoski (2009) audited their process with the same statistical analysis, histograms, and control charts used in their study. These tools enabled them to observe and determine if their process was statistically performing well.

Summary

Throughout this chapter, information regarding the main construction of optical films (substrates and substrate coatings) was given including the benefits they provide to electronic displays. Such values are increasing battery life, increased brightness to displays, and providing an anti-glare feature to viewing display. Also included in this chapter were examples of common defects found in both the manufacturing of the substrates and coating of the substrates. Finally, it contained the quality improvement tool of Six Sigma methodology and how it was utilized in various studies to enhance quality using the define, measure, analyze, improve, and control stages.

Next in chapter three, the study discusses each stage of the Six Sigma's define, measure, analyze, improve, and control methodology the project went through. The stages include detailed information of the importance of each stage and how each stage was completed utilizing the quality tools that were chosen.

Chapter III: Methodology

The purpose of this study was to investigate the root cause of low rolled throughput yield and improve it, thereby allowing the new product introduction team to pass launch phase. Six Sigma methodology was chosen to address the low quality issue. This chapter will go through the define, measure, analyze, improve, and control (DMAIC) process stages and conclude with the methodology limitations. Each stage includes a detailed description of data collection and the Six Sigma tools used to analyze the data.

Define

In the define stage, it was critical to identify the key process improvement opportunities. By doing this, the team was able to focus their efforts on reducing the top two quality issues thus making a significant difference in yield and overall cost of the product. The Pareto chart tool was used in this stage to determine the issues that needed to be addressed.

Calculating Yield. Product X2 was converted differently than most optical films at Company DEF. To properly function in an electronic device, the film needed to be converted at a 45 or 135 degree bias. This requirement caused yield loss risk to be greater due to design loss and due to the possibility that two parts could be affected by a continuous downweb defect in certain crossweb positions, as seen in Figure 2 below.

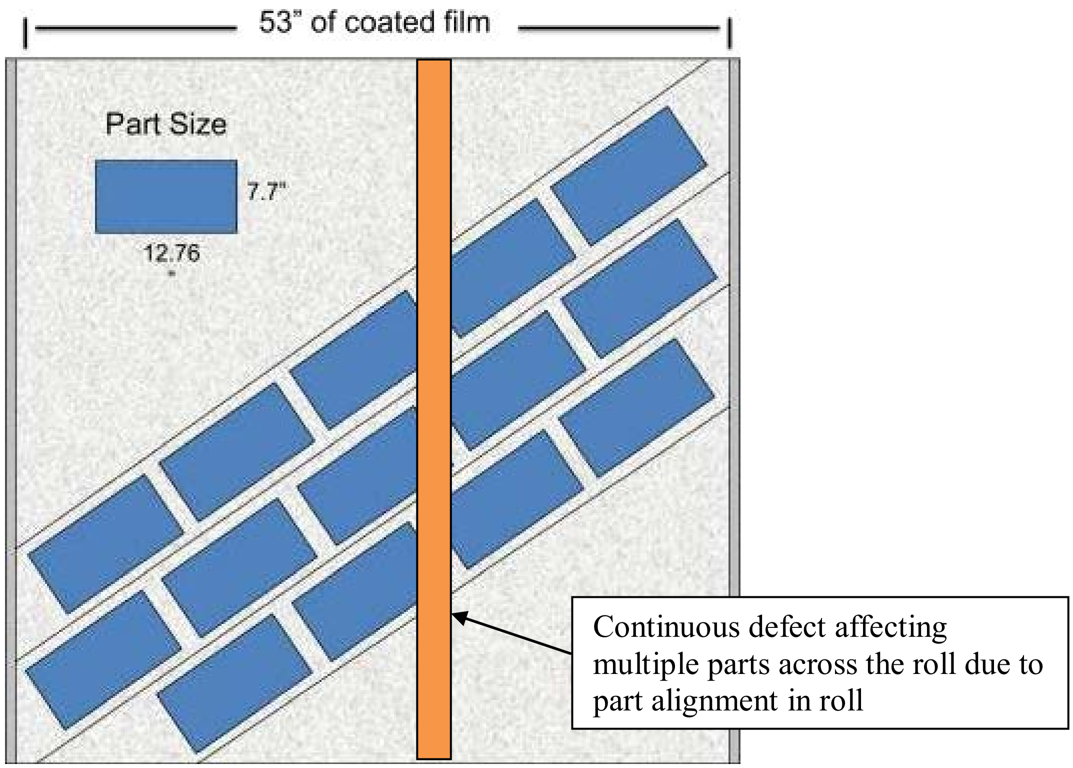

Figure 2. Part size converting visual. This figure demonstrates how final part pieces are cut from a roll.

Product X2 goes through five converting steps before final parts are shipped to customers. These steps consist of laminating a protective plastic on the film, angle cutting across the entire roll to get 45 or 135 degree strips (as depicted in Figure 2), cutting off the end pieces of each strip to make it rectangular, die cutting individual parts from the strips, and finally inspecting the quality of each part. At each converting step, yield was calculated by the total amount of good output material divided by the total amount of input material. The rolled throughput yield was then calculated by multiplying all five converting step yields together.

Defining the quality issue. Four weeks of rolled throughput yield data were collected from two converting locations. The data were classified by yield loss due to the process, part design, and quality defects at each converting process step. Furthermore, the quality yield was sorted into waste by cause categories of streaks, point defects, bagginess, banding, roll formation impressions, coating defects, dewets, and bubbles. The data measured total lost square yards from each category to help identify the biggest opportunity for improvement. In addition to the data collection, defective samples were sent by converting locations to the U.S. labs to verify correct defect categorization.

Next, Microsoft Excel 2007 was used to create a Pareto chart based on defect categories and the lost volume that was attributed to those categories. Cost was not associated with the defects because the price of the material throughout the converting process was shown to have no significance. The Pareto chart in Figure 3 was ranked from most to least significant.

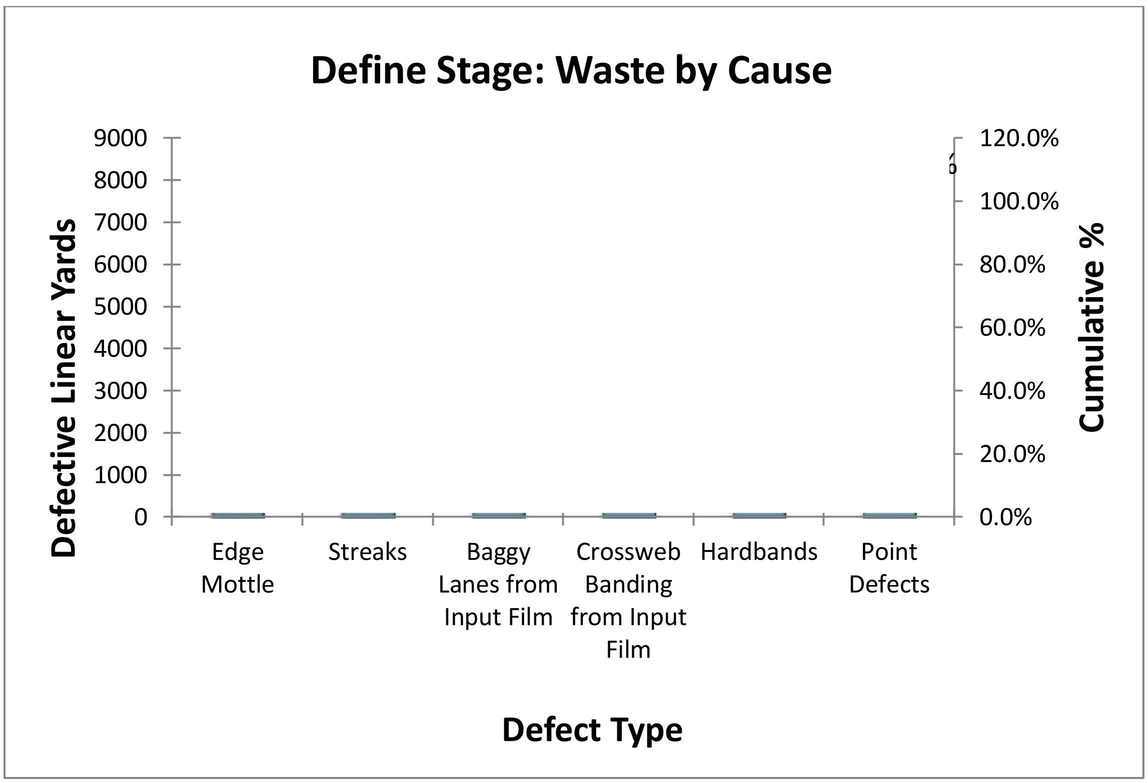

Figure 3. Pareto chart for define stage: waste by cause. This figure illustrates the Pareto chart that was used to find the biggest opportunity for yield improvement.

Next, the Six Sigma methodology led the project into measuring the current state of the process based on the results from the Pareto chart in Figure 3.

Measure

The measure stage of Six Sigma was used to better understand the current process capability. In this stage, a baseline of quality issues was established by also using a Pareto chart similar to the one shown in Figure 3. It was then utilized in the improve and control stages to track project progress.

Process Measuring Method. In measuring the current quality of the process, all rolls made from June's and July 2011's production runs were used (a total of 126 rolls) to compare the quality data recorded with the converting data provided in the define stage. Each roll was sampled by taking a 52" section at the beginning and end of the roll. Using both transmitted and reflected lighting systems, each piece was inspected for defects. Defects were marked on the sample and were identified using a defect book created by a quality engineer. The defect type, size, and crossweb location were then recorded on a roll map (see Appendix B).

Next, a yield estimate was then taken from each sample utilizing a 14.9" diagonal part. These parts were organized across the roll similar to the parts illustrated in Figure 2. This 14.9" part was used consistently throughout the stages of the project since changing the part size would also change the yield. Additionally, depending on the size, type, and location of any potential defect, the parts within the angled strips could be moved slightly to exclude the defect and thereby avoid being a defective part. This was determined using a Microsoft Excel 2007 model that was created to analyze the yield loss due to continuous defects in the machine direction. Each lane of parts affected in the machine or downweb direction results in a yield loss of 20%, or 1 out of 5 parts based on the 14.9" part size map.

Each roll's yield loss estimate was calculated by taking the average of the yields from the beginning and end of roll inspection results. Furthermore, the yield losses were categorized by defects. For example, if the start of the roll inspection had a yield loss estimate of 20% due to edge mottle and the end of the roll inspection had a yield loss estimate of 40% where half was due to streaks and the other half was due to edge mottle, the total yield loss is 30%. Of the total 30%, 20% of the yield loss would be due to edge mottle and 10% would be due to streaks. These percentages were then used to calculate the amount of square yards affected by each defect by multiplying the yield loss percentage by the total amount of square yards in each roll. For instance, if the roll was 1500 square yards, the streaks affected 150 square yards (1500 x 10%) while edge mottle affected 750 square yards (1500 x 30%). After analyzing all samples, a sum of square yards affected by each defect type was calculated. See Appendix C for example of how yield by cause estimate is completed for each production roll. These totals were then utilized to create another Pareto chart like the one in Figure 3. This chart was then used to confirm that the defects are the same as those found in the define stage.

Analyze

The third step of the Six Sigma methodology process is understanding the root cause of top defects discovered through the define stage. These defects were edge mottle and streaks. A cause and effect diagram was chosen to brainstorm possible root causes of the two quality issues. In using this tool, seven components in the process were analyzed; methods, mother nature, manpower, materials, machines, management, and measurement systems.

Cause and effect diagram. The cause and effect diagram exercise was utilized to identify all possible root causes for the edge mottle and streak defect, as seen in Figure 5 below. The team brainstormed several failures that could occur at each process component. After this exercise was completed, the team then began to narrow down the actual root cause. Since the team had a limited amount of time to run experiments, they first investigated all possible root causes that could be tested in the lab or with historical data. In doing this, the team was able to reduce the amount of possible root causes to only a few for edge mottle and streaks.

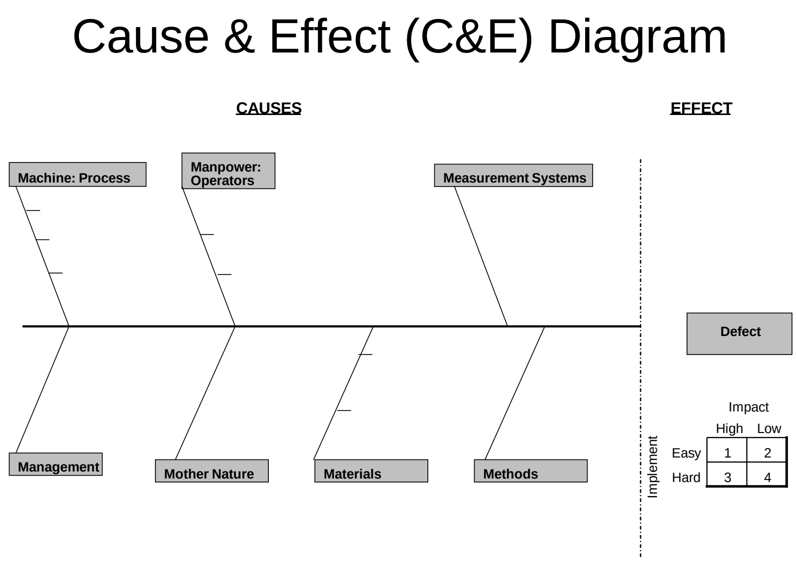

Figure 5. Analyze stage: Cause and effect diagram. This figure illustrates the cause and effect diagram to capture all possible root causes of a type of defect.

The remaining possible root causes from each type of defect were then carried into the improve stage to find possible solutions that would eliminate or reduce the occurrence of the defect.

Improve

As part of the improve stage, an improvement action plan was developed based on the results of the analyze section for edge mottle and streaks. These analysis results are provided in chapter four. To reduce these defects, the following experiments were completed.

Edge mottle. As stated in the analyze stage, the four root cause possibilities were air flow disturbances, drying process conditions not being robust, drying solvents used in coating formulation not being robust enough for the process, and the shelf life of solutions causing drying defects. The team chose to complete experiments in an order based on highest confidence of improving the defect.

The first experiment that was planned in the trial was testing if air flow disturbances were factors in the coating. In assessing this theory, certain locations inside the dryer were taped off to minimize the air flow. Then, the verification process was to compare the quality of edge mottle with this condition against previous production samples.

Secondly, a design of experiments was created to analyze if the original process conditions and coating formulation were robust enough to eliminate the edge mottle defect. Again, the improvement assessment was completed by comparing the quality of the edge mottle with previous production samples.

Last on the experimental trial, a modification of the coating formulation was created with an even percent blend of two drying solvents. The original formulation contained one drying solvent. By adding a different solvent, coating robustness of the modified formulation was theorized to eliminate edge mottle and increase process and product capability.

Streaks. In previous production runs, small scratches or dents were found on the coating die, a critical piece of equipment in the coating process. These scratches were present in the same crossweb location as the streaks. To improve upon this, the die was repaired. In addition, process standard procedures were revised to add precise directions in how to adjust the die so as to minimize the impact of the scratches in the die.

Secondly, another design of experiments around coating thickness was created to verify if coating thinner causes streaks. In analyzing these experiments, standard visual inspections were completed to detect streaks in the coating.

Based on the results of the design of experiments and repairs of the die, the next improvement plan was to update the troubleshooting guide and provide training to all operators on proper procedures to minimize streak defects.

Control

The final step of the define, measure, analyze, improve, and control quality improvement process was to establish a control plan that would mitigate the risk of edge mottle and streaks. The control plan consisted of utilizing quality tools to monitor the improvement plans that were implemented in the improve stage.

Edge mottle. Control charts were chosen to enable production engineers and operators to monitor the progress of improvement changes. The chart displayed the percentage of material that was affected by edge mottle for every production run. This data was collected with the same yield estimate calculations used in the measure stage.

Streaks. Similar to the edge mottle control plan, control charts were also utilized to monitor the improvements implemented to reduce streaks. The control charts also measured the percentage of material that was lost due to streaks from every production run. A percentage of material lost measurement was chosen instead of amount of material lost due to the variation of volume made throughout the year. Again, the control plan would enhance the ability for operators and engineers to track quality improvements.

Limitations

As with many processes, the quality of the output material can be based on the quality of the input material. One weakness to this study is the small duration of time the quality was analyzed, since only one month of quality data was collected. This limited duration is a weakness because substrate or coating variations between different production runs could result in different quality issues. For instance, one production run of the substrate could have low yields due to roll formation issues, while the next run may have minimal issues from that cause. This specific issue was seen between the define and measure stage of the process.

Summary

Within this chapter, the Six Sigma methodology of define, measure, analyze, improve, and control phases were utilized to improve the overall quality of product X2. Quality tools such as Pareto charts and cause and effect diagrams were used to define the problem, measure the current process, analyze root causes, create improvement plans, and create control plans. The improvement plans consisted of evaluating four experiments and proper maintenance procedures to improve edge mottle and streaks. The results of these trials are provided in the next chapter.

Chapter IV: Results

The intention of this research was to determine the reason for low rolled throughput yield at converting sites, improve upon the team's findings, and increase overall rolled throughput yield thereby allowing the team to pass launch stage. By using Six Sigma methodology tools, edge mottle and streaks were found to be the top two quality issues causing low yields. Pareto charts were then used to understand the current process while cause and effect diagrams were utilized to find the root cause of these defects. Throughout this chapter, results from the define, measure, analyze, and improve stages are provided to show the successes the team had in reducing poor quality material.

Define Stage Results

In the beginning of the this study, a collection of waste by cause data for the month of May 2011 was used to find product X2's top quality defects. The data was used to create the Pareto chart in Figure 5 which was ranked from most to least significant based on the amount of material that was affected by type of defect.

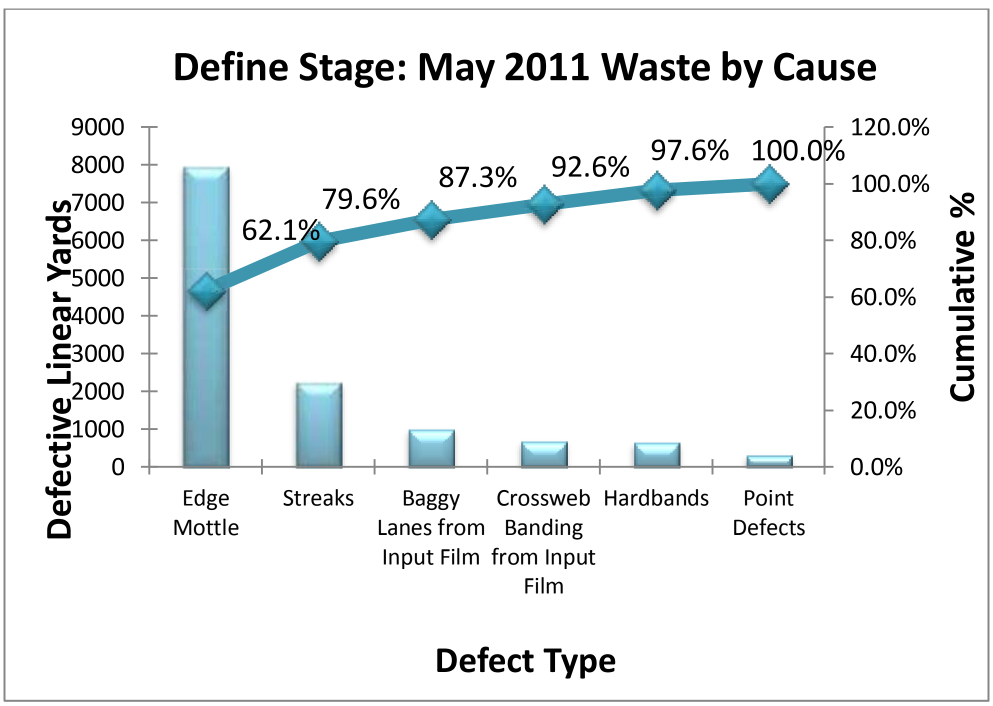

Figure 5. Define stage: May 2011 waste by cause. This figure illustrates the Pareto chart used to define edge mottle and streaks as the largest opportunity for yield improvement.

From this Pareto chart, it was concluded that the top two quality issues that needed to be improved were edge mottle and streak defects. Pictures of these defects can be found in Appendix A. Next, Six Sigma methodology led the project team to measure these defects in the current state of the process.

Measure Stage Results

Another Pareto chart analyzing the yield loss data due to categorized defects was then created using Microsoft Excel 2007. The data consisted of June and July 2011's production results. The Pareto chart in Figure 6 confirmed that edge mottle was indeed the predominant quality issue, while streaks were the third highest quality issue.

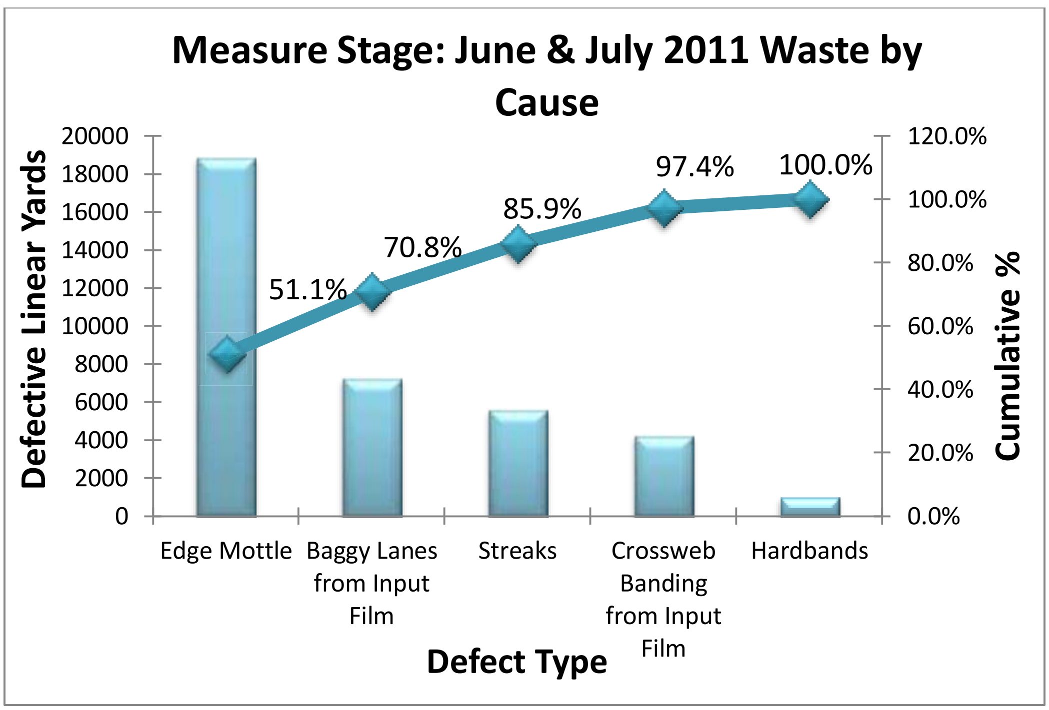

Figure 6. Measure stage: June & July 2011 waste by cause. This figure illustrates the Pareto chart used to measure the current quality status of the process.

In analyzing this data, bagginess from input material was found to be a quality issue during the June and July runs. However, from past experience it is known that the bagginess issue is not consistent and therefore it was decided to continue with quality improvements on edge mottle and streaks.

Edge Mottle Analyze Stage Results

The cause and effect diagram exercise identified seven possible root causes for the edge mottle defect, as seen in Figure 7 below. To narrow down the actual root cause, the team investigated three of the seven items listed because these items did not require additional roll production experimentation to verify root cause. These three possible root causes were variation in coating thickness across the web, mistake of running wrong process conditions, and error in making solution.

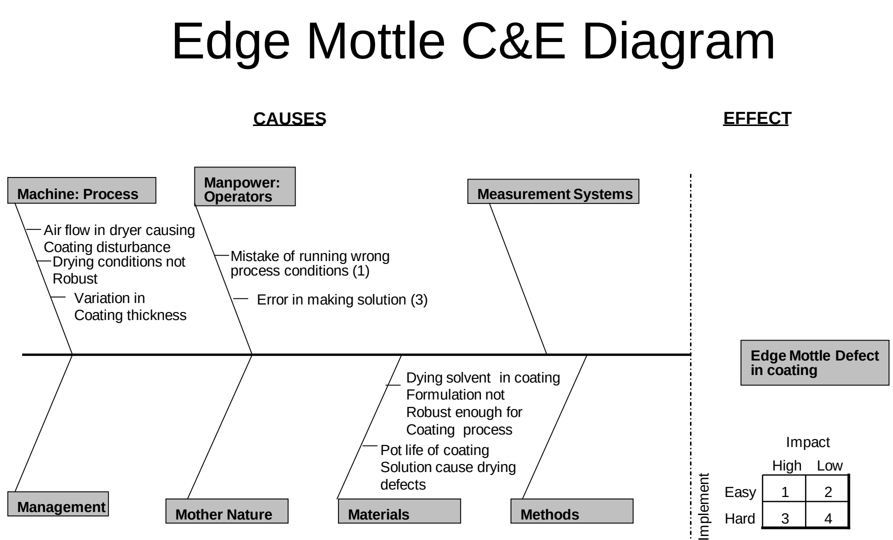

Figure 7. Analyze stage: Edge mottle cause and effect diagram. This figure illustrates the possible root cause of edge mottle.

First, the variation in coating thickness was tested in several cross web positions of the film including the edges of the film where the defect was located. Microscope images of product cross sections were used to measure different layers of the product. Results showed no variation in the coating and thus ruled out coating thickness variation as a root cause.

Second, the process condition information was retrieved from the machine's archived data to verify if there was anything suspicious that would cause disturbances in the coating. These process conditions were compared to other production times where edge mottle was non-existent. Again, there was no evidence that showed signs of possible coating disruptions.

Lastly, the coating solution mixing process records were assessed for any solution making mistakes. In addition, solution samples that were taken were also tested for material composition. The paperwork and solution analysis showed that the solutions were made correctly, thus eliminating another item off the root cause list.

After investigating and eliminating three possible root causes, four still remained. These possible root causes were air flow in the dryer causing coating disturbances, the drying process conditions not being robust, drying solvents used in coating formulation not being robust enough for the process, and the shelf life of solutions causing drying defects. Solution shelf life refers to the amount of time that a solution is usable, much like the shelf life of food items. The remaining causes were then assessed in the improve stage which will be discussed later in this chapter.

Streak Analyze Stage Results

The same cause and effect diagram was also used in brainstorming possible root causes for streak defects. In reviewing the diagram illustrated in Figure 8, the team found ten possible root causes for streaks. Solution contamination was the only possible root causes that could be verified without experimentation. In conjunction with the coating solution testing for the edge mottle root cause, the solution was also tested for any particle contamination. Results came back showing no indication of contamination.

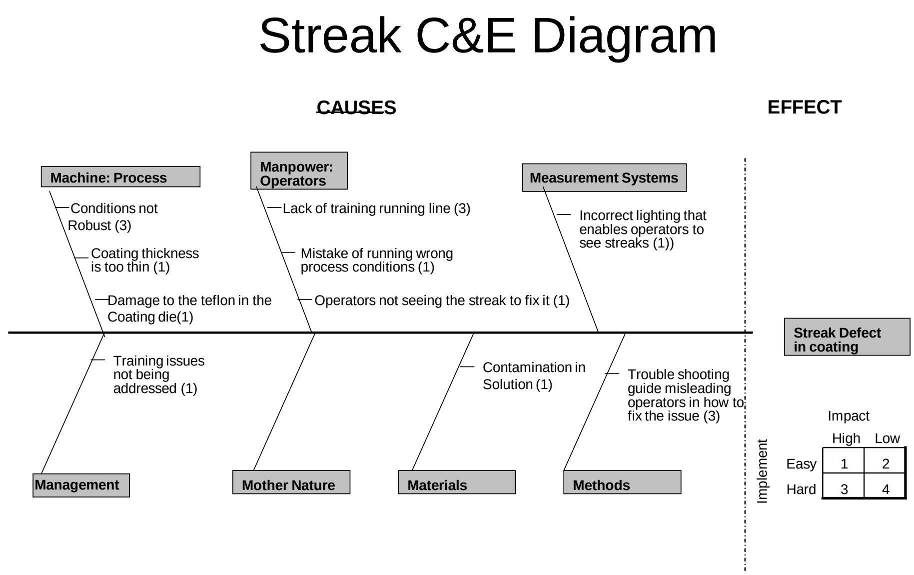

Figure 8. Analyze stage: Streak cause and effect diagram. This figure illustrates the possible root cause of streaks.

The remaining nine possible root causes focused on process robustness, machine maintenance, training, and defect detection capability. Like the edge mottle analyze stage, these items were then reviewed during the improve stage

Edge Mottle Improve Stage Results

As discussed in chapter three, edge mottle was the top quality defect causing low throughput yield in Asia. From the cause and effect diagram in Figure 5, four possible root causes of edge mottle remained. The four root cause possibilities were air flow disturbances, drying process conditions not being robust, drying solvents used in coating formulation not being robust enough for the process, and the short shelf life of solutions leading to drying defects.

Air flow disturbances. In order to find if air flow was causing a disruption in the coating, the team analyzed the coating dryers on the production line. In certain areas of the dryers, air flow slots located near the edges of the film were blocked with pieces of tape. If air flow was the root cause of edge mottle, the tape would cause the coating disruption to move in a different area or eliminate the defect overall.

Before the air flow slots were covered, a control was made using standard process conditions. Edge mottle was still present in the control. Next, the tape was used to cover the slots, and the same process conditions were used to run the experimental trial. After running the experiment, a 52" visual sample was collected to inspect the film for edge mottle. Visual results showed no difference in location or intensity of the edge mottle thus eliminating another potential root cause that was brainstormed during the analyze stage.

Process and formulation robustness. Based on the process and coating formulation, the team looked at coating thickness and drying conditions as handles to test for process and formulation robustness. First, coating thicknesses were tested at low, medium, and high levels. Real thicknesses are not shown due to Company DEF's confidentiality rules. Observations were completed by doing a visual inspection of a 52" sample. The visual reports in Table 1 indicated that as coating thickness increased the edge mottle would decrease in width but become more visible due to higher contrast of light and dark areas. As coating thickness became thinner, the edge mottle would widen, thereby affecting a larger area of the product, but it became less intense. Though it was lighter, it still failed visual inspection. It was concluded that coating thickness was not a process handle that would eliminate edge mottle.

Table 1

Edge Mottle Coating Thickness Trial

Coating Thickness	Visual Inspection Comments
Low	Edge mottle wider. Medium level 0”-2” from both edges of the film. Light contrast from 2”-6” from edge of film. All 6” fail visual inspection.
Medium	Medium level of edge mottle 0”-3”from both edges of the film.
High	Edge mottle narrower. Only 0”-1.5” from both edges of the film. Heavy level: appears very dark

Next, dryer temperature conditions were tested to see if drying hotter or cooler would make a significant difference in the defect. The team had reason to believe that if the drying was done faster or slower through temperature, it would affect or improve the coating disturbance. Like the coating thickness, actual drying temperatures are disguised due to confidentiality. The drying temperatures evaluated were low, medium, and high. Again, 52” samples were inspected for changes in edge mottle.

In examining these trials in Table 2 below, it was found that the low and medium temperatures in the process condition range were found to have no effect on the appearance of edge mottle. However, it was uncovered that the high drying temperatures worsened the edge mottle by creating thicker and more intense contrasts of light and dark areas in the coating.

Table 2

Edge Mottle Drying Temperature Trial

Drying Temperature	Visual Inspection Comments
Low	Medium level of edge mottle 0”-3” from both edges of the film.
Medium	Medium level of edge mottle 0”-3”from both edges of the film.
High	High level edge mottle. Much wider. Appears very dark 0”-7” from both edges of the film.

Overall, it was concluded that the current process capability conditions of product X2 were unable to eliminate edge mottle. The most important learning was the ability to minimize web area affected by edge mottle by increasing the coating thickness. Coating thicker was implemented during August 2011’s production run until a permanent solution was found.

Coating formulation modifications. Next, the coating formulation was investigated to attempt improving the edge mottle defect. The current coating formulation consists of 100% of solvent A. During the improve stage, the team found a possible improvement by blending solvent A with another solvent, B. Solvent A and solvent B are both used as drying agents in coating formulations. By mixing both solvent A and B together, the coating would dry quicker and smoother by reducing the chance of drying disturbances.

Since there was a limited amount of experimental time given to the team due to production orders, the team was only able to evaluate one ratio of solvent A and solvent B. The coating specialists on the product X2 team chose to use a 50% ratio of both solvent A and B. From their previous experience on other products, they believed that 50% was more than a significant difference and would fully illustrate if solvent B would eliminate edge mottle.

On Sept. 21st, 2011, the team ran the experimental coating formulation. The coating formulation was able to eliminate the edge mottle completely. As depicted below in Figure 9, it can be seen that the edge mottle was clearly present using only solvent A, but was eliminated when using both solvent A and B.

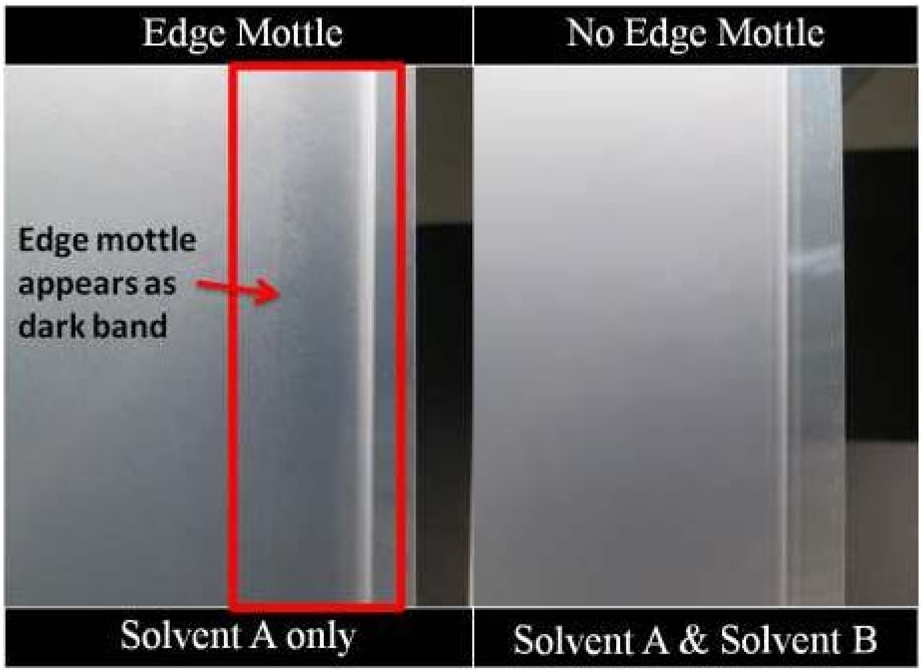

Figure 9. Edge mottle experimental results. This figure illustrates the elimination of edge mottle using a blend of solvent A and solvent B.

In addition to eliminating edge mottle, the blended formulation also made the overall coating look more uniform. The uniformity of the coating does not add functionality to the product, but it does enable the process to be more robust. Despite having better coating uniformity, the blend caused product X2's haze to increase to the point where it was no longer within specifications. The haze specification range is from 55%-70% haze. Once the haze reaches over 70% the brightness that product X2 creates for an electronic device begins to decrease, which diminishes its value to customers.

Based on the results from this experiment, it can be concluded that the blend of solvent A and B eliminates the edge mottle, but also causes the haze to be out of specification. Since the team added an aggressive amount of solvent B, the next step for the team is to optimize the ratio of solvent A versus solvent B. This will be further explained in Chapter 5's recommendations. In addition, since the solvent modification experiments were successful, there were no experiments done to test for shelf life of the coating formulation.

Streak Improve Stage Results

Before beginning the August 2011 production run of X2, process engineers trained operators to inspect and repair the die bars for any scratches. Operators gently rubbed the edge of the die until they felt a scratch or damaged area on the surface. They were then shown how to safely repair it by using a blade to smooth the surface.

In addition to minimizing scratches in the die, a design of experiments was also completed looking at coating thickness and vacuum level at the coating die. Coating thickness measures how thick the coating is put on the substrate. Vacuums systems are used to stabilize the coating solution as it coats the surface of the substrate. It does this by reducing the amount of air flow created by the moving web. ("Vacuum System", n.d.)

First, the coating thickness was tested at low, medium, and high levels. Real thicknesses are not shown due to Company DEF's confidentiality rules. Observations were completed by completing a visual inspection of a 52" sample. The visual reports in Table 3 indicate that as the coating thickness increased the amount of streaks decreased, while coating thinner caused streaks to increase. Since coating thicker also improved edge mottle, the process condition targets were modified to coat thicker.

Table 3

Streak Coating Thickness Trial

Coating Thickness	Visual Inspection Comments
Low	Five streaks. All fail streak standards.
Medium	Two streaks. One failed, one passed streak standards
High	One very light streak. Passed streak standards.

Next, the vacuum levels of low, medium, and high were analyzed to find if they affect the number of streaks. Again, visual inspections of 52” samples were carried out and were reported in Table 4 below. Interestingly, it was found that at low vacuum levels streaks were nonexistent, while increasing the vacuum level made streaks more apparent. With this finding, process conditions were also changed to target low vacuum levels.

Table 4

Streak Vacuum Level Trial

Vacuum Level	Visual Inspection Comments
Low	No streaks
Medium	Medium level of edge mottle 0”-3”from both edges of the film.
High	Edge mottle narrower. Only 0”-1.5” from both edges of the film. Heavy level: appears very dark

As seen in Figure 10, the implementation of die bar repair procedures, modified coating thickness conditions, and optimized vacuum levels has reduced streaks starting with the August 2011 production. It was further decreased in September’s 2011 production run with more operator training and experience. Though streaks have not been eliminated altogether, the changes implemented have made a significant improvement in the Asia converting sites.

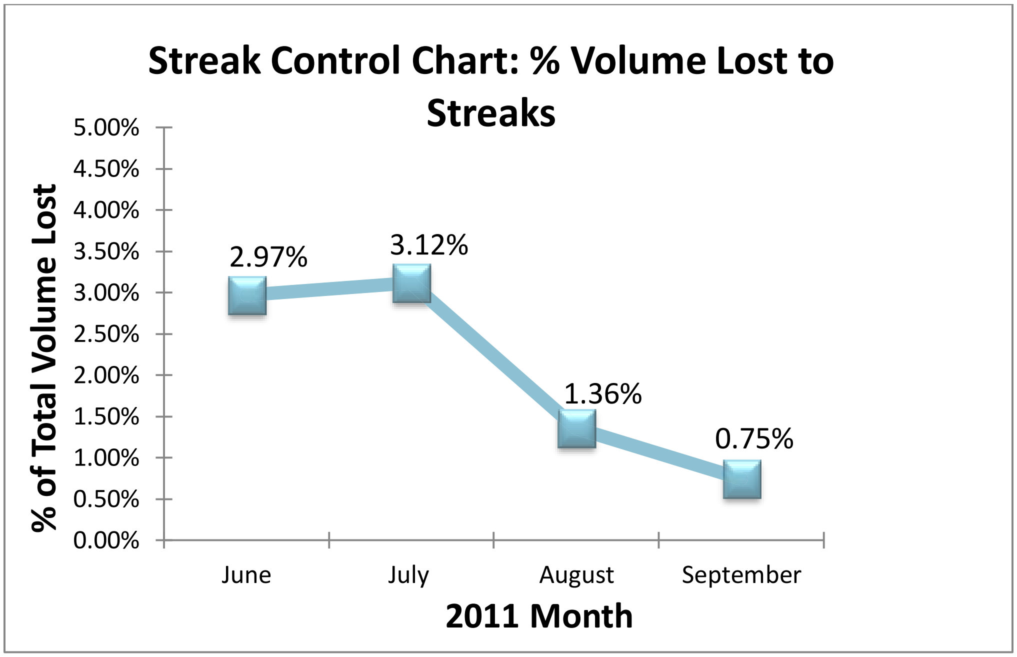

Figure 10. Streak control chart. This figure illustrates the reduction of volume lost due to streaks after implementing die bar scratch repair procedures and optimum vacuum levels and coating thickness.

Summary

In conclusion, the team found that the original process and formulation were not robust enough to enable them to eliminate edge mottle. As a result of these analyses, the team was able to solve the edge mottle defect issue by performing an experiment using a blend of solvent A and solvent B. Even though results ended in high haze, the team was confident in their ability to resolve this issue by completing more trials to optimize the blend of the solvents.

In addition to finding a solution to edge mottle, the team was also successful in reducing the amount of yield loss due to streaks. Streak waste was reduced from 3% of total volume to less than 1% of total volume. This was accomplished by implementing new die bar repair procedures and optimized vacuum level conditions. With improvements to both edge mottle and streaks, the rolled throughput yield is estimated to be 60% which exceeds the team's target by 5%. Concluding the study, project X2 was expected to pass launch phase in February of 2012 due to the improvements made on streaks and the confidence the team had in eliminating edge mottle.

In the next chapter, a recap on the findings of this research, limitations to the study, and recommendations for further research are discussed to enable more efficient future research.

Chapter V: Discussion

Product X2 was an optical film created in 2010 to enhance displays in electronic devices such as laptops and tablets. Like every product created in Division C, product X2 went through a new product introduction process to ensure that it was capable of being produced and profitable. During the transition of scale up to launch phase, the team faced a road block due to low rolled throughput yield at the Asia converting sites. To pass scale up phase, a rolled throughput yield of 55% was to be achieved. Therefore, this study was completed to raise the rolled throughput yield of 39% to 55%.

Throughout this study, a literature review was investigated to broaden the knowledge of known defects in optical films and in quality assurance tools used to help increase yield. With this information, the team was able to use the six stages of Six Sigma methodologies; define, measure, analyze, improve, and control to find the root cause and solutions to the top quality issues affecting low rolled throughput yield (edge mottle and streaks). The product X2 team is expected to pass launch phase at the February 2012 gate review.

Limitations

As with any study, there are limitations to what is researched. Within this study there are three major limitations. The first limitation is the duration of this study. Longer time is needed to ensure that quality improvements are not a special cause situation. For example, as seen in chapter three between the define and measure stage, baggy lane defects created by substrate manufacturing had increased during June 2011 and July 2011 production. This increase could have been a special cause or it could be an increasing issue in the future. Since a substrate lot lasts four to six months before coating, a trend would only observable over the course of a full year.

The second limitation is that yield improvements from potential equipment changes were not considered. Only process targets with existing equipment, formulation changes, and processing method changes were considered for the purpose of this study.

The third limitation to this study is the limited scope of products that may benefit from the findings. The defect itself and the improvements made to eliminate it may not be relevant to other products. This is possibly due to its unique construction and the coating manufacturing line that it is made on.

Conclusions

Concluding this study, the X2 new product introduction team was able to find a solution to eliminating edge mottle and reducing the yield loss due to streaks. These solutions were found utilizing quality tools throughout the Six Sigma define, measure, analyze, improve, and control stage methodology.

Edge mottle. As discussed in the previous chapter, air flow disturbances were found to be a possible root cause using the cause and effect diagram during the analyze stage. However, when an air flow investigation was completed on product X2, the team found no improvement on edge mottle by changing the flow of air during coating.

Furthermore, the coating formulation and process capability were also found to lack robustness. The team carried out experiments of several drying conditions and coating thicknesses which only resulted in reducing the width of edge mottle. By coating thicker, the team observed the edge mottle narrowed, but it was never eliminated.

Finally, mottle was eliminated by modifying the original formulation to contain a blend of solvent A and solvent B. With the addition of solvent B, the coating was able to dry quicker and smoother. Though edge mottle was eliminated, more experiments will need to be completed to optimize the blend ratio of solvent A and solvent B since the 50% ratio of each resulted in increasing haze to an unacceptable level.

Despite not finding any literature regarding the edge mottle defect, the team was able to utilize the Six Sigma methodology and tools discussed in chapter three. By using the define, measure, analyze, improve, and control stages, the team was successful in finding a solution to edge mottle.

Streaks. As a result of using Six Sigma methodology, improvements were found and implemented in order to reduce yield loss due to streaks. It was found that finding damage on the die bar and training operators how to efficiently repair it reduced streaks. In addition to these procedures, experiments showed that an optimal vacuum level further helped to reduce streaks. With the implementation of both findings, streak waste was reduced from 3% of total volume to less than 1% of the total volume.

The literature review also helped in identifying causes of streak defects. In particular, studies written by Cohen (2010) and Spengos and Fegley (1970) discussed how physical disturbances and solution flow instability were found to be common causes of streaks. The physical disturbance in this study was the damage to die bar. The solution flow instability in this study was related to the vacuum level. Additionally, Six Sigma methodologies discussed in the literature were also utilized in learning and applying quality improvement tools to enhance product X2's ability to reduce streaks.

Launch phase. The team is expected to pass through to the launch phase during the February 2012 gate review since they were able to exceed their rolled throughput yield goal of 55% by 5%. By passing the launch phase, the product will be successfully created and capable of mass production.

Future Research Recommendations

Based on the limitation of having short experimentation duration, it is recommended to extend the time of the research. If a similar process is being investigated where a certain lot of input material is used for a long period of time, it would be beneficial to analyze defect trends with those lots.

Another recommendation is to further analyze various levels of solvent B in the formulation. This additional experimentation will help optimize the solvent ratio, and hopefully will eliminate edge mottle without resulting in unacceptable haze levels. Since the product X2 team was unable to have more experimental time, more experiments must be completed at a later date to ensure good quality film.

The final recommendation for future studies is to search further into the root cause of coating streak defects. In this study, the team found that one of the root causes was damage to the die bar. Operational procedures to repair the die bar were implemented and successful, but the main reason for die bar damages was never investigated. Since the manufacturing line is used by several products across a few of Company DEF's divisions, it was difficult to monitor where the damages were coming from. A more efficient way of eliminating damage to the die bar is investigating the reason for the damage and implementing preventative maintenance.

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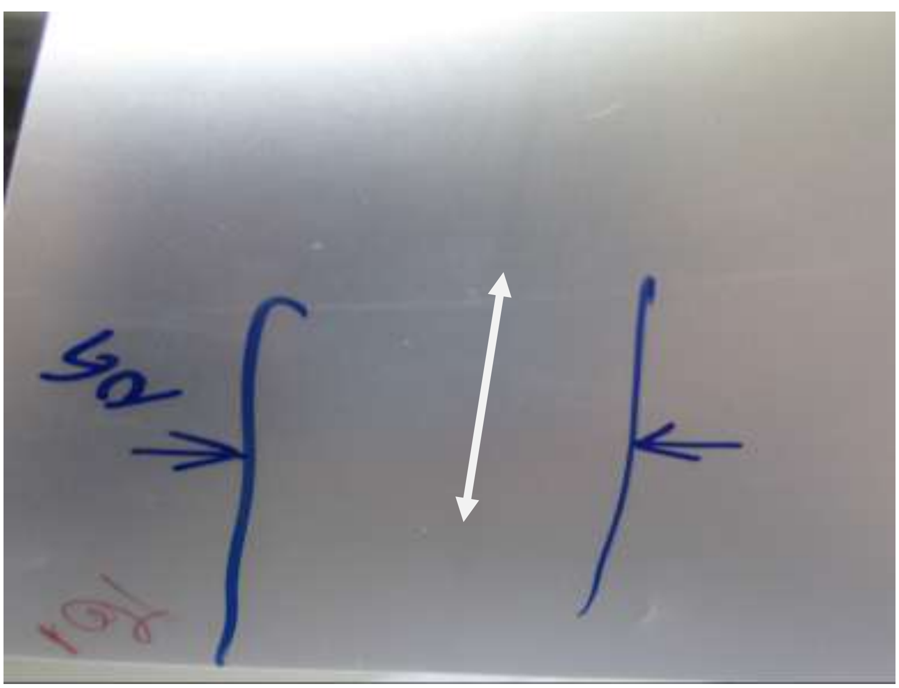
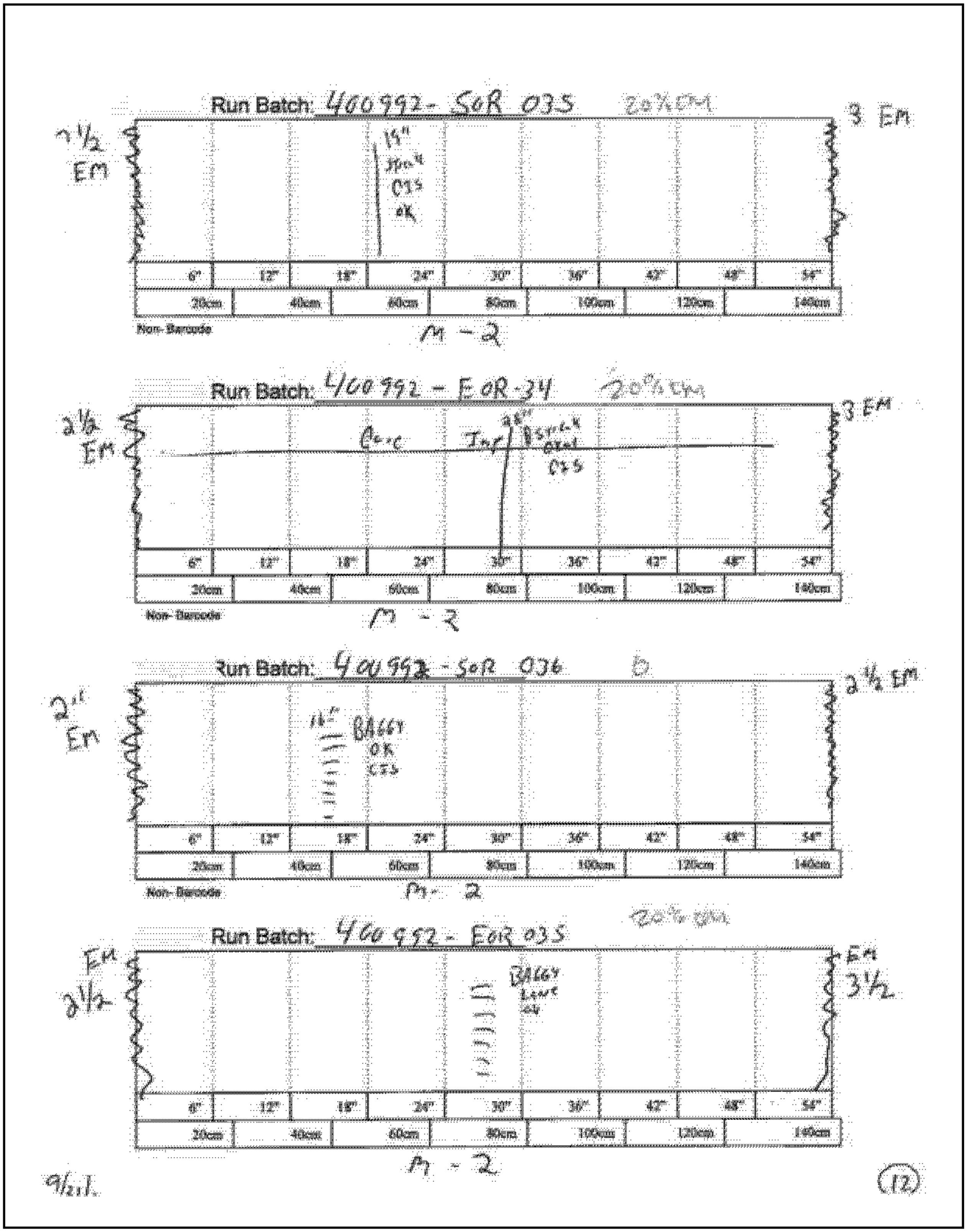
Appendix A: Defect Pictures

Edge Mottle: Dark band in machine direction at edge of film.

Streak: Thin dark line in machine direction causing disturbance in coating (see white arrow for reference



Appendix B: Example of Defect Roll Map



Appendix C: August 2011 Waste by Cause Yield Estimate Worksheet

Output Roll #	Input Roll #	Total Output Length Lnyds	Total Output in Sqyds	Sqyds Lost to Streaks	Sqyd Lost to Edge Mottle	Sqyd Lost to Baggy Lane	Sqyd Lost to CW Banding
400946-006		1607	2410.5	743.4			
400946-006	101148521		0				
400946-007		1290	1935				193.5
400946-007	101148525		0				
400946-009		1511	2266.5				906.6
400946-009	101203004		0				
400946-010	101205004	1705	2557.5				
400946-011	101148527	1765	2647.5		264.75		
400946-011			0				
400946-012	101203035	1713	2569.5	256.95			
400946-012			0				
400946-013	101201519	883	0				
400946-014			0				
400946-014	101203524	1427	2140.5				
400946-015	101203532		0				
400946-015			0				
400946-020	101203533	1595	0				
400946-021	101203520	1514	2271				
400946-022	101148522	1577	2365.5		473.1		
400946-024			0				
400946-024	101147532	1093	1639.5				
400946-025	101148523	1666	2497.5				
400946-028	101204513	1665	2497.5				
400946-028			0			249.75	
400946-029	101203037	662	993				
400946-031	101204003	1575	2362.5			236.25	
400946-031			0				
400946-032	101204003	1549	2323.5			232.35	
400946-032	101204001		0				
400946-033	101204508	1379	2068.5			206.85	
400946-033			0				
400946-034		1621	2431.5			243.15	
400946-034	101203532		0				
400946-044	101203024	1428	2142				214.2
400946-044			0				
400946-045	101203023	1568	2352				235.2
400946-045			0				
400946-046	101203031	954	1431				
400946-046			0				
400946-047	101203013	1399	2098.5				
400946-047			0				
400946-049	101203030	1358	2037				203.7

400946-049			0				
400946-050		1412	2118	211.8		423.6	
400946-050	101203517		0				
400946-051	101203513	1496	2244				
400946-051			0				
400946-054		609	913.5		182.7		
400946-054	101205027		0				
400946-055	101206007	1629	0				
400946-056	101205532		0				
400946-057			0				
400946-057	101206510	1444	0		0		
400946-058	101204002	1501	0				
400946-058			0				
400946-059		1629	2443.5				
400946-059	101204014		0				
400946-060	101205023	1531	2296.5				
400946-060			0				
400946-062	101201019		0				
400946-063		1488	2232			223.2	
400946-063	101205524		0				
400946-064	101205011	1652	2478				
400946-064			0				
400946-065			0				
400946-065	101202008	1067	0				
400946-066	101206009	1089	1633.5				
400946-072		1366	2049				
400946-072	101204501						
400946-073	101202504	961	1441.5				
400946-073			0				
400946-074		1739	2608.5				
400946-074	101147015		0				
400946-075	101203505	1733	2599.5				
400946-075			0				
400946-076		1730	2595				
400946-076	101204512		0				
400946-077	101204503	1706	2559				
400946-077			0				
400946-078	101204020	1367	2050.5				
400946-079	101203521		0				
400946-080	101204009	1748	2622				
400946-081	101206509	1719	2578.5				
400946-083	101204515	788	1182				
400946-085	101204516	1588	2382				
Total			**89064**	**1212.15**	**920.55**	**1815.15**	**1753.2**
Percent of Total Volume				**1.36%**	**1.03%**	**2.04%**	**1.97%**