Implementation of Six Sigma at Company XYZ

to Eliminate Finished Goods

Nonconformance

by

Debra Poirier

A Research Paper
Submitted in Partial Fulfillment of the
Requirements for the
Master of Science Degree
in

Technology Management

Approved: 2 Semester Credits

Dr. John Dzissah

The Graduate School

University of Wisconsin-Stout

May, 2009

The Graduate School
University of Wisconsin-Stout
Menomonie, WI

Author: **Poirier, Debra A.**

Title: ***Implementation of Six Sigma at Company XYZ to Eliminate Finished Goods Nonconformance***

Graduate Degree/ Major: MS Technology Management

Research Adviser: **John Dzissah, Ph.D.**

Month/Year: **December 2008**

Number of Pages: **46**

Style Manual Used: **American Psychological Association, 5th edition**

ABSTRACT

Over five months in 2007 Company XYZ received eight complaints of loose wind from various customers. Loose wind is unacceptable to customers, and each complaint resulted in returned product. Company XYZ needed to determine the root cause of the nonconformance and implement a permanent corrective action. A second purpose of the study was to implement the Six Sigma problem-solving methodology at Company XYZ. The Six Sigma methodology was developed at Motorola Corporation and utilizes statistical analysis to reduce variation and defects. Company XYZ selected one complaint of the eight loose wind complaints to develop a template using the Six Sigma methodology. The template will be used for future problem-solving opportunities.

ACKNOWLEDGMENTS

I would like to thank my employer and fellow employees for working with me on this project. We have worked together to create a useful problem-solving template for the company. I would also like to thank my husband and daughter for supporting and encouraging me during my graduate studies. Finally, I would like to thank my advisor, Dr. John Dzissah for his patience and advice while completing my research project.

TABLE OF CONTENTS

List of Tables

List of Figures

Chapter I: Introduction

Company XYZ is a custom manufacturer of embossed polyolefin films. The company was formed in the early 1970's to service specialized markets requiring embossed polyolefin films for industrial applications. Adhesive, automotive, composite, landscaping, medical, packaging, release liner, rubber, and tape substrates represent industries serviced by Company XYZ. Customers order film in various colors, thicknesses, widths, lengths, and emboss patterns and convert the film into finished product such as table cover, landscaping fabric, automotive headliners, medical gowns, etc. Over the years Company XYZ has grown in all aspects, including sales revenue, number of employees, shipping volume, products, and customer base. The company's emphasis on quality and customer service in specialty films is the primary reason for its continued success.

Word of mouth has been Company XYZ's primary method of advertising and sales growth. Customers and distributors have come to expect high standards in product quality, service, and delivery. These expectations allow the company to pursue its strategy as a custom manufacturer and price leader. Although the company has maintained returns and allowances to less than 0.5% of sales, an objective of the quality management system includes reducing the number of product returns.

Polyethylene resin, a by-product of natural gas, is Company XYZ's primary raw material. The resin is mixed, heated, and extruded through a flat die to form sheet film. The film then passes over an embossed roll and is wound tightly onto a core. In order for customers to further process the film into a finished product, even wind throughout the roll of film is critical.

Statement of the Problem

Over five months in 2007 Company XYZ received eight complaints of loose wind from various customers. Loose wind is unacceptable to customers, and each complaint resulted in returned product.

Purpose of the Study

Company XYZ needs to determine the root cause of the nonconformance and implement a permanent corrective action. The company's corrective action policy is to take action to eliminate the cause of a major nonconformance that has occurred, and prevent reoccurrence of the nonconformance in the future. Major nonconformances are defined as significant failures in the quality system including trends in customer complaints.

A second purpose of the study is to implement the Six Sigma problem-solving methodology at Company XYZ. The Six Sigma methodology was developed at Motorola Corporation as a strategy to deal with product and system failures (Summers, 2003). The methodology has evolved to a business strategy involving the measurement of how well business processes meet their organizational goal and offers strategies to make needed improvements (Breyfogle III, 2003). "The application of the techniques to all functions results in a very high level of quality at reduced costs with a reduction in cycle time, resulting in improved profitability and a competitive advantage" (p. 4). The Six Sigma methodology is a good fit with Company XYZ's strategy to achieve high quality and operational efficiency in all departments.

Assumptions of the Study

1. Historical data collected by Company XYZ is accurate.
2. Accuracy of Company XYZ's measurement tools can be verified.

3. Company XYZ's management and employees are willing to test and implement recommendations based on the study.

Definition of Terms

Following is a list of terms commonly used in the production of plastic films.

Additive. A substance compounded into resin to modify film properties. Additives can be antioxidants, colorants, pigments, light stabilizers, etc. (Butler, 2005).

Blocking. The adherence of adjacent film layers to each other (King III, 2005).

Cast Film. Film extruded through a flat die onto chill rolls (Butler, 2005).

Chill Roll. A cored roll, usually temperature controlled by circulating water, which cools the film on contact before winding (Butler, 2005).

Coefficient of Friction. "Resistance to movement of sliding or rolling surfaces of solid bodies in contact with each other" (Butler, 2005, p. 592).

Die. A steel block containing an orifice through which plastic is extruded, shaping the molten plastic to the desired form (Butler, 2005).

Embossing. Technique providing a textured surface to roll goods. It is used in line with extruders. The focal point of the equipment is the textured roll (emboss roll) which provides the impression (Butler, 2005).

Extruder. A machine for producing continuous lengths of plastic sections such as films, rods, sheets, tubes, profiles, and cable coatings by melting and pumping resin through a forming die (Butler, 2005).

Fogging. The tendency of small individual water droplets to form (via condensation) on the surface of the film (King III, 2005).

Gauge. "Thickness of plastic film measured in mils (thousandths of an inch) or microns (thousandths of a millimeter" (Butler, 2005, p. 596).

Impact Strength. A measure of the amount of energy a material can take before breaking (Spalding and Butler, 2005).

Modulus. A measure of stiffness or the ability of the film to retain its shape when a force is applied to it (Spalding and Butler, 2005).

Polyolefins. Polymers of simple olefins including ethylene and propylene. The term polyolefins means "oil-like" and refers to the oily or waxy feel that these materials have. Polyolefins are usually processed by extrusion, injection molding, and blow molding methods (IDES, n.d.).

Limitations of the Study

Company XYZ needs to determine the root cause of the loose wind complaints and propose a permanent corrective action. Due to time constraints, the permanent corrective action may not be implemented in time to complete the research paper. Although Company XYZ will complete the Six Sigma project, the final stages may not be completed in time for the research project. The research project will provide recommendations for the implementation of the corrective action.

Chapter II: Literature Review

Introduction

Sheet film is extruded at a variety of thicknesses and widths to serve packaging, automotive, medical, appliance, construction, and other industries. Selection of raw materials is critical depending on the film application. The required physical properties of the film such as tensile strength, orientation, ultraviolet (UV) stability, surface finish, and oxygen or moisture permeability all influence how, and on what type of equipment the sheet is produced (Darrow, 2005). The literature review includes a description of raw materials used in cast film, the cast film manufacturing process, and process control and quality assurance testing methods. In addition, the literature review provides a description of the Six Sigma problem-solving methodology.

Raw Materials

Plastics for extrusion are called thermoplastic which means the plastic materials get soft when heated and harden again on cooling (Griff, 1994). Plastics are usually obtained in the form of granules, powders, flakes, and pellets. Some plastics process with ease and others can develop problems if not properly processed within tight control settings. This situation occurs when processing thermoplastics with certain additives such as colorants, heat stabilizers, etc. (IPLAS, n.d., *Processing plastic material).*

Resins. The primary ingredient in the polymer recipe is the resin. The thermoplastic resin families used for films include polyethylene (PE) and polypropylene (PP) (Spalding and Butler, 2005). The polyethylene family primarily includes low density (LDPE), ethylene vinyl acetate copolymer (EVA), linear low density (LLDPE), and high density (HDPE) (Schwank, 2005). Selection of the proper resin is the key to a quality finished product.

The resin selected for an application must provide the necessary strength, modulus, and other properties to the end product (Spalding and Butler, 2005). Table 1 provides physical properties and applications for several common resins. As indicated, the modulus and impact strengths vary widely for the various resin types. The resin selected must have the correct balance of these and other physical properties in order to provide the required performance for the application. Physical properties related to processing are also important as they control the production rate and equipment requirements. These properties include bulk density, coefficient of dynamic friction, heat capacity, specific energy, thermal conductivity, melting flux, melt density, and viscosity.

Table 1: Resin Properties

RESIN	TENSILE MODULUS, MPa	IMPACT STRENGTH, J/cm	MELTING TEMPERATURE (T_M), °C (SEMI-CRYSTALLINE)	GLASS TRANSITION TEMPERATURE (T_g), °C (AMORPHOUS)	APPLICATIONS
HDPE	1070-1090	0.2-2.1	135	-20	Liners, sacks
HIPS	1100-2500	0.5-3.7		105	Packaging, specialty films
LDPE	170-280	No break	110	-20	Films
LLDPE	260-520	No Break	120	-20	Films
PA 6,6	1600-3400	0.5-1.1	260		Barrier films
PET	2800-4100	0.13-0.37	240		Packaging films
PLA	3300-3800	0.03	160	58	Packaging, fibers
PP	1140-1550	0.2-0.75	170	-20	Packaging (sheet)
PS	3100-3300	0.20-0.24		105	Packaging, foam sheet
PVDC	340-550	0.1-0.5	165	0	Oxygen and water barrier applications (food packaging)

(Spalding and Butler, 2005, p. 363)

Additives. When the resin selected is combined with additives, fillers, or different levels of co-monomers, the end product will have different physical properties (Spalding and Butler, 2005). A variety of additives are readily available not only to increase the monetary and aesthetic value of the film product, but also to improve film processing (King III, 2005). Additives include anti-block agents, antifogging agents, colorants, and slip additives to name a few. Typically, one or more of these additives are used in combination to differentiate film products.

Blocking can occur during the blown or cast film process or when roll stock are stacked and subjected to pressure, time, and heat. Anti-block agents are added to the film recipe to reduce the intimate contact between the polymer film layers and prevent the layers from bonding to one another.

Under certain conditions, fogging obscures the clarity of the film, compromising aesthetics. This is especially undesirable in food packaging. In applications like greenhouse films, the water droplets can act to focus the light, potentially damaging the plants (King III, 2005). Antifogging agents are used to eliminate this problem. The agents work by lowering the surface tension of the film to the water droplets. After the film is processed, the antifogging agent migrates out of the polymer and concentrates on the film surface thus lowering the surface tension of the water condensed there. The water droplets then coalesce resulting in a thin clear film of water which gives the perception of enhanced clarity. The concentration of the additive must be large enough in the recipe so that the additive continues to migrate to the film surface over the lifetime of the item packaged.

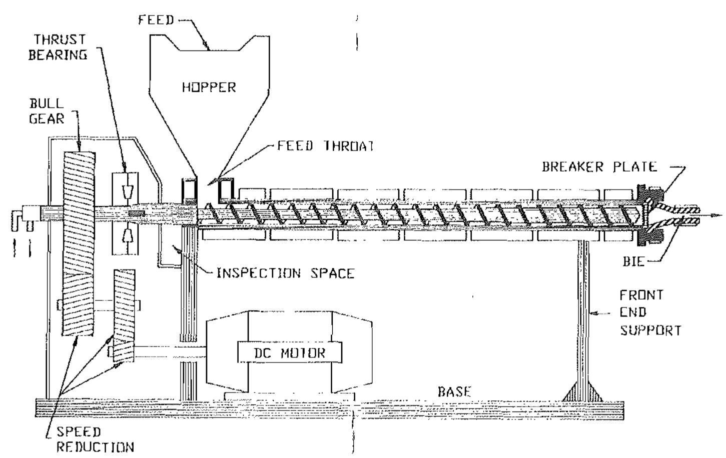
Color is added to the film recipe to make products more attractive or to color code. Colorants can be used to change the color as well as opacity of the final product (King III, 2005). Special effects such as flourescence, optical brightening, and pearlescence can also be achieved with more exotic pigments.

Slip additives promote lubrication on the surface of the film and reduce the coefficient of friction (King III, 2005). Slip additives used in polyolefin film extrusion are generally based on various types of fatty amides. These amides are not compatible with the resin, and once the resin is extruded through the film die, the amide migrates to the film surface. This promotes surface lubrication which reduces the coefficient of friction (COF). The reduced COF decreases drag across the collapsing frame resulting in more rapid extrusion rates and fewer problems with film wrinkles. Levels of COF are also important in other post film extrusion operations. In addition, some types of slip agents also perform as an anti-block to prevent adhesion of film surfaces.

Extrusion Process

Extrusion. In an extruder, a screw turns in a cylinder called the barrel (See Figure 1).

Figure 1: Extruder



THE EXTRUDER AND ITS PARTS

(Griff, 1994, pp. 28-29)

Plastic material enters through the feed hopper at one end of the barrel, and is caught by the screw and conveyed through the barrel while it becomes soft and eventually melts (Griff, 1994). Heat is generated by the friction of the screw turning in the plastic mass, and therefore most of the energy to melt the plastic materials usually comes from the motor that turns the screw. More heat is added by barrel heaters. As the screw turns, it tries to unscrew itself backward out of the barrel full of material. It can't come out because a bearing holds it in place, but its reaction is a push against the molten material, forcing that material out the other end. The opening at the output end of an extruder is called the die. As the hot, soft plastic emerges it takes the shape of the hole it passes through: a long slit makes a sheet or flat film, a circular opening makes pipe or a tube to be blown out to thin film or a bottle, many small holes make filaments, etc.

Gauge bands in a roll of film are caused by varying film thickness across the sheet. As the roll of film increases in diameter, the thicker film builds on itself and the thinner film is stretched. The greater the winding tension, the more pronounced the bands are, severely distorting the surface of the roll (Roller and Vedder, 2005). Gauge bands from dies can be caused by improper adjustments, by using equipment not designed for the product being produced, or by poorly maintained equipment. In addition, internal leakage that is degraded or carbonized inside the die can make it impossible to adjust. The die needs to be cleaned frequently. A die that has been damaged and repaired by re-welding, applying new chrome, and polishing can still cause a gauge band from a weld line in the film. The welded metal does not have the same heat transfer rate of the original metal affecting flow rates across the die flow patterns. A nick in the exit of the die, no matter how slight, may leave lines in the melt that cannot be removed except by replacing the source of the damage. All of these defects in the die can lead to gauge bands.

Cast Film Process. The primary technique used to produce cast film is chill roll casting (Post and Davis, 2005). In chill roll or cast film extrusion, the melted polymer is cast through a narrow slot die, drawn down, and formed onto a rotating chill roll. Additional chill rolls can be added for improved film cooling and increased output. The primary advantages of cast film over blown film are:

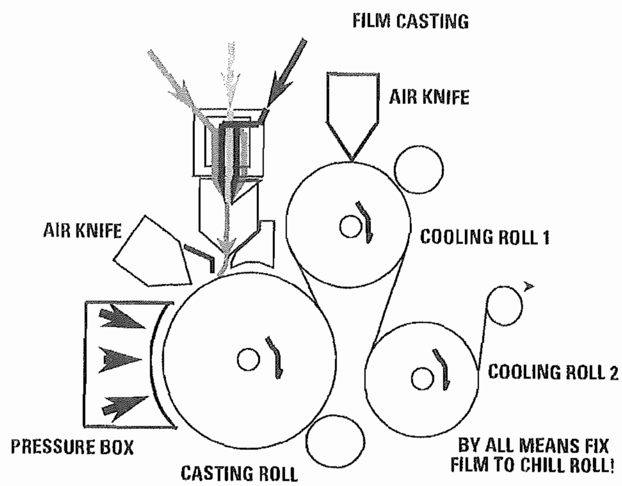
1. Substantial improvements in the control of optical properties of the film.
2. Potentially higher output with larger diameter chill rolls.

3. Production of films having a higher modulus.

4. Improved thickness and profile control (Post and Davis, 2005).

In cast film extrusion (See Figure 2), the melted polymer drops onto the chill roll and

Figure 2: Chill Roll Casting Layout



(Post and Davis, 2005, p. 229)

contacts the roll above the tangent line (Post and Davis, 2005). The alignment of the roll to the die is critical in relation to the falling film. Whenever wrinkling of the film occurs on the casting roll surface, the first roll must be carefully repositioned in relation to the die lip. The chill rolls are constructed of a double shell where the cooling medium is pumped through the gap formed between the inner and outer shells. The cooling medium can be any heat transfer fluid including water or water/glycol mixtures. For high temperature or engineering polymers having temperatures exceeding 150°C, heat-transfer oils are used.

The surface finish of the casting roll is also important in determining the properties of the film. Gloss, smoothness, and haze are all affected by the roll finish (Post and Davis, 2005). Casting rolls are generally chrome plated due to chrome's resistance to heat, corrosion and wear, its low surface energy, and its ability to conduct heat. Rolls can also be nickel plated for additional protection from corrosion and heat.

During the forming process of the film, the web is subject to many variables including draw down ratios, plant air drafts, and variations in melt strength (Post and Davis, 2005). The web forming devices attempt to correct or minimize the effects that these variables have on the properties of the film. Four options for web forming and pinning a molten polymer to the casting roll include an air knife, a vacuum box, an air chamber, and/or an electrostatic wire. Each device has its own advantages and disadvantages. Some extrusion processes use a single device while others use a combination of the above listed devices.

The air knife is used to ensure close contact between the melted polymer web and the casting roll (Post and Davis, 2005). As the polymer is pushed through the die and contacts the casting roll, an air stream from the air knife strikes the polymer. An air blower supplies the air. The air knife must not only supply an even distribution of air, but allow for a variety of pressures. Uneven air velocity leads to uneven web pinning and gauge variation or gauge bands. Uneven web pinning can cause defects in films such as chevrons, fisheyes, and blotches. The air supplied is typically at room temperature although it can be heated or cooled depending on the application. The room temperature or cooled air provides additional cooling to the film leading to higher film clarity. Positioning of the air knife is also critical. Many materials such as PP and LDPE have a small processing window for the position of the air knife. Outside this window, web stability decreases and film defects can occur. The air knife needs to be adjustable in three directions: horizontally, vertically with respect to the roll, and angular with respect to its axis. "As the repeatability of obtaining this position is critical, it is important that the adjustment mechanism be calibrated for controlling position" (p. 232).

As with the air knife, a vacuum box can be used to ensure close contact between the melted polymer web and the casting roll (Post and Davis, 2005). However, unlike the air knife, the vacuum box relies on negative pressure rather than positive pressure. A well-designed vacuum box creates a true vacuum between the molten polymer and the casting roll, thereby sucking the film to the roll. As with the air knife, an even pinning force across the width of the web is required to prevent film imperfections.

The third device, the air chamber, works in the same manner as the air knife in that air from the air chamber strikes the molten polymer after it contacts the casting roll to ensure close contact between the film web and the roll (Post and Davis, 2005). The difference between the air chamber and air knife is in the amount of effective area and air velocity used to pin the web to the roll. An air knife results in high air velocity over a small surface area. The air chamber uses a relatively lower air velocity over a larger surface area. This makes the pinning force of an air knife much higher than that of an air chamber. The result is a more "gentle" pinning method with an air chamber. While being more "gentle", the air chamber can also provide more cooling to the film, improving the optical properties of the film. The air chamber is used mostly with polymers that require high clarity and are subject to surface defects such as "fisheyes" and "chevrons". The drawback with the air chamber is its low pinning force. As line speed is increased, the casting roll will carry a greater volume of air. With a low pinning force, it becomes difficult for the air chamber to remove all the air at higher line speeds.

"Unlike the three previously mentioned web forming devices, the electrostatic wire uses a static charge to create the pinning force rather than negative or positive air pressure" (Post and Davis, 2005, p. 236). A DC charging generator is used to generate a high voltage output to a wire which, in turn, emits either positive or negative ions. Negative ions are generally preferred as positive ions have a tendency to neutralize more quickly. When the charged wire is placed against a grounded metal surface, the casting roll, an electric field is created between the two, which forces ions to move towards the grounded surface. Non-conductive materials or insulators will maintain a static charge for a long period of time. The ability for a material to hold this charge is related to its surface resistivity – the lower the surface resistivity, the greater the ability for the material to hold the charge. When the molten polymer is placed between the wire and the roll, the ions are intercepted by the film, and subsequently charge the film. The charged polymer will be attracted to the casting roll and be held in place as long as the charge remains on the plastic.

The electrostatic wire yields a very uniform electric field across the width of the film and results in a very uniform pinning force (Post and Davis, 2005). Film produced using this method will have a very smooth surface with no sharp peaks or valleys in the thickness profile, making it the best device for minimizing gauge variation. Since the vacuum box sucks the film rather than blows the film to the roll, the vacuum box also produces a smooth film with minimal gauge variation. However, poor vacuum seals on the end of the vacuum box will often affect the flatness on the ends of the film web.

Two methods exist to pin the edges of the melted polymer as it necks in and draws down onto the casting roll (Post and Davis, 2005). These devices include air jets and electrostatic edge pinners. "The ultimate goals of the edge pinning devices are to maximize the effective width of the film by minimizing the distance the web necks-in and to produce a stable film edge" (p. 238). Neck-in can be minimized by keeping the die as close as possible to the casting roll. The amount of neck-in can be decreased by using air jets to direct a stream of air at the heavy edge bead as it necks-down onto the casting roll. The exact location of the nozzle is an art that is only optimized when positioned by a highly skilled operator. After the edge of the film falls onto the casting roll, it has a tendency to neck-in further. The edge of the film will also oscillate creating a very unstable edge. Using a highly polished or "mirror" casting roll can minimize further neck-in. The higher surface energy of the roll causes the film to adhere to the roll more readily.

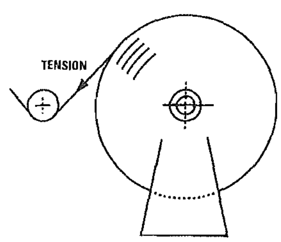
Electrostatic edge pinners work on the same principle as the electrostatic wire (Post and Davis, 2005). The charging device generates an ionic charge on the film creating an electrostatic field between the film and the roll. The major differences are that the electrostatic edge pinners generate only a point charge rather than a uniform charge over a wide distance, and the charging density is much stronger than that generated by the wire. This may cause some pinholing on the film edges. For effective edge pinning at high line speeds, air and electrostatic edge pinning are recommended.

Winding. The final step of the production process involves winding the film onto a core. The function of the winder is to continuously transform the film into rolls of material that can be handled, transported, and reprocessed without affecting the properties or dimensional stability of the film (Smith, 2005). Plastic film webs are typically still warm when wound. The film may have tack or slip agents that can migrate to the surface after a period of time. In addition, plastic film webs have memory. This memory is a history of the previously imposed stresses from the manufacturing process. These stresses will often be relaxed during the curing process that will take place anywhere from 12 to 48 hours after production. This curing process takes place throughout the roll which causes sometimes wanted but usually unwanted dimensional changes in the web.

"If all webs were perfect, then the ability to produce perfect rolls of film products wouldn't be much of a challenge. Unfortunately, due to the normal variation in resins and additives and non-uniformity's of the film formation processes, there is no such animal as a perfect film" (Smith, 2005, p.313). The challenge is to wind plastic film webs having slight imperfections and produce quality rolls that will run in your customer's process without problems resulting in high quality products for their customers.

Three basic film winding methods include center winding, surface winding, and combination center/surface winding (Smith, 2005). Typically, a center winder uses only tension to control the roll's hardness (See Figure 3). However, a center winder could also incorporate a

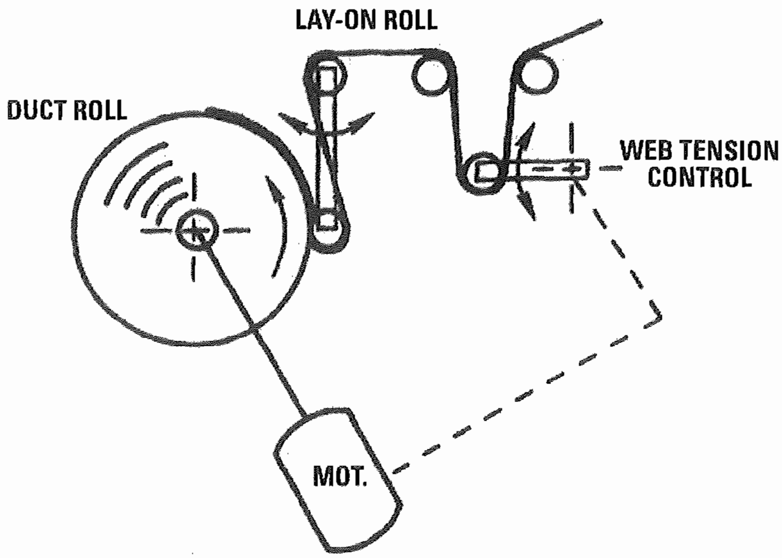
Figure 3: Center Winder



(Smith, 2005, p. 319)

layon or pressure rolls in which both tension and nip are used to control the roll's hardness (See Figure 4). Advantages of center winding include the ability to wind softer rolls and faster

Figure 4: Center Winder with Lay-on Roll



(Smith, 2005, p. 319)

cycle times. The disadvantage of center winding is the limitation of maximum roll diameter due to the torque applied through the layers of film. Also, center winders tend to have a higher scrap rate during production setup.

Surface winder winders use a motor-driven winding drum (Smith, 2005). The winding rolls of film are loaded against the drum and are surface wound. When surface winding elastic films, web tension is the critical factor. When surface winding inelastic materials, nip is the critical factor. The advantage of surface winding is that web tension is not supplied from torque being applied through the layers of film wrapped into the roll. However, the disadvantage of surface winding is that air cannot be wound into the roll to minimize gauge bands and roll blocking problems. In addition, drum type surface winders provide only single direction winding. Surface winders are best for winding hard rolls and large diameter rolls. They are also less expensive and produce less scrap during production setup.

A center/surface winder uses both center winding and surface winding processes (Smith, 2005). Center/surface winding uses web tension, nip pressure of the roll or drum, and torque from the center drive to control the wind. Web tension is controlled by the surface drive connected to the layon roll to optimize the slitting and web spreading processes. The web tension is held constant during the winding operation. The layon roll loading applied to the winding roll of film controls the nip. The torque from the center drive is programmed to produce the desired inwound tension for the roll hardness profile desired. "The advantage of center/surface winding is that the winding tension can be independently controlled from the web tension. The disadvantage of center/surface winding is that the winding equipment is more expensive and more complex to operate" (p. 321). Center/surface winders are best for winding high slip films to larger diameters, best for slitting and winding extensible films to larger diameters, best for ability to significantly taper inwound tension without affecting the width of the film, and able to supply web tension without stretching the web over caliper bands.

Rolls that are wound too tight will exaggerate web defects (Smith, 2005). No film web is perfectly flat. Typically, webs have slight high and low areas in the thickness profile. When winding hard rolls of film, the high caliper areas build on each other. As hundreds of layers are wrapped into a roll, the high areas form ridges or high spots in the roll. As the film is stretched over these ridges, it is deformed. Then when the roll is unwound, these areas produce a defect known as bagginess in the film. Slight defects of these types will not be noticeable if sufficient air is wound into the roll in the low areas and the web is not stretched over the high areas.

However, rolls of material must be wound hard enough so that they will be round and will stay round during handling and storage.

To overcome thickness variations the film web can be moved back and forth as it is being slit and wound, or the slitters and winder can be moved back and forth relative to the web (Smith, 2005). This is called oscillation, which randomizes these localized thickness variations across the wound rolls. The oscillation speed needs to be fast enough to randomize thickness defects and slow enough that it does not strain or wrinkle the film. In addition, the film must be wound with straight edges. The maximum oscillation speed that should be used is 1 inch per minute per 500 feet per minute (fpm). For best results, the oscillation speed should vary proportionally with the winding speed.

Other winding components include: the slitting operation, the spreading operation, the winder drives and tension control system (Smith, 2005). On cast film lines, the edge is trimmed to remove the edge bead or non-uniform material at the edge of the web.

> When plastic webs are slit with a razor blade, the edges tend to thicken. This is due to resistance set up by the stationary blade and the fact that the plastic material is usually not brittle. Thus, there is flow in the plastic at the point of resistance (Hawkins, 2003, p. 67).

Thicker edges increase the buildup radius of the slit roll edges resulting in many winding problems (p. 67).

The function of the web spreader is to prevent wrinkles during the web processing and to separate the slit webs when inline slitting without needing to take bleed trim (Smith, 2005). The most common spreading systems for cast film lines include the reverse crown spreader roll, the flex spreader roll covering, the single bowed spreader roll, and the dual bowed roll. The reverse crown spreader is a conventional roll, normally an idler but may be driven, that has a diameter at the ends slightly larger than the diameter in the center of the roll. The surface speed is greater at the ends than the center. The surface speed difference causes an ingoing web tension distribution acting to remove wrinkles in the web. The flex spreader is a straight roller that has a special grooving cut into a soft outer cover. The grooving is undercut at an angle so that the web tension deflects the lands outward, carrying the web with it to accomplish the spreading action. A bowed roll spreader is a curved roll with a stationary axle on which separate metal rotating sleeves are mounted. The metal sleeves are typically covered with soft, synthetic rubber. Bowed roll spreaders can be used on processes having a wide range of material types and can be adjusted to tighten the center or ends of the web. The dual bowed roll spreading system has two bowed rolls between which the spreading takes place. These systems allow for excellent control of spreading action and can be adjusted to tighten the center or edges of the web.

Another function of the winder drive or drives is to properly control the winding web tension (Smith, 2005). The electric motors and drive control systems must provide precise speed and torque control during the buildup of the winding roll. This control needs to be programmable to consistently reproduce the speed and tension profiles for all the various products and conditions that the film winder will encounter. In addition, winder drives must be capable of winding large diameter rolls and need wide torque and speed ranges.

The best tension control can be obtained with a build-up ratio not exceeding 6/2 from the core diameter to the finished roll size (IPLAS, n.d., *Sheet*). Thus, a 3 inch core diameter is best suited for rolls not exceeding 18 inches in diameter. Cores having a 6 inch diameter are suitable for rolls up to 36 inches, and 8 inch cores should be used for rolls up to 48 inches in diameter.

Process Control and QC Testing

Producing quality cast film requires the monitoring of a number of variables during and after the production process. The variables include, but are not limited to, web tension, roll hardness, roll circumference, film thickness, and coefficient of friction.

Web Tension. According to Hawkins (2003), tension control of the web is essential for quality control of a product in any machine producing products such as paper, metal foil, plastic film, or cloth. Roll density, or inwound tension, is the most important factor in determining the difference between good and poor quality rolls (Smith, 2005). Rolls that are wound too soft will go out of round while winding or while being handled or stored. The roundness of rolls is critical in customer operations. When unwinding out of wound rolls, each revolution will produce a tight and slack tension wave resulting in processing variations. Rolls that are wound too tight will also cause problems. Some rolls of film will "block" when wound too tightly. Roll blocking results in the layers of film adhering together. In addition, winding film too tightly onto thin wall cores can cause the cores to collapse. This can cause problems in removing the shaft or with inserting the shaft or chucks on subsequent unwinding operations. Tightly wound rolls contain high residual stresses or high inwound tension. The film will stretch and deform as these stresses are relieved during the curing process.

Two tension sensing systems are commonly used on film winders including dancer control systems and transducer controlled systems (Smith, 2005). A dancer tension control system consists of an idler roll and a set of pivoting arms that are positioned by one or more air cylinders. The web tension is controlled by the air pressure to the cylinders. A potentiometer indicates the position of the arms and trims the winder drive to keep the dancer in the proper position. A dancer system does not provide a direct readout of the web tension. In addition, dancers are slow to respond to tension changes. A transducer tension control system consists of a precision balanced idler roll, or a tension roll, that is supported by two electronic load sensing devices. A transducer system provides a direct readout of the web tension. The winder drive uses the web tension feedback signal to trim the torque or speed to the winding roll to provide the proper web tension.

Roll Hardness. Smith (2005) states that winding of film is often referred to as an art. This is due to the fact that the setting and programming of the tension, nip, and torque vary depending on:

- The type and design of the winder
- The type of web material being wound
- The width of the rolls being wound
- The speed of the winding operation (p. 323)

Not only will the same settings result in different roll hardness with the variations above, different film products and different end use applications will vary the roll hardness and profile desired. Once the hardness profile has been established, this hardness must be reproducible on a consistent basis. To accomplish controlled roll hardness, measuring devices must be available to the winder operators. With these devices, an operator can test roll hardness and make adjustments accordingly.

To measure the roll hardness across the outer surface of the roll, it is suggested that either a Rhometer or a PAROtester be used. Both of these are impact-based devices for measuring relative roll hardness (Smith, 2005). The Rhometer is an instrument that measures the peak deceleration of a small hammer as it strikes the outer surface of the roll. The PAROtester is similar to the Schmidt hammer. The Schmidt Hammer was developed for concrete hardness testing and has been borrowed for use of roll hardness testing. The PAROtester is considerably more sensitive, has less impact energy, and is less operator dependent due to its more defined direction of impact then the Schmidt hammer.

The operator also needs to have a means available on the winder to measure the roll hardness from both cores to full roll and across the roll (Smith, 2005). A Smith meter is an instrument that can be used to measure the hardness profile from the core to the outer wraps of the roll. The Smith meter measures the penetration of a small needle as it is inserted in the wraps of the web along the roll's sides.

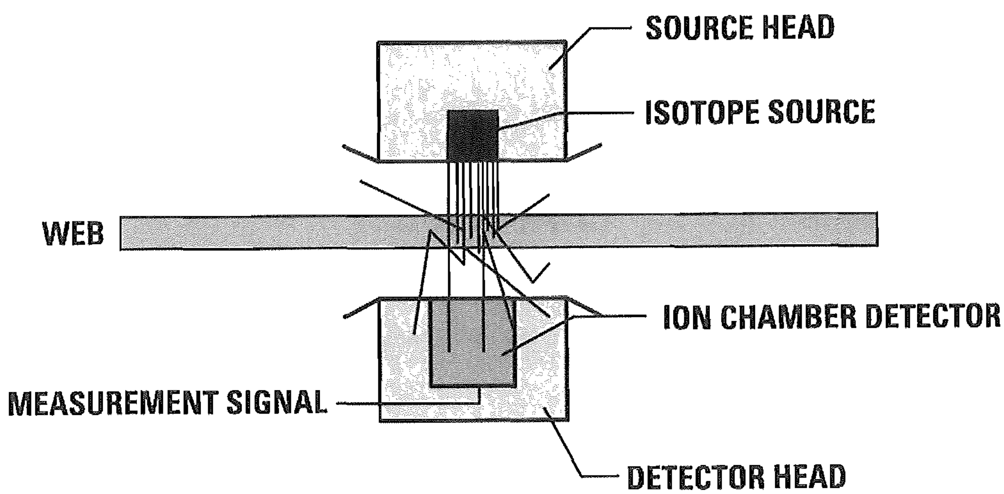
Computerized data acquisition systems such as the Black Clawson AccuWind systems are able to calculate the Roll Density Factor (RDF) and plot the relative roll density from core to full roll as the roll winds (Smith, 2005). These systems compare the actual winding roll's diameter with the theoretical diameter and plot the ratio as a fraction of the winding roll's diameter. The RDF is displayed to the operator on the Operator Interface Terminal (OIT) at the winder console.

Roll Circumference. According to Timm (2005) taking circumference measurements across the face of a roll can give an indication of gauge bands. He states, "Many plants have used a circumference difference of 3/16" as the acid test for a good and bad roll. Circumferential variation of greater than this can be an indicator of excessive profile variation, or poor rotational randomization" (p. 340).

Film Thickness. Over the years films and coatings have become thinner with more complex layer structures, while line speeds have increased to improve production efficiency (Schnackertz, 2005). Customer requirements for consistent film thickness across the web and throughout the roll of film have become tighter. Two technologies have been developed for measuring cast film thickness during the production run. These include beta transmission and gamma backscatter.

According to Schnackertz (2005), beta transmission is the oldest and best known of the gauging technologies. The sensor consists of two assembly heads separated by an air gap (see Figure 5). An isotope source or beta (high-speed electron) emitter is in the upper head and a

Figure 5: Beta Transmission Sensor

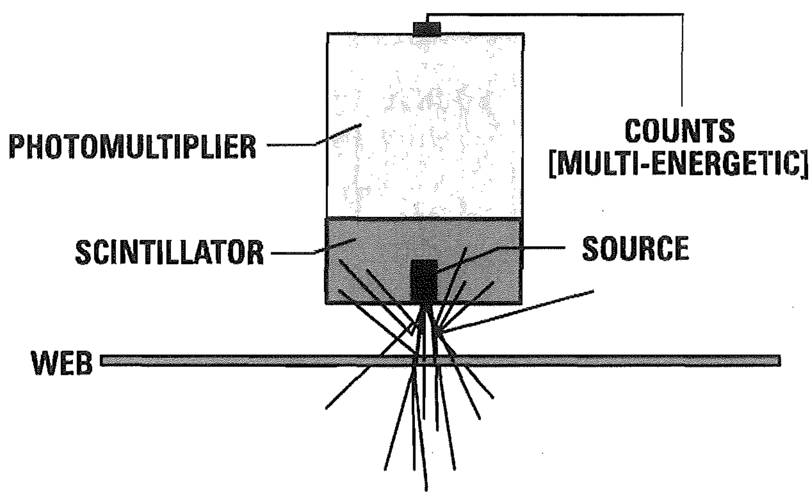


(Schnackertz, 2005, p. 88)

detector (ionization chamber) is in the lower head. The detector is filled with a gas whose molecules ionize when struck by beta particles. The detector is connected to a high voltage power supply in series with a very high ohm or "high meg" resistor. The ionized gas causes a very small current to flow through the "high meg" resistor which develops a small signal voltage. This voltage varies with the changing mass placed in the air gap. The voltage is amplified, linearized, and then converted to appropriate engineering units (mils, gsm, #/ream, etc.) for use in displays and control. The principle operation is based on the absorption of the beta particles (high-speed electrons) by a materials mass. The greater the mass of the material, the more beta particles are "absorbed" in a process called inelastic collision. At the same time some beta particles are being scattered by elastic collision. This absorption and scattering are a function of a materials mass and composition. Scattering is affected by the atomic number (Z) of a material or additive, as Z goes up, scattering increases (p. 87). The fast response of the beta transmission sensor is particularly suited to wide web, high-speed film lines (p. 88).

Gamma backscatter (GBS) technology is newer than beta (Schnackertz, 2005). The sensor (see Figure 6) is single sided, with the gamma source (photon emitter) and a sodium

Figure 6: Gamma Backscatter Sensor



(Schnackertz, 2005, p. 89)

iodide (NAI) crystal detector in the same housing. The NAI crystal is optically coupled to a photo-multiplier tube (PMT). The sensor's operation is based on a principle known as Compton Photon Backscattering (p. 88). When gamma rays or photons strike material mass, most pass through without change. About 15% of the photons are scattered to the side and backward. The number of photons backscattered at exactly 180 degrees, increase proportionately with mass and also undergo an energy level shift allowing their detection. When any photons strike the NAI crystal, the crystal emits light pulses that are amplified by the PMT. The pulse output of the PMT is multi-energetic, meaning its output represents all scattered photons. The pulse output must be electronically filtered to remove all energy levels except that of the 180 degree backscattered photons. The filtered output or pulse rate (pulses/sec) is now directly proportional to the mass of the material. An increase in mass results in a proportionally higher pulse rate. The processing electronics count the pulses/sec and convert them to an output voltage, which represents the mass (weight/unit area) of the material being measured. This output is linear and only requires conversion to engineering units (mils, gsm, #/ream, etc.) to be used for display and control (p. 88). The most common GBS application is in blown film where the single sided sensor is often mounted on the bubble. The GBS technology is also well suited to slower cast film or sheet lines (p. 89).

Coefficient of Friction. Coefficient of friction (COF) measures resistance to movement of sliding or rolling surfaces of solid bodies in contact with each other (Butler, 2005). To conduct the COF test, a weighted sled covered with film is placed on a flat bed, which is also covered with film, and is pulled across the bed (Timm, 2005). "The ratio of the weight of the sled to the force necessary to pull the sled is the COF. For example, if the sled is 200 grams (common to the film industry) and it takes 100 grams to pull the sled, the COF is 100/200, or 0.5" (p. 344). COF measurements range between 0 and 1. Anything over 1.0 is not measurable. A film's static COF is the measure of the force needed to get the sled moving. A film's kinetic COF is the force needed to sustain motion.

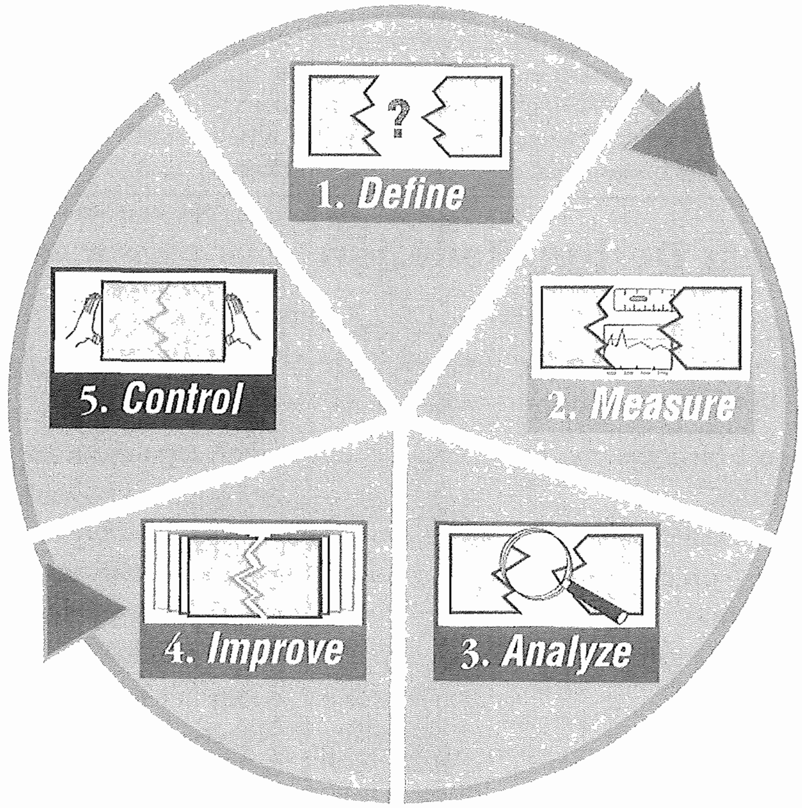
Six Sigma Methodology

The Six Sigma methodology is based on a specific problem-solving approach and makes use of various quality tools to improve processes and products (Brussee, 2004).

The methodology is data-driven with a goal of reducing unacceptable products or events. "The technical goal of the Six Sigma methodology is to reduce process variation such that the amount of unacceptable product is no more than 3 defects per million parts" (p. 3). In other words, the purpose of Six Sigma is to reduce variation so that almost 100% of products meet or exceed customer expectations (Pande, Neuman, and Cavanagh, 2002).

Six Sigma utilizes statistical analysis to reduce variation and defects, improving the efficiency and the effectiveness of the organization (Breyfogle, 2003). "There will always be some variation in a process: the core issue is whether that variation means your services and products fall within or beyond customer requirements" (Pande, Neuman, and Cavanagh, 2002, p. 5). Figure 7 lists the five steps in the Six Sigma process including define, measure, analyze, improve, and control (DMAIC).

Figure 7: Six Sigma Process



(Pande, Neuman, Cavanagh, 2002, p. 15)

1. Define the problem and what the customers require.
2. Measure the defects and process operation.
3. Analyze the data and discover causes of the problem.
4. Improve the process to remove causes of defects.
5. Control the process to make sure defects don't recur.

(Pande, Neuman, Cavanagh, 2002, p. 14)

Define. During the define phase a specific problem statement is formulated and a team is assigned (Breyfogle III, 2003). Activities of the define phase include identifying the customers and CTQ characteristics or KPOVs, and identifying and documenting the business process (Pande, Neuman, and Cavanagh, 2002).

Measure. One objective of the measure phase is to develop a reliable and valid measurement system of the business process identified in the define phase (Breyfogle III, 2003). The measurement phase uses statistical tools to quantify and define the capabilities of the existing business process. It provides a baseline against which progress is to be measured (Pande, Neuman, and Cavanagh, 2002).

Analyze. During the analyze phase the team is focused on determining the root cause of the problem. Again, statistical tools are used to provide insight into the relationships between KPIVs and KPOVs (Breyfogle III, 2003). Data collected during the measurement phase can be used to find patterns, trends, and other differences that can suggest, support, or reject theories about the causes of defects (Pande, Neuman, Cavanagh, 2002). Hypotheses and experiments are formulated and tested to verify or eliminate possible causes of defects.

Improve. During the improve phase a solution is selected and tested prior to full implementation (Pande, Neuman, Cavanagh, 2002). Several solutions may need to be tested before a final one is selected for implementation. Design of experiments is a key tool used in the improve phase.

Control. Once improvements have been made and results documented, the control phase begins (Pande, Neuman, Cavanagh, 2002). Without the control phase, the improved process may very well revert to its previous state, undermining the gains achieved in the Six Sigma process. The control phase provides an operation that is stable, predictable, and meets customer requirements. Ongoing process measurements are established and methods are put in place to monitor those measurements.

Chapter III: Methodology

Introduction

Over five months in 2007 Company XYZ received eight complaints of loose wind from various customers. Loose wind is unacceptable to customers, and each complaint resulted in returned product. The purpose of the study was to determine the root cause of the nonconformances and recommend solutions to eliminate the problem.

Methods

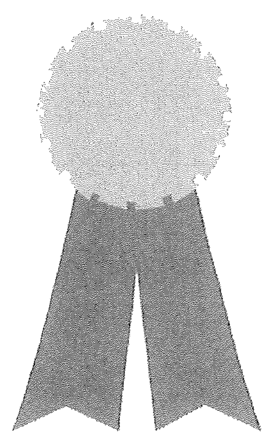
A second purpose of the study was to develop and implement a template using the Six Sigma problem-solving methodology. Organizations which have implemented Six Sigma and have made significant strides in reducing the defect level towards the 3.4 defects per million opportunities or less have found their profitability has improved, their customer satisfaction ratings have improved, and, in turn, their businesses have grown. The Six Sigma team selected one complaint from the eight complaints of loose wind and used the five steps of the Six Sigma methodology to design Company XYZ's problem-solving template.

Define. The define phase was comprised of three steps: 1) Drafting the project charter, 2) Identifying customer requirements, and 3) Developing a process map. To complete the first step, the team used a project charter worksheet and a problem/opportunity statement worksheet (see Tables 2 and 3). The tools helped the team in clarifying the problem and developing the steps to resolve the problem.

Table 2: DMAIC Project Charter Worksheet

DMAIC Project Charter Worksheet	
Project Title:	
Project Leader:	Team Members
Business Case:	
Problem/Opportunity Statement:	Goal Statement:
Project Scope:	Stakeholders:

PRELIMINARY PLAN	Target Date	Actual Date
Start Date:		
DEFINE		
MEASURE		
ANALYZE		
IMPROVE		
CONTROL		
Completion Date:		



(Pande, Neuman, Cavanagh, 2002, p. 103)

Table 3: Problem/Opportunity Statement Worksheet

Problem/Opportunity Statement Worksheet
Project Title:
What is the area of concern? What first brought this problem to the attention of your business?
What impact has this problem already had? What evidence do you have that it is really a problem worthy of attention?
What will happen if the business doesn't address this problem?
Summarize the above information in a concise statement.

(Pande, Neuman, Cavanagh, 2002, p. 104)

Step two of the define phase was to identify customer requirements. The team learned how the customer was affected by the problem and the requirements of the customer. The team used a requirement statement worksheet for step 2 (see Table 4).

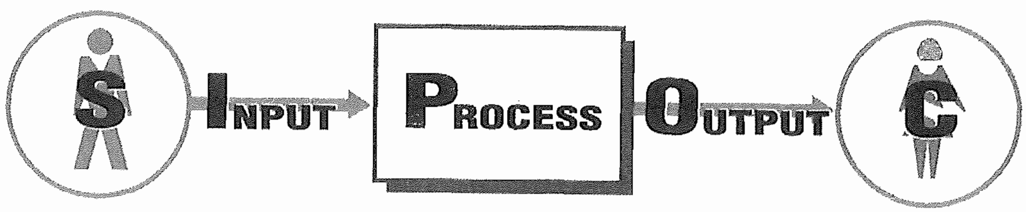
Table 4: Requirement Statement Worksheet

CUSTOMER COMMENT	IMAGE OR ISSUE	REQUIREMENT

(Pande, Neuman, Cavanagh, 2002, p. 112)

During step three the Six Sigma team developed a SIPOC diagram identifying the process suppliers, inputs, process, outputs, and customers (see Figure 8).

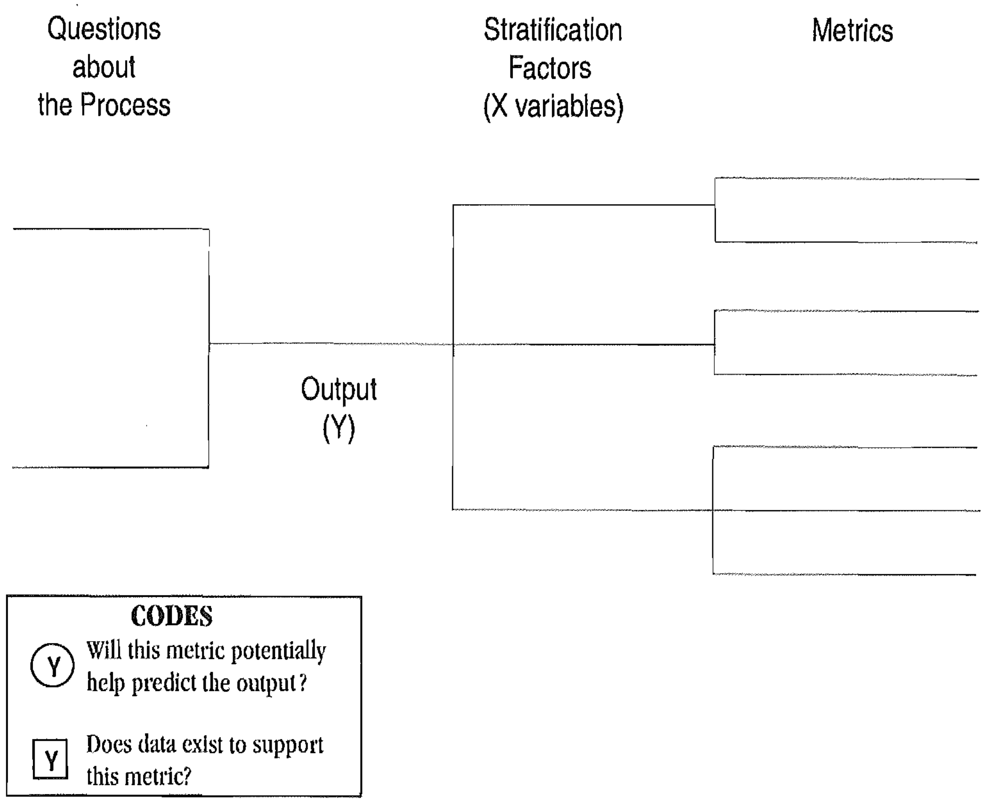
Figure 8: SIPOC Diagram



(Pande, Neuman, Cavanagh, 2002, p. 94)

Measure. During the measure phase, the Six Sigma team developed a measurement assessment tree (see Figure 9) to determine outputs and metrics for the process. The data was tabulated and statistical analyses performed. The team was able to identify current process capability.

Figure 9: Measurement Assessment Tree



(Pande, Neuman, Cavanagh, 2002, p. 167)

Analyze. The Six Sigma team utilized a root/cause, or fishbone, diagram to list potential root causes of the problem. The potential causes resulted in additional KPIV's. Each KPIV was reviewed by the Six Sigma team. Several KPIV's required further testing to determine their likelihood for the root cause. The Six Sigma team developed a list of likely potential root causes.

Improve. The likely root causes were submitted to the engineering department along with recommendations for testing. The Six Sigma team turned the project over, and the engineering department proceeded with testing using design of experiments. Results of the testing along with implementation of the process improvements have been provided in Chapter V of the study.

Control. The Six Sigma team discussed potential methods for controlling the process. Results of the control phase have been provided in Chapter V of the study.

Chapter IV: Results

Introduction

The Six Sigma team selected one complaint from the eight complaints of loose wind and implemented the DMAIC template described in the previous chapter. This chapter provides the results of the study.

Define Phase

Step 1 – Create Project Charter.

Table 5: Completed Project Charter Worksheet

<table>
<tr><th colspan="3">DMAIC Project Charter Worksheet</th></tr>
<tr><td colspan="3">Project Title: Eliminate Loose Wind Complaints in Product M12</td></tr>
<tr><td>Project Leader: Debbie Poirier</td><td colspan="2" rowspan="2">Team Members:
Company XYZ Quality Improvement Team
Employee A, Process Engineer
Employee B, Product Engineer
Employee C, Sales Engineer
Employee D, Maintenance Technician
Employee E, Machine Operator
Employee F, Quality Control Technician</td></tr>
<tr><td>Business Case: Company XYZ produced more than 75,000 pounds of Product M12 in 2007. More than 4,500 pounds (or 5.8%) of the material was returned due to loose wind complaints. The returned material cost Company XYZ more than $5,000.</td></tr>
<tr><td>Problem/Opportunity Statement: In 2007 Company XYZ received two complaints of loose wind from Customer M. Loose wind is unacceptable, and each complaint resulted in returned product.</td><td colspan="2">Goal Statement: Eliminate loose wind complaints in Product M12.</td></tr>
<tr><td>Project Scope, Constraints, Assumptions: This being Company XYZ's first Six Sigma project, the scope was limited to one complaint of loose wind to simplify the problem-solving process. Historical data for conforming and nonconforming rolls of Product M12 will be used for the study. Historical data collected by Company XYZ is accurate. Accuracy of Company XYZ's measurement tools can be verified. Company XYZ's management and employees are willing to test and implement recommendations based on the study.</td><td colspan="2">Stakeholders:
Quality Improvement Team
Customer M
Other customers having complaints of loose wind
Company XYZ machine operators
Company XYZ sales engineers</td></tr>
<tr><th>PRELIMINARY PLAN</th><th>Target Date</th><th>Actual Date</th></tr>
<tr><td>Start Date:</td><td>05/01/2008</td><td>05/01/2008</td></tr>
<tr><td>DEFINE</td><td>05/16/2008</td><td>05/16/2008</td></tr>
<tr><td>MEASURE</td><td>06/30/2008</td><td>06/20/2008</td></tr>
<tr><td>ANALYZE</td><td>07/31/2008</td><td>09/05/2008</td></tr>
<tr><td>IMPROVE</td><td>08/31/2008</td><td>09/19/2008</td></tr>
<tr><td>CONTROL</td><td>09/30/2008</td><td></td></tr>
<tr><td>Completion Date:</td><td>09/30/2008</td><td></td></tr>
</table>

Table 6: Completed Problem/Opportunity Statement Worksheet

Problem/Opportunity Statement Worksheet
Project Title: Eliminate Loose Wind Complaints in Product M12
What is the area of concern? What first brought this problem to the attention of your business? On August 30, 2007, Customer M submitted a complaint for loose wind. The customer stated that the rolls were very loosely wound and not usable because the looseness would cause telescoping as it unwound.
What impact has this problem already had? What evidence do you have that it is really a problem worthy of attention? The one complaint resulted in almost $5,000 of returned product. During 2007, Company XYZ had seven other complaints of loose wind from various customers.
What will happen if the business doesn't address this problem? Not addressing the loose wind complaints will most likely result in additional returned product in the future which is extremely costly and may also result in lost customers.
Summarize the above information in a concise statement. In 2007 Company XYZ received eight complaints of loose wind from various. Loose wind is unacceptable, and each complaint resulted in returned product.

Step 2 – Identify Customer Requirements.

Table 7: Completed Customer Requirements Worksheet

Customer Comment	Image or Issue	Requirement
Rolls were very loosely wound and not usable because the looseness would cause telescoping as it unwound.	Loose wind	Rolls need to be tightly/uniformly wound

Step 3 – Create Process Map.

Table 8: Completed SIPOC Diagram

Suppliers	Inputs	Process	Outputs	Customers
Chevron Standridge	Low density polyethylene resin High density polyethylene resin Color additive (green)	Receive and test raw material Pump raw materials to hoppers Mix and heat raw materials Extrude film Wind film onto core Inspect and test film Package film for shipment	Rolls of film	Customer M

Measure Phase

Step 1 – Complete Measurement Assessment Tree.

Table 9: Completed Measurement Assessment Tree

Questions about the Process	Output (Y)	Stratification Factors (X variables)	Predict Output?	Metrics	Data Available?
Precisely how many rolls are loosely wound? What trends or patterns exist?	Number of rolls having loose wind	For order By employee/crew By raw material supplier By production line	Yes Yes Yes	# nonconforming rolls for order # nonconforming rolls by employee # nonconforming rolls by raw material # nonconforming rolls by production line # nonconforming rolls over time	Yes Yes Yes Yes Yes

Step 2 – Determine Process Capability.

Table 10: Capability Analysis

Metric	Number Nonconforming (Internal)	Number Nonconforming (Customer)	Total Nonconforming and Conforming	Yield	DPMO	Sigma
Nonconforming rolls for order	3	14	27	37.0%	629,630	1.1250
Nonconforming rolls for Employee 1	2	4	15	60.0%	400,000	3.2500
Nonconforming rolls for Employee 2	1	10	13	15.4%	846,154	0.5000
Nonconforming rolls for raw material blend (same blend used for entire order)	3	14	27	37.0%	629,630	1.1250
Nonconforming rolls for production line (order ran on one line)	3	14	27	37.0%	629,630	1.1250
Nonconforming rolls over time - Order ran 15 hours						
1. Hours 1 - 3	0	0	4	100.0%	0	6.0000
2. Hours 4 - 6	0	1	5	80.0%	200,000	2.3750
3. Hours 7 - 9	2	3	6	16.7%	833,333	0.5000
4. Hours 10 - 12	1	6	7	0.0%	1,000,000	0.0000
5. Hours 13 - 15	0	4	5	20.0%	800,000	0.6250

Analyze Phase

Step 1 – Root/Cause Analysis.

Table 11: Root/Cause Analysis

Problem	Loose Wind

Potential Causes	
Material	Incorrect raw materials Poor quality raw materials
Equipment	Mechanical failure with winder Tension or other controls not accurate Test equipment out of calibration
Procedures	Incorrect machine settings Machine settings changed
People	Operators running multiple lines (too busy) Inexperienced operators

Step 2 – Determine Most Likely Causes. The Six Sigma team verified that other lots were run with the same raw materials and found evidence that raw materials was not the source of the problem. Similar lots were also run on the same production line with no evidence of loose wind. The order ran almost six hours before loose wind occurred. Therefore, a change in machine settings seemed to be the most likely cause. In addition, both machine operators were fairly inexperienced (less than 5 years) compared to the majority of machine operators. Also, the quality control (QC) lab was being operated by a backup setup indicating the crews may have been short-handed during the production run. In summary, the Six Sigma team reported potential root causes to be: change in machine settings, operators too busy, inexperienced operators.

Chapter V: Discussion

Introduction

The Six Sigma team reported the potential root causes to the production manager. Improvement methods were implemented to increase awareness of the defect for future production runs. In addition, the selected Six Sigma team was able to develop a template to address future problems and opportunities for improvement.

Observations

Over five months in 2007 Company XYZ received eight complaints of loose wind from various customers. Loose wind is unacceptable to customers, and each complaint resulted in returned product. Company XYZ needs to determine the root cause of the nonconformance and implement a permanent corrective action. A second purpose of the study is to implement the Six Sigma problem-solving methodology at Company XYZ. The selected Six Sigma team chose one complaint from the eight complaints of loose wind and implemented the first three phases of the DMAIC template. The results of these phases were provided to the engineering group who completed the improve and control phases of the DMAIC methodology.

Improve Phase. The Six Sigma team reported potential root causes to be: change in machine settings, operators too busy, inexperienced operators. The engineering group compared the lot in question with known good lots and was not able to find a difference in any of the machine variables. However, they did find increased variation in the thickness of the film. In addition, good rolls of the order were compared with the returned rolls. The returned rolls had larger gauge bands; however, the gauge bands did meet customer tolerances. However, the gauge bands for the returned product were located on the ends of the rolls causing the rolls to be concave or telescope. The location of the gauge bands on the ends of the rolls caused the rolls to loosen during curing and transit.

Control Phase. The engineering team is still in the process of developing requirements for the location of gauge bands. However, the team did implement tighter control limits for film thickness. In addition, a recommendation was made to measure roll hardness. Company XYZ does not have a method to measure roll hardness. However, roll hardness is the best indicator as to whether or not a roll is subject to loose wind.

DMAIC Methodology. The Six Sigma Team developed a template for the first three phases of the DMAIC methodology: define, measure, analyze. The template forced the team to use a statistical, fact-based approach to problem-solving. In addition, the template allowed the team to explore multiple causes for the problem.

Recommendations

Company XYZ should implement the DMAIC template developed by the charter Six Sigma team. Using the template developed in the pilot project with additional projects will allow the team to refine the template. In addition, the template should be expanded to include tools for the improve and control phases.

According to Pande, Neuman, and Cavanagh (2002), many times Six Sigma teams drop the ball when they get to the improve phase. "It's tough to change gears from being a detailed data detective to being a developer of innovative new processes" (p. 286). The skills needed to analyze problems can be very different from those needed to create and implement solutions especially in a complex manufacturing environment. There is a danger that the Six Sigma team will settle on slight modifications of the process and miss an opportunity for more substantial gains. In addition, the team may fail to pick the best possible choice among the options available or overlook some potential problem with the new solution that causes it to fail at a another critical moment. The following guidelines are recommended for the improve phase:

- Whatever the team selects as a solution should address the root causes of the problem and the goal the team set for itself in the project charter.
- Although the team will brainstorm many possible solutions, one or two will be better than the others. The team must decide which are the best options and determine what it will take to make each option work.
- The solutions must not cost so much or be so disruptive that the expenses outweigh the benefits in the long run.
- The chosen solutions must be tested to prove their effectiveness before they are completely implemented (p. 287).

The goal of the improve phase is to find and implement solutions that will eliminate the causes of the problems, reduce the variation in a process, or prevent a problem from recurring (Pande, Neuman, and Cavanagh, 2002). Steps in the improve phase include generating solution ideas through brainstorming techniques, refining the list of possible solutions, selecting the best solution, pilot testing, and full implementation.

Again, changes to more complex processes may result in failure at other critical steps. More advanced tools such as Failure Mode and Effects Analysis (FMEA) (See Table 12) and

Table 12: FMEA Worksheet

FMEA Worksheet

Project or Person ______________________ Date __________

Process, Product, Service ______________________

Feature or Step	Failure Mode	Cause	Effect/Impact (severity data)	Frequency (occurrence data)	Ratings			RPN SxOxD	Response		
					S	O	D		Action	Who	When

(Pande, Neuman, and Cavanagh, 2002, p. 327)

Design of Experiments (DOE) should be used in these situations. Using FMEA tools, team members are able to identify ways in which a change in a process, product, or service may cause unintended problems (Pande, Neuman, and Cavanagh, 2002). Appropriate countermeasures for the potential problems can then be developed. A FMEA worksheet can be easily incorporated in the pilot team's template.

DOE techniques can be used to verify cause-and-effect relationships as well as to find optimal operating conditions to achieve a desired output (Pande, Neuman, and Cavanagh, 2002). DOE is especially useful when a process is exposed to a number of factors that have to be controlled to minimize defects and improve quality.

The final phase of the DMAIC methodology is control. The purpose of the control phase is to maintain a process whose operation is stable, predictable, and meets customer requirements (Pande, Neuman, and Cavanagh, 2002). Without implementing the control phase, the improved process may very well revert to its previous state, undermining the gains achieved in the Six

Sigma project. The control phase involves documenting the improvement and establishing ongoing process measures. A process documentation checklist as shown in Table 13 could be incorporated in the Six Sigma template. Using the checklist would increase the chances that

Table 13: Process Documentation Checklist

Process Documentation Checklist

The documentation is concise and easy to understand.

- ❑ The language is simple and clear; we have avoided the jargon and technical language.
- ❑ We have used pictures as much as possible (flowcharts, photographs, charts, videotapes).
- ❑ Our documentation reads more like a cookbook than an encyclopedia.

The documentation includes instructions for both routine work and "emergencies."

- ❑ Flowcharts depict standard work procedures.
- ❑ Warning signs of problems (which might have first surfaced in the pilot test) are clearly identified.
- ❑ Instructions describe specifically what to do if problems recur, and who has the responsibility for taking action.

Our documentation is a living, vital part of our process management.

- ❑ Key instructions are posted visibly in the workspace. Additional documentation is easily accessible.
- ❑ The people who work with the process every day are familiar with the documentation and refer to it regularly to remind themselves of standard procedures.
- ❑ When problems appear, the first question we ask is "Did we follow procedures as defined in the process documentation?" (If not, see if following the process fixes the problem; if yes, then determine if a change in the documentation is needed.)
- ❑ It is easy to revise and update procedures when the evidence shows that change is needed.

(Pande, Neuman, and Cavanagh, 2002, p. 355)

process documentation will be both useful and used. Control charts are the method of choice for process control at Company XYZ and are used by production employees for a variety of process and product parameters. New control charts may need to be developed to monitor the critical characteristics established in the define phase of the project.

Finally, members of the Six Sigma team should pursue additional training in the Six Sigma methodology. The training would provide increased understanding of the DMAIC phases and introduce additional tools for each step in the Six Sigma process. Training programs are available through local technical colleges, universities, and private firms. In-house training may be a good option for Company XYZ as it would provide more managers and employees with access to the training. This option would also allow the training to be customized to Company XYZ and allow the employees to take on small Six Sigma projects relevant to Company XYZ during the training course.

References

Breyfogle III, F. W. (2003). *Implementing Six Sigma: Smarter Solutions Using Statistical Methods* (2nd ed.). Hoboken, NJ: John Wiley & Sons, Inc., 3-51, 61-62, 385.

Brassard, M. and Ritter, D. (2001). *Sailing Through Six Sigma: How the Power of People Can Perfect Processes and Drive Down Costs*. Marietta, GA: Brassard & Ritter, LLC., 2, 166.

Brussee, W. (2004). *Statistics for Six Sigma Made Easy!* New York: McGraw-Hill, 3-15.

Butler, T. I. (Ed.). (2005). *Film Extrusion Manual: Process, Materials, Properties* (2nd ed.). Atlanta: TAPPI Press, 589-596.

Darrow, D. (2005). Chapter 17: Sheeting. In T. Butler (Ed). *Film Extrusion Manual: Process, Materials, Properties* (pp. 245-248). Atlanta: TAPPI Press.

Griff, A. L. (1994). *Plastics Extrusion Operating Manual* (11th ed.). Bethesda, MD: Edison Technical Services, 1, 28-29.

Hawkins, W. E. (2003). *The Plastic Film and Foil Web Handling Guide*. Boca Raton, FL, 33-39.

IDES (n.d.). *The Plastics Web*. Retrieved February 28, 2008 from: http://www.ides.com/generics/Polyolefin.htm.

IPLAS (n.d.). *Processing plastic material*. Retrieved February 28, 2008 from: http://www.plasticextrusiondata.com/PDF_files/28103_03.pdf.

IPLAS (n.d.). *Sheet*. Retrieved February 28, 2008 from: http://www.plasticextrusiondata.com/PDF_files/28103_09.pdf.

King III, R. E. (2005). Chapter 45: Additives for Film Products. In T. Butler (Ed). *Film Extrusion Manual: Process, Materials, Properties* (pp. 547-568). Atlanta: TAPPI Press.

NDC Systems (1992). *NDC Model 6100-T Measurement and Control System User's Manual.* Monrovia, CA: NDC Systems, 65.

Pande, P. S., Neuman, R. P., and Cavanagh, R. R. (2003). *The Six Sigma Way.* New York: McGraw-Hill.

Post, S. J. and Davis E. (2005). Chapter 16: Cast Film Process. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (227-244).

Roller, R. and Vedder, D. A. (2005). Chapter 12: Blown Film Maintenance and Troubleshooting. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (161-183). Atlanta: TAPPI Press.

Schnackertz, T. (2005). Chapter 6: Instrumentation and Process Control. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (87-92). Atlanta: TAPPI Press.

Schwank, D. (2005). Chapter 3: Film Applications. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (15-19). Atlanta: TAPPI Press.

Smith, R. D. (2005). Chapter 21: Winding. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (313-338). Atlanta: TAPPI Press.

Spalding, M.A. and Butler, T. I. (2005). Chapter 24: Resins. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (363-380). Atlanta: TAPPI Press.

Summers, D. C. S. (2003). *Quality* (3rd ed.). Upper Saddle River, NJ: Prentice Hall, 20.

Timm, D. (2005). Chapter 22: Film Test Methods. In T. Butler (Ed.), *Film Extrusion Manual: Process, Materials, Properties* (339-346). Atlanta: TAPPI Press.