Author: **Lorenzen, Douglas M**

Title: ***The Effect of Powder Flow on a High-Speed Form Fill Seal Packaging Process***

The accompanying research report is submitted to the **University of Wisconsin-Stout**, **Graduate School** in partial completion of the requirements for the

Graduate Degree/ Major: MS Manufacturing Engineering

Research Advisor: Robert Nelson, Ph.D.

Submission Term/Year: Fall Semester, 2013

Number of Pages: 53

Style Manual Used: American Psychological Association, 6th edition

☒ **I understand that this research report must be officially approved by the Graduate School and that an electronic copy of the approved version will be made available through the University Library website**
☒ **I attest that the research report is my original work (that any copyrightable materials have been used with the permission of the original authors), and as such, it is automatically protected by the laws, rules, and regulations of the U.S. Copyright Office.**
☒ **My research advisor has approved the content and quality of this paper.**

STUDENT:

NAME Douglas M. Lorenzen DATE: 1/8/2014

ADVISOR: (Committee Chair if MS Plan A or EdS Thesis or Field Project/Problem):

NAME DATE:

This section for MS Plan A Thesis or EdS Thesis/Field Project papers only
Committee members (other than your advisor who is listed in the section above)

1. **CMTE MEMBER'S NAME: DATE:**
2. **CMTE MEMBER'S NAME: DATE:**
3. **CMTE MEMBER'S NAME: DATE:**

This section to be completed by the Graduate School
This final research report has been approved by the Graduate School.
Director, Office of Graduate Studies: **DATE:**

Lorenzen, Douglas M. ***The Effect of Powder Flow on a High-Speed Form Fill Seal Packaging Process***

Abstract

Food manufacturing companies in the United States have been subjected to unprecedented increases in raw materials, labor and other resources over the last five years. Products and process that once returned the most attractive margins are now fighting for their collective lives through the application of rigorous continuous improvement processes designed to obtain the most efficient output with the resources available. Yield loss, as reinforced in the literature, can be the hidden factory within the facility. This research paper investigates the application of a vibratory bulk feeder and the effect it has on the documented yield loss for a high speed powder packaging line. The results will be used to determine if the facility involved in the study should spend additional capital on vibratory feed devices, or invest their money elsewhere to combat the production line yield loss.

Acknowledgments

I would like to thank Dr. Robert Nelson for agreeing to advise me on this research paper. Dr. Nelson, along with the entire staff I have encountered in the MS Manufacturing Engineering program at the University of Wisconsin Stout has made my graduate school experience truly enjoyable.

I would also like to thank my employer. Their flexibility and financial support have made this possible.

Last but not least, I would like to thank my wife and three daughters. Their tolerance of the time commitment was more than greatly appreciated.

Table of Contents

List of Figures

Chapter I: Introduction

GAC is an industry leading food manufacturing company that has over 23,000 employees with facilities located in the United States, Canada and Mexico. The company produces a wide range of consumer food products sold through various outlets worldwide. In particular, GAC is the market share leader in the production of a powdered drink mix that is manufactured at a facility located in the upper mid-west. Total annual production of powder drink mix at this facility is 65,000,000 lbs.

The powder drink mix is produced by blending several dried dairy components with sugar and other sweeteners in a continuous process. The blended final product is loaded into intermediate canisters in preparation for packaging on one of nine different packaging lines. Intermediate canisters each hold approximately 4,400 lbs. of powdered drink mix. The packaging lines transfer the powder from the intermediate canisters into the end use package in the form of 0.75 oz. individual product envelopes. High speed horizontal form fill seal machines are utilized to fill the 0.75 oz. individual envelopes at a rate of 500-900 per minute depending on the product. The individual envelopes are processed further into carton form, palletized and shipped to product distribution centers or final retail locations.

Like many other North American food manufacturing companies, GAC has been exposed to the recent head winds of inflation brought on by a struggling domestic economy and depressed currency in foreign markets. Margins that were once robust are being challenged in the current economic situation due to increased raw material and transportation costs. In order to help combat these increases the company has employed rigorous continuous improvement techniques across all facilities.

Product waste or yield loss is one area of improvement that has received significant attention. Early projects have done a sufficient job of identifying and harvesting the low hanging fruit in this category at the upper Mid-West facility. However, there is still ample opportunity for improvement on the powder drink mix packaging lines that currently show annual yield loss figures in the 5%-7% range. Quality sampling can attribute the yield loss on these lines to slight over filling of each individual pouch. Yield losses at these percentages equate to annual loss of 2,750,000 lbs. to 3,850,000 lbs. of powder drink mix. The financial loss associated with this loss stream approaches $1,000,000 annually.

General observations made by the researcher indicate that the over filling problem may be caused by an inconsistent flow of powder from the intermediate canisters to the filling machine. The inconsistency comes as the head pressure generated by a full intermediate canister slowly decreases when the canister is emptied during the filling process. As a result of this observation the facility opted to install a powder flow aid device on one of the filling lines. The flow aid device mitigates the head pressure effect by supplying a consistent level, or flow of powder to the filler. Determining the annual impact of one device is nearly impossible with the available information because the annual yield loss calculated by the facility financial department is done using the production data from all of the packaging lines combined. More in depth analysis is needed to determine what roll powder flow plays on the yield loss associated with the filling lines before a decision can be made to replicate the technology over the entire packaging department.

Statement of the Problem

The current high speed form fill seal packaging process for powdered drink mix produced at GAC's upper Mid-West facility experiences annual yield losses of 5% to 7%. The yield loss at this level translates to a significant financial loss for the company in the form of over filled drink mix pouches. The yield loss from overfilling is associated with the inconsistent flow of powder to the individual horizontal form fill seal machines.

Purpose of the Study

The purpose of this study is to determine if a relationship exists between powder flow to the filler and fill weight variation of the pouches. If statistical and visual proof can be generated showing a direct relationship, the recommendation will be made for GAC to explore spending additional capital on powder flow aid devices that will supply a consistent flow of powdered drink mix to the horizontal form fill seal machines across all lines at the upper Mid-West facility.

Assumptions of the Study

1. The powder delivery system from the filler surge hopper to the actual filler on both lines in the study is the same.
2. The operation crews in this study are capable of executing correct machine operating procedures.
3. The operating parameters of both filling machines will remain unchanged during the sampling process.

There will be no modifications to product formulation during the sampling procedure.

Definition of Terms

Envelope. 0.75 oz. Individual containers of powdered drink mix.

FFS. A packaging process that forms the package, fills, and then seals it.

Funnel flow. A material flow characteristic exhibited in a vessel or bin when not all of the material flows out at the same time.

HFFS. A packaging machine that forms the package, fills and then seal it at a high rate of speed.

Mass flow. A material flow characteristic exhibited in a vessel or bin when all the material flows out at the same time.

Rat hole. A physical hole formed in the material as a result of funnel flow. It resembles the burrowing hole of a rodent.

Limitations of the Study

1. The study will focus on the product yield of two filling lines only.
2. The study will focus on one powdered drink mix formulation. All other formulations will not be included in this study.
3. Product scheduling for use in the study will be determined by customer demand. It will not be dictated by the needs of the study.
4. It is assumed that the material handling equipment between the intermediate canister and the filler on Production line 1 and Production line 10 are the same, except for the vibratory feed device used on Production line 1.
5. The specific time to discharge an intermediate canister on each line is not linear. The discharge time was impacted by events that were not controllable by the researcher such as employee breaks or departmental meetings.

Methodology

This study attempted to find a relationship between powder flow to the filling machine and product fill weight variation. An adequate number of random envelopes were obtained from both lines and weighed individually. One line uses a device designed to supply a consistent flow of material to the filler. The other uses only unrestricted gravity flow to supply material to the filler. Analysis was conducted to determine if the mean fill weight on the line with the powder flow device differs from the line that has no flow enhancing equipment.

The first analysis conducted included visual graphs showing the relationship between the powder level in the intermediate canister and fill weight variation on each line for nine separate sets of sample data. The second analysis included comparing the mean fill weight of the samples obtained from each line using the Students t-test to determine if the mean fill weights are the same or differ significantly.

Chapter II: Literature Review

Handling dairy based bulk powders is not the easiest task to carry out. It can require very specialized and expensive equipment, thus the players are few and far between. GAC handles upwards of 65 million pounds annually in the company's powder drink mix manufacturing and packaging operation. In order to off-set the handling difficulties the plant is presented with, standard operating procedure is to err on the side of over-filling. Without setting the target fill weight slightly higher than required, an unacceptable percentage of material would be below weight thresholds for saleable product. Traditionally, the lesser of two evils has been to make sure they are meeting the minimum requirement, even if it means giving away a small amount of product. Like many other food manufacturing companies, GAC is faced with ever tightening margins due to inflation of input costs and labor. What was an acceptable norm is now fruit on the loss tree.

In this chapter the researcher looks at publications that describe why bulk solids, especially powders, can be difficult to handle. Also, the research looks at what specific equipment applications can do to help solve the problem and the benefits associated with flow and yield control.

The Challenge Behind Handling Bulk Solids

Bulk solids in the form of powders, plastics, grains, metals and minerals have been used and handled in industry for years. Their use in the bulk form typically requires specialized storage and conveyance equipment. Properly designing this equipment to handle each specific application is still very much an art form, as the handling characteristics vary greatly.

Bulk solids provide a particular challenge to design engineers as they are neither a true gas nor liquid. Most process engineers have no problem designing systems to handle gas or liquids, but the challenges of powder handling processes cause problems for the most experienced engineers (Freeman, 2011). There must be a firm understanding of how the materials behave in different states to make the proper applications. Even though there has been significant progress made in the recent past to better understand how these materials act under different conditions inside vessels, the literature linking the process behavior and the specific powder properties is limited (Freeman, 2011).

In theory the flowability of bulk solids, particularly powders, should be related directly to the microscopic characteristics of the powder and the geometry of the equipment handling it. The understanding of the interactions has become better known, but is far from an exact science (de Jong, Hoffman & Finkers, 1999). Flowability of a material is subject to a considerable amount of factors. Describing how a material will flow is a bit like hitting a moving target, ambiguous at best. Ambient temperature and humidity are examples that can have a significant impact on how a powder will behave.

According to de Jong et al., (1999) the lack of true understanding of flow properties is very evident in the equipment manufacturing industry. The firms that design and build equipment to handle bulk solids and powders often design to ideal specifications. The ideal specifications rarely exist in real industrial applications.

Powders and other bulk solids can exhibit flow problems in a hopper like erratic flow, aeration or flooding, and even stoppages (Mehos & Kozicki, 2011). According to Mehos and Kozicki, (2011) there are two primary patterns that fine powders exhibit when discharging from a bin or silo: mass flow and funnel flow.

Funnel flow, or rat holing, describes when only a small column of the whole mass moves at one time inside a bin or vessel. Funnel flow is not a desirable state for feeding material to downstream processes. It can cause erratic flow and segregation while also reducing the capacity of the vessel (Mehos & Kozicki, 2011). In most materials the funnel, or rat hole, is very unstable, meaning it could potentially collapse at any time. The size of the funnel and subsequent collapse can vary greatly and have an effect on the flow rate from the vessel (Mehos & Kozicki, 2011). The collapsing of rat holes or funnels can both compact the material and alter the bulk density; it can also entrap gas or air in the material causing it to exhibit fluid-like properties and flood a downstream process.

Mass flow describes when the entire mass of the bin or vessel contents moves at one time. Mehos & Kozicki's (2011) research suggests the mass movement of the entire contents of the bin does not allow for stable rat holes to form. The mass movement of material provides a more consistent feed of material to down steam processes.

The Effects of Flow on Down Stream Processes

The at-rest or starting state of a powder has a significant impact on the manner in which it will flow to a downstream process. According to de Jong et al., (1999) the most frequently occurring states are slightly consolidated, loosely packed, and fluidized.

Cohesion is the largest obstacle to overcome for slightly consolidated powders. The consolidation usually occurs due to its own weight (de Jong, Hoffman & Finkers, 1999). The compaction force can apply loads to downstream feeding equipment to adversely affect their performance. Alan W. Roberts (n.d.) found there was a direct correlation between mass flow hopper head pressure and the loads acting on a downstream feeder in his study (Roberts, n.d.).

Cohesion, or settlement, is much more prevalent in fine powders than other more course bulk solids. The air space between particles is obviously much smaller with fine powders. This characteristic does not allow air and gases to flow freely out of the column of material causing an upward gas pressure gradient (Royal & Carson, 2000).

The initial filling of a bin or vessel can be the main cause of the compaction or cohesion in the vessel. Product characteristics and vessel size can play a significant role in product settlement (Royal & Carson, 2000). Alan Roberts (n.d.) found there were five factors that contributed to the compaction of powders during a bin filling sequence when the feeder was not running (Roberts, n.d.).

1. The rate of filling and height of the drop may produce impact effects.
2. Uniformity of filling over the length and breadth of the feed bin.
3. Clearance between the hopper bottom and feeder surface.
4. Degree of compressibility of the bulk solid.
5. Rigidity of the feeder surface.

The alternate problem to compaction or cohesion in handling powders is fluidization. Fluidization occurs when gas or air becomes entrapped or entrained in fine powders making them act in a similar manner of a fluid when flowing. Funnel flow, or rat holes, often are the cause of fluidization. When the rat hole collapses, falling powder entraps air within the particle spaces causing them to become fluidized (Royal & Carson, 2000). The problem with fluidization is that most feeding devices are designed to handle a solid, not a fluid. This inevitably results in material flooding at the discharge point of the vessel (Mehos & Kozicki, 2011).

Handling Bulk Solids and Powders

There are many different kinds of feeders, conveyors, storage devices, dischargers and other handling aids on the market specifically designed to handle fine powders and other bulk solids. Feeders are different from conveyors and dischargers in that they are designed to move or supply a material at a specific rate or state of flow (Carson & Petro, n.d.).

According to Carson & Petro (n.d.), feeders fall into two categories for industrial applications: volumetric and gravimetric. Volumetric feeders are designed to supply a specific volume or rate of material from a bin or storage container (Carson & Petro, n.d.). Common forms of these devices include vibratory pan, screw, belt and rotary valves. The application of each entirely depends on the specific properties of the material being handled. Gravimetric feeders focus on moving material by modulating the mass flow. This is done by either a batch sequence or on a continuous basis (Carson & Petro, n.d.). Common forms of gravimetric feeders include loss-in-weight applications, where a set volume or mass is moved by measuring the weight loss from a vessel or hopper with a weighing device utilizing load cells. Gravimetric feeders are better suited for applications where precise rates of discharge are required, often better than +/- 2% (Carson & Petro, n.d.).

As stated earlier, the specific selection of which device to use often varies greatly given the application and material properties. John Carson, Ph.D. and Greg Petro, P.E. (n.d.) have defined the following five criteria to aid in selecting the appropriate device:

The device should provide uninterrupted and reliable flow of material from some upstream device.

1. The desired degree of control of discharge rate over the necessary range.
2. Uniform withdrawal of material through the outlet of the upstream device.

3. Interface with the upstream device so the loads acting on the feeder are minimal.

When designing a feeding device for fine powders, the maximum flow rate is always an important consideration. If undersized, product starvation will occur resulting in loss of flow rate control (Carson & Petro, n.d.).

Specific Use of Vibratory Feeding Devices

The use of vibratory feeding devices for bulk solids and powders has been used for decades. They are an efficient, gentle form to move fine powders that tend to pack, cake or smear (Yandrick, 2009). They are particularly well suited for handling fine powders. A study conducted by Gabriel Tardos and Quingyang Lu (1995) found there was a direct correlation between vibratory amplitude and powder flow rate (Tardos & Lu, 1995). The researchers found the linearity did not exist for materials that were coarser in nature.

Over the years there have been advancements in the drives and control that power these devices. The vibrating motion can be generated by direct mechanical linkage or by amplifying the vibration through the use of off-set weights and springs (Yandrick, 2009). Vibratory feeding systems are very reliable and robust in that they have very minimal moving parts (Mitchell, 2001). Precaution should be taken to ensure they are operated in a continuous flow state as the vibration can actually cause compaction concerns if the powder flow is stopped while the feeder remains in motion (Carson & Petro, n.d.).

The Hidden Factory of Product Loss

Typically the food manufacturing industry is faced with low margins and high cost of inputs and labor. Product loss is becoming a popular area for these firms to focus the attention of process improvement projects (Akkerman & von Donk, 2006). Many of the processes that these companies use are complex in nature. The interactions between the various process equipment and intermediate storage devices often make the task of identifying product losses difficult (Akkerman & von Donk, 2006). The complex nature of the interaction can cause this area to be often over looked. Firms are finding that by taking the time to better understand where the losses are occurring can often yield project results of up to 20% improvement in product loss (Akkerman & von Donk, 2006).

Sometimes the product loss can come from intermediate processes where product has to be disregarded due to the nature of the cleaning requirements in the process. Other times the loss can come from variation in packaging process of a product. The standardizing of filling quantities not only yields significant savings, it also frees up capacity; sometimes referred to as the hidden factory (Wheatley, 2010). Often times these loss streams can be fixed with little expense or capital investment. This is particularly useful in the food manufacturing environment, where unlike other manufacturing assets, a food process line is much more complex in nature. You can't make slight changes or bring in parts and pieces like a machining center (Wheatley, 2010).

Give away or over filling in a packaging process is often driven by variability in the filling target weights and not by filling process alone (Wheatley, 2010). Food manufacturing firms need to hit a certain percentage of acceptable target weights to allow for legal sale of the product in the open market. Generally speaking, no more than 2.5% of the sampled products can land outside of the upper and lower control limits (Wheatley, 2010). The regulations driving this often result in significant loss for food manufacturing productions lines, especially high volume lines that rely on efficiency to make certain margins (Vlok & Fourie, 2010). Wheatley (2010) suggests the best way to go about attacking this problem is to first do anything possible to minimize the variability of the product supply to the filling process. After that has been tackled, statistical controls can be implemented into the filling weights themselves to allow for a tighter range of control. Once the product flow variability is addressed and product filling tolerances are reined in, plants that typically see 3% yield loss can often lower that number to 1% (Wheatley, 2010). When millions of units are processed annually, even these small percentages can add up to big dollars on the bottom line and added manufacturing capacity.

Chapter III: Methodology

GAC utilizes nine separate FFS packaging lines to produce 0.75 oz. individual powder drink mix pouches. All lines operate at high speed in order to most effectively apply labor and overhead resources. The product packaging lines have shown a typical annual yield loss in the range of 5% to 7%. The yield loss can be attributed to product weight over filling caused by inconsistent powder flow to the filling machine on the FFS unit. Operators routinely have to set the target fill weight beyond the upper limit in order to guarantee the product fill weights are at the regulated minimum.

The purpose of this study is to determine what effect the powder flow has on the fill weights of the individual pouches.

Flow Issues

The powder supplied to the fill machine comes from an intermediate canister that holds 4,400 lbs. of material. The canisters are inverted and placed on a discharge chute that conveys powder gravimetrically to the fill machine. As the canister empties during the packaging run, the powder is subjected to physical changes that affect the flow properties. This study measured the effect of mean fill weight as the powder level in the intermediate canister changes during a normal production run.

The subject of the study included two filling lines that only differ in the manner in which powder is supplied to the filler. One uses a device specifically designed to provide a consistent flow of powder to the filler, the other has no flow aid device.

Instrumentation

This study focused on weighing product samples to measure the contents of individual 0.75 oz. product envelopes. A Metler Toledo Model XS 802S certified bench top digital scale was used to weigh all samples obtained from both lines. All sample weights recorded were in grams. Data was manually documented using pen and paper on the production floor. The data was entered into an electronic format at a later date for further processing and storage. There were no special devices needed or special training required to gather the data from the production floor. Everything used was existing equipment employed by the production department.

The data analysis tool in Microsoft Excel 2010 was used to conduct the Student's t-test. Microsoft Excel was also used to construct the graphical analysis of the data.

Data Collection Procedures

A single carton containing 50 or 60 individual envelopes was randomly selected from the each line at 30 minute intervals over the course of nine separate shifts of production. A total of 16 cartons from each shift were collected. From each carton five individual envelopes were randomly selected. 144 individual envelopes were obtained for each shift. A total of 720 individual envelopes were sampled from both lines in the study. Each envelope was weighed and recorded, including the time of fill obtained from the laser jet code on the corresponding carton.

Product supply records were obtained for each line on each of the nine shifts in which samples were obtained. The product supply records indicate the specific time that an intermediate canister was changed out during the production run. From this information the researcher could pin-point the exact time in which a full canister was discharged to the filler.

Data Analysis

There were two primary tools employed to analyze the data gathered for this study. The first was a graphical analysis to visually show what the relationship was between varying powder flows caused by changes in the powder level in the intermediate canisters and mean product fill weight. The second was statistically comparing the mean fill weight of all samples gathered for both lines using the Student's t-test.

For the graphical comparison the mean fill weight of samples taken from each line was plotted over the course of nine separate shifts of production. On each graph a visual indicator was given to show where an intermediate canister was discharged to the filler. The point at which a full intermediate canister is discharged is the point at which product flow is the greatest due to maximum head pressure. Visual analysis was then conducted to see how the mean fill weight of the samples reacted to the fluctuation in flow immediately after a full intermediate canister was discharged.

The statistical analysis was conducted using the Student's t-test to show if a statistical difference exists between the mean fill weight of the line with a powder flow device and line without any flow devices. Stated in the form of a null and alternative hypothesis, the test intended to evaluate:

H_0: Line 1 Mean Fill weight = Line 10 Mean Fill Weight

H_1: Line 1 Mean Fill Weight ≠ Line 10 Mean Fill Weight

Limitations

Generally the production lines are very reliable; in this study the data could be affected by an unforeseen production shut down. It was assumed the filling machine and all downstream processes were operating optimally during the gathering of data. If there was an unseen anomaly, the data could have been skewed. The random samples were gathered by a line production associate. The same associate gathered all the samples for both of the production lines in the study. Instruction was given on gathering a sample to ensure the carton selected was random, but visual verification was not possible. The date code information on each carton sampled did indicate the process was conducted in a random manner. The researcher conducted the entire envelope sample weighing in person, eliminating the chance for operator error in the procedure. Due to the nature of the production schedule and process it was impossible to conduct the sampling procedure for both lines on the same shift.

Summary

This study is a side by side comparison of the mean fill weight realized on two high speed form fill seal machines. The analysis intended to show both graphically and statistically if the mean fill weight differs between each of the production lines. The intention of the graphical analysis is to indicate visually if variation in mean fill weight can be attributed to variation in product flow caused by discharging a full intermediate canister of powder. The intention of the statistical analysis was to show if there was a significant difference in the mean fill weight of the production line with a flow aid device and the production line with no flow aid device.

Chapter IV: Results

GAC uses nine separate HFFS packaging lines to manufacture nearly 65 million pounds of powder drink mix per year. The typical total yield loss associated with these filling lines has historically been in the 5% to 7% range annually. GAC has employed many different tools and processes in the past to combat this yield loss. Recently, the company installed a mechanical device specifically intended to supply a consistent flow of material to the packaging line in the hopes that it would allow the filler to operate closer to the target fill weight. This study uses graphical and statistical analysis to determine if the packaging line using the powder feed device exhibits better filling accuracy than an identical packaging line without the feeding device.

Graphical Analysis

The intention of the graphical analysis was to be a simple way to visually show how the mean fill weight of the envelopes behaves when a full intermediate canister of powder is discharged to the filler on both production lines involved in the study. Based on un-official feedback generated by production employees, GAC was led to believe there was a significant effect involving the discharge of a full canister and fill weight accuracy. Until now, the suggestion had never been explored further for proof.

Samples were obtained at thirty minute intervals over the course of nine separate eight hour shifts on production line 1 and production line 10. The mean fill weight of the samples was plotted for each of the nine shifts. Visual indicators were inserted onto the graphs at the point in which a full intermediate canister was discharged to the filler. Visual analysis was conducted to see how the mean fill weight behaved during the time period immediately following the discharge. For the purpose of the study the researcher elected to select and discuss the top two graphs showing the most variation and least variation for both of the production lines. For the purpose of this analysis the researcher assumed a mean fill weight variation of greater than or equal to +/- 2 grams following the discharge of a full canister to be significant. A variation in the mean fill weight of less than 2 grams following the discharge of a full canister was assumed to be insignificant.

The results obtained from production line 1 showed significant change in the mean fill weight of the samples for six of the nine shifts tested. Figure 1 and Figure 2 are the two samples that visually indicated the most significant impact to the mean fill weight immediately following the discharge of a full intermediate canister of powder.

There were three intermediate canisters discharged during shift sample 2, and four canisters discharged during shift sample 6 on production line 1. For shift sample 2, a significant variation in the mean fill weight occurred immediately following the discharge of a canister at approximately 8:00 PM. Shift sample 6 showed a significant variation in mean fill weight following the discharge of canisters at approximately 2:00 AM and 5:30 AM.

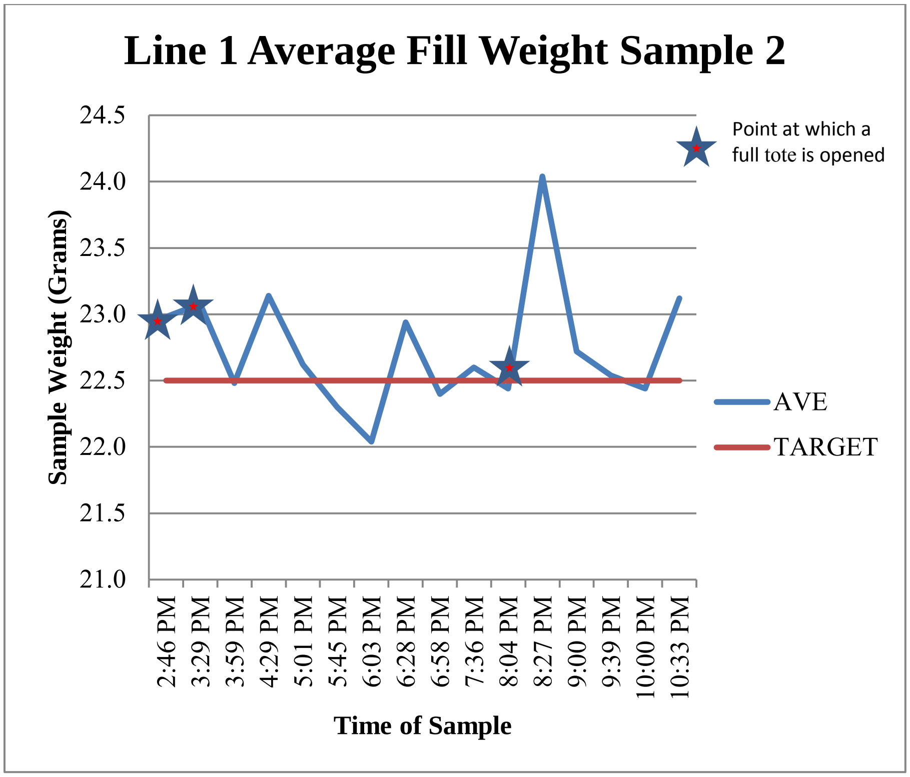

Figure 1. Line 1 Impact of Canister Discharge, Sample Set 2

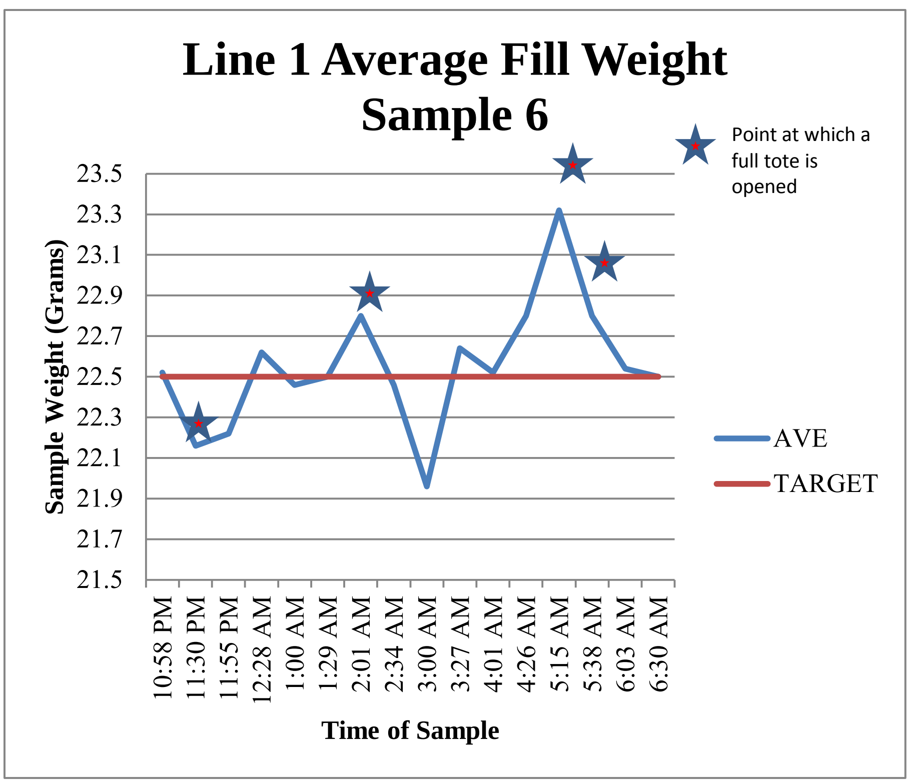

Figure 2. Line 1 Impact of Canister Discharge, Sample Set 6

The results obtained from production line 1 showed no visual effect to the mean fill weight of the samples for three of the nine shifts tested. Figure 3 and Figure 4 are for the two shifts in which no significant variation occurs immediately following the discharge of a full intermediate canister.

Shift sample 5 for production line 1 experienced the discharge of four intermediate canisters while shift sample 9 experienced three discharges. Variation did occur during each of the samples, but visually there appears to be a less dramatic effect to the mean fill weight immediately following each canister discharge.

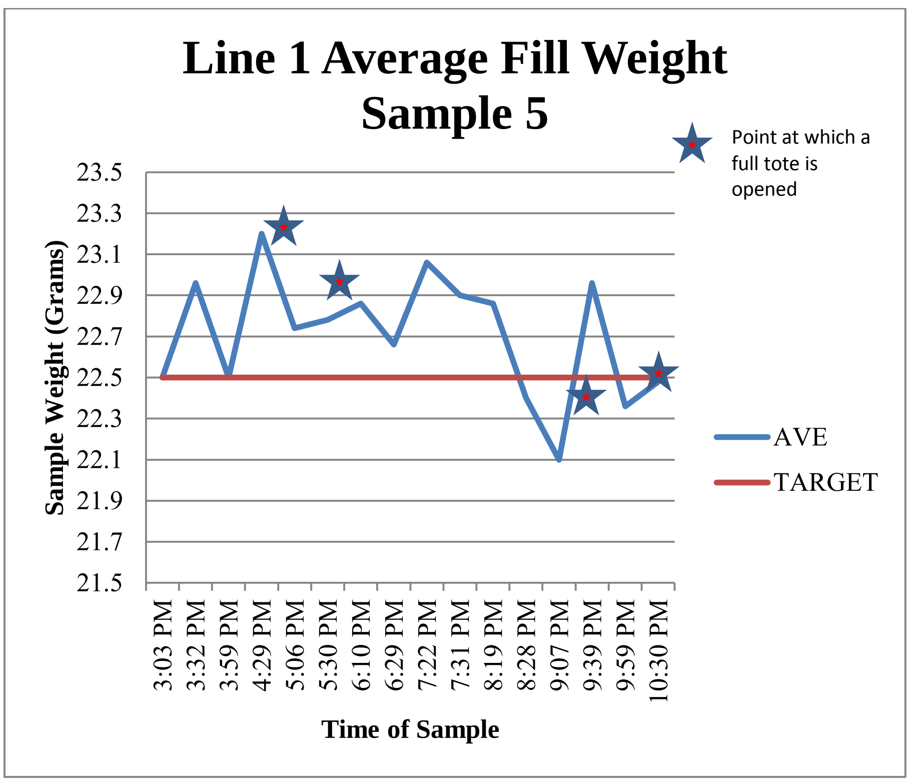

Figure 3. Line 1 Impact of Canister Discharge, Sample Set 5

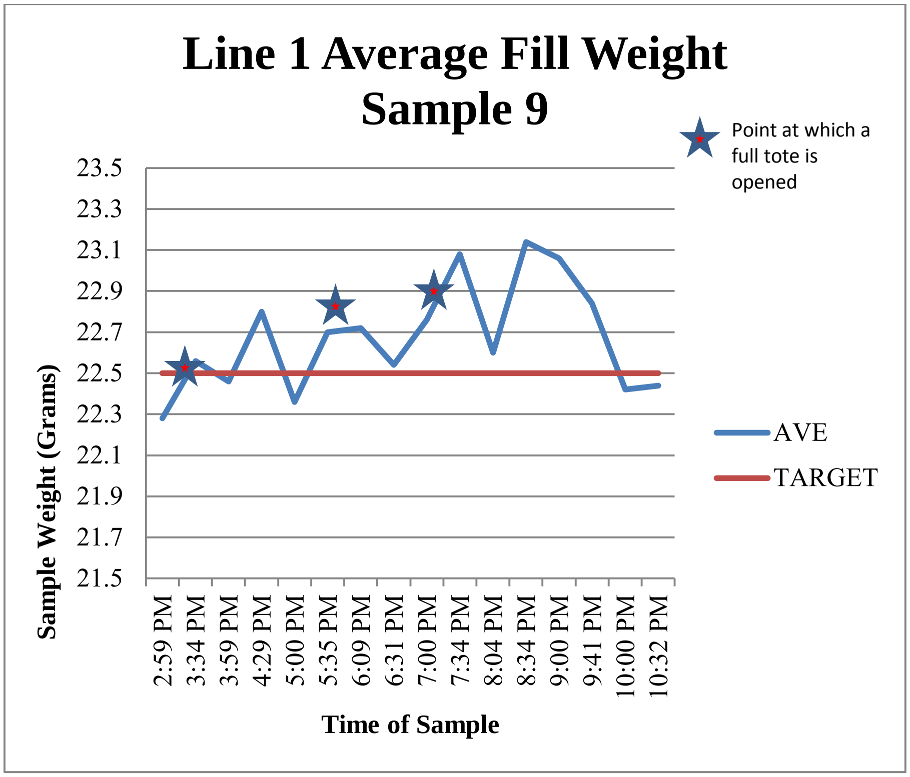

Figure 4. Line 1 Impact of Canister Discharge, Sample Set 9

The results obtained from production line 10 showed significant change in the mean fill weight of the samples for five of the nine shifts tested. Figure 5 and Figure 6 are the two samples that visually indicated the most significant impact to the mean fill weight immediately following the discharge of a full intermediate canister of powder.

There were two intermediate canisters discharged during shift sample 3, and three canisters discharged during shift sample 1 on production line 10. For shift sample 3, a significant variation in the mean fill weight occurred immediately following the discharge of both canisters at approximately 3:00 AM and 3:30 AM. Shift sample 1 showed a significant variation in mean fill weight following the discharge of canisters at approximately 12:30 AM, 4:15 AM and 5:00 AM.

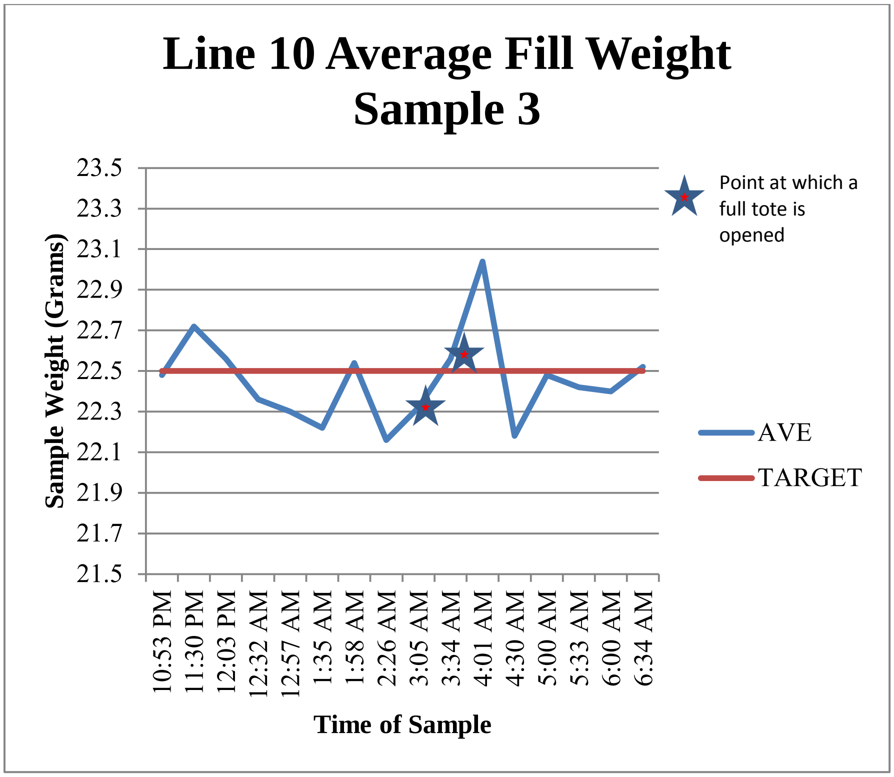

Figure 5. Line 10 Impact of Canister Discharge, Sample Set 3

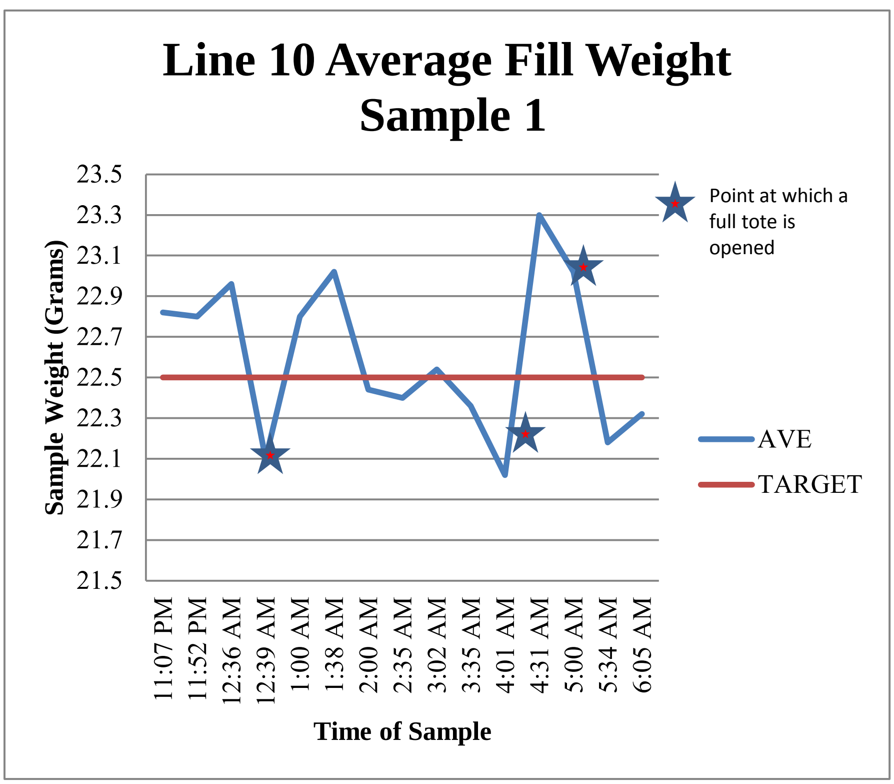

Figure 6. Line 10 Impact of Canister Discharge, Sample Set 1

The results obtained from production line 10 showed no visual effect to the mean fill weight of the samples for four of the nine shifts tested. Figure 7 and Figure 8 are for the two shifts in which no significant variation occurs immediately following the discharge of a full intermediate canister.

Shift samples 4 and 7 for production line 10 experienced the discharge of five intermediate canisters each. Variation did occur during each of the samples, but visually there appears to be a less dramatic effect to the mean fill weight immediately following each canister discharge.

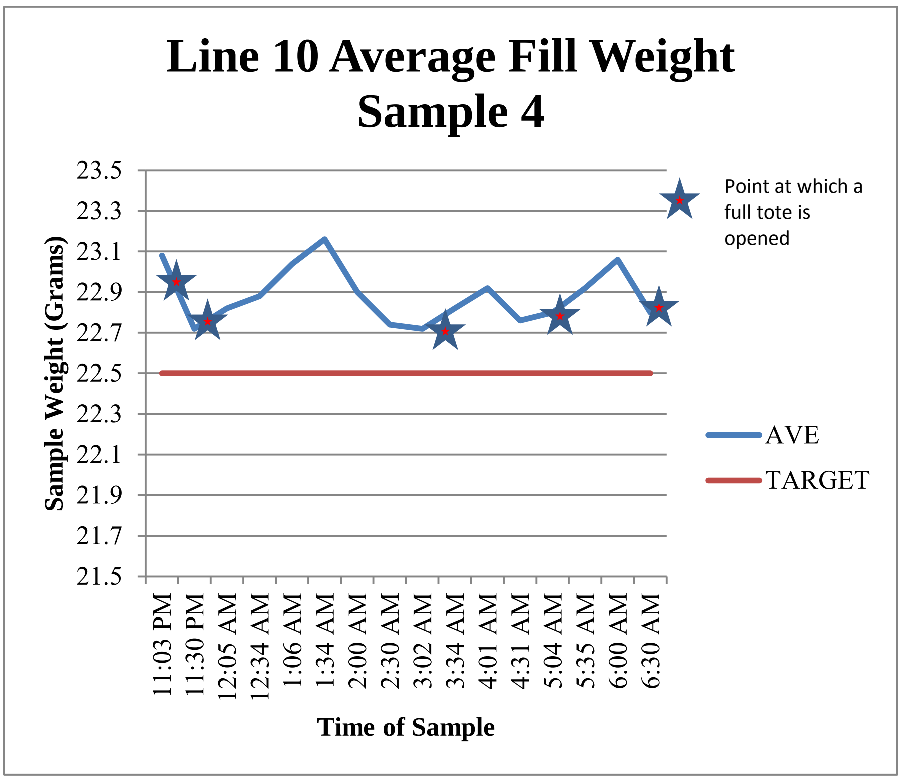

Figure 7. Line 10 Impact of Canister Discharge, Sample Set 4

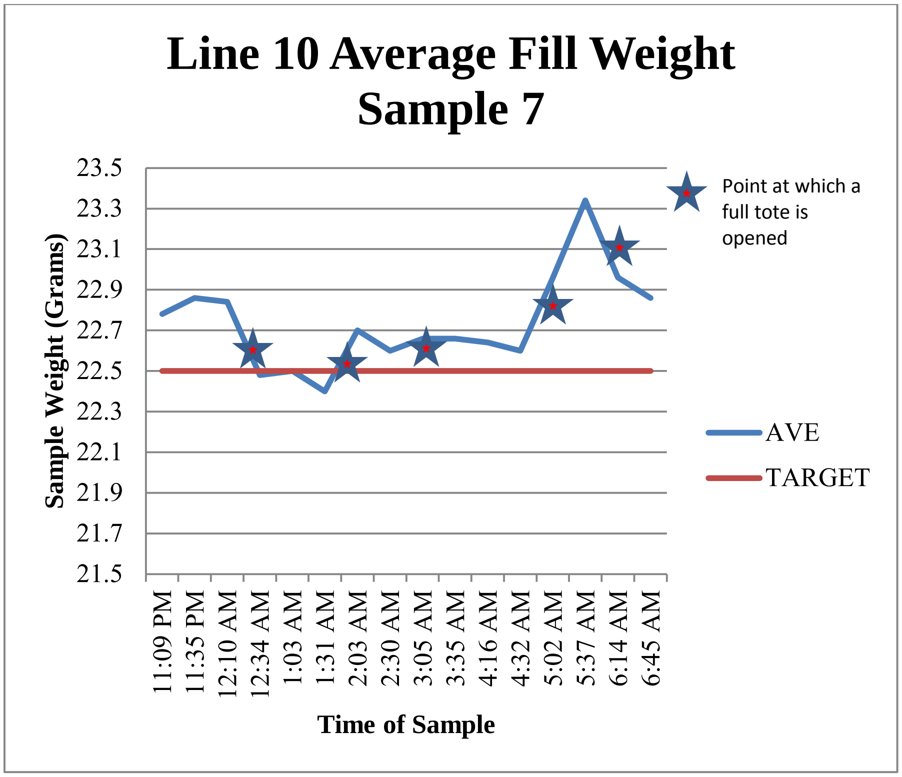

Figure 8. Line 10 Impact of Canister Discharge, Sample Set 7

The graphical analyses displayed in the contents of this research paper are specific examples of how the powder flow was, or was not affected by the discharge of an intermediate canister. After careful examination of all nine repetitions for both lines, there cannot be a definitive conclusion drawn that indicates the powder flow device on production line 1 improved the mean fill weight of envelopes immediately following the discharge of a full canister. Based on the visual investigation it appears as if the performance of mean fill weight on production line 1 was actually worse than that of production line 10.

Statistical Analysis

The Student's t-test was chosen to test the hypothesis that the mean fill weight from production line 1 was equal to production line 10, or that they were not equal.

Two separate repetitions of the test were conducted. The first was done using the mean fill weight of 720 samples from each production line. The second repetition was done using 50 randomly selected samples from each production line. The purpose of this approach was to ensure that there was no diminishing return effect on the results due to the large sample size of the first repetition.

The Student's t-test is best suited for normally distributed populations. Before the actual t-test calculations were conducted, a histogram was compiled for the samples gathered on each production line, for each repetition of n = 720 and n = 50.

Figure 9 and Figure 10 represent the histogram plots of the mean fill weight data for both production line 1 and production line 10 at n = 720. Both histograms for the repetition using 720 samples shows the classic bell curve indicating both sample sets are in fact normally distributed.

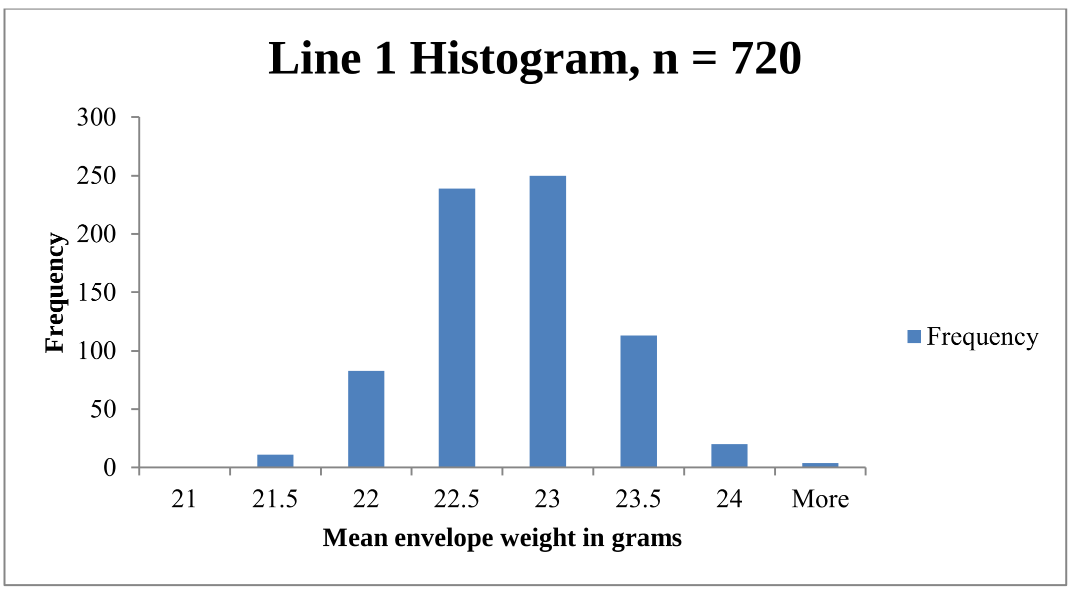

Figure 9. Line 1 Histogram, n = 720

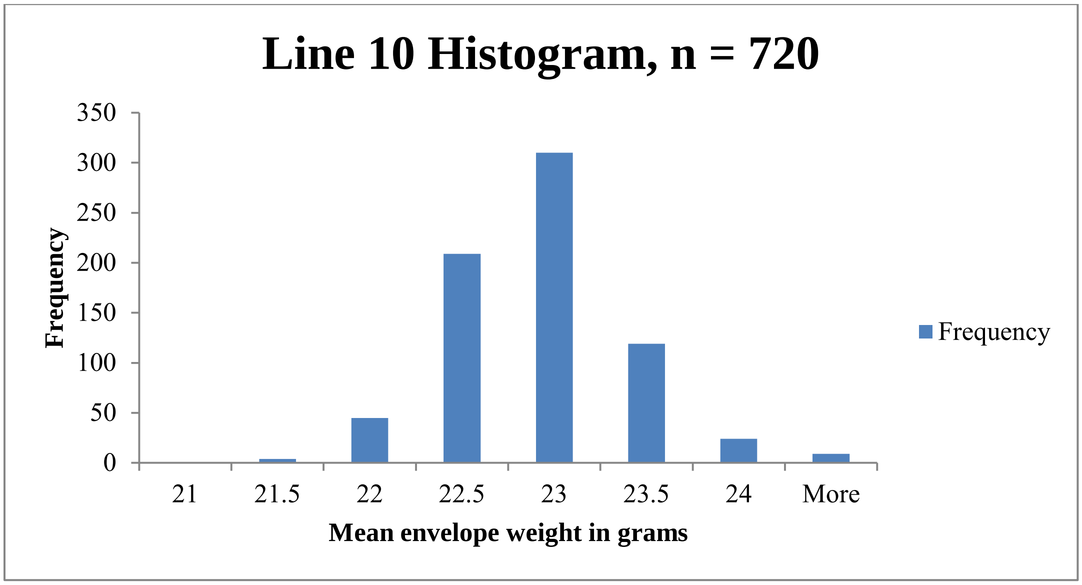

Figure 10. Line 10 Histogram, n = 720

Figure 11 and Figure 12 represent the histogram plots of the mean fill weight data for both production line 1 and production line 10 at n = 50. Both plots for production line 1 and production line 10 at n = 50 also appear to be normally distributed, indicated by the bell shaped distribution of each.

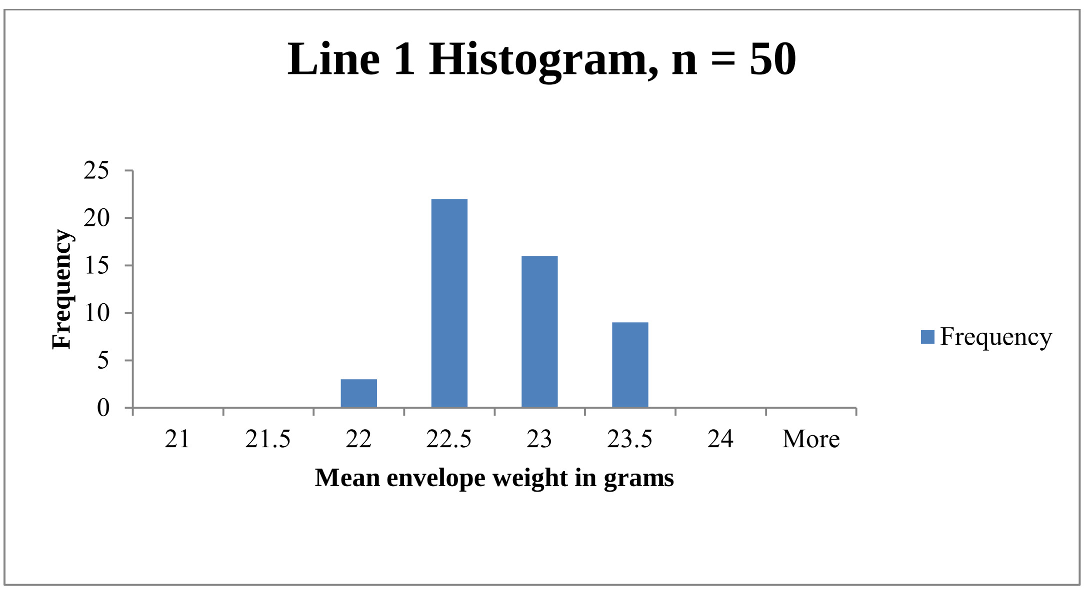

Figure 11. Line 1 Histogram, n = 50

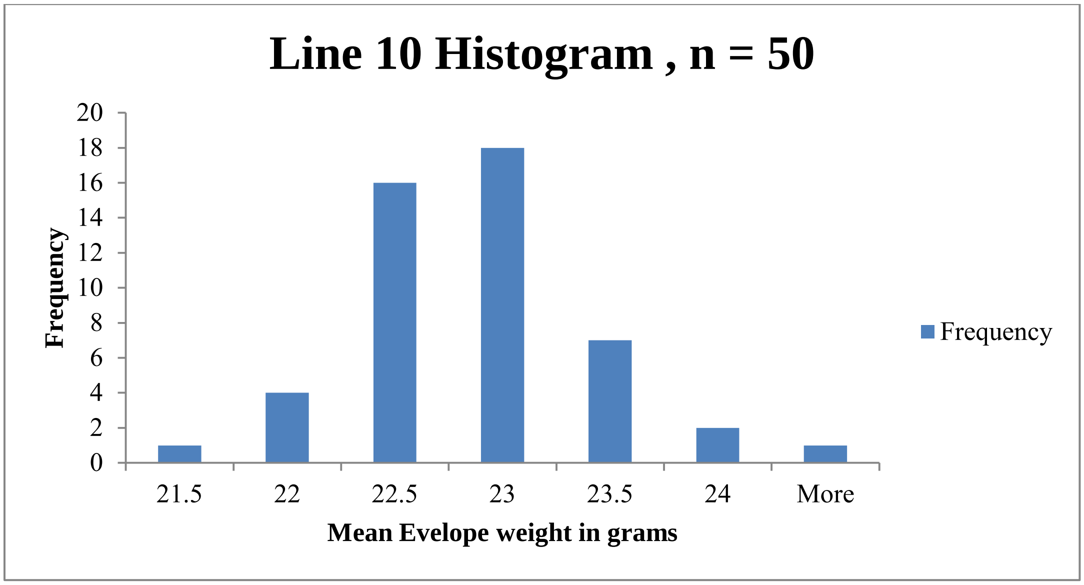

Figure 12. Line 10 Histogram, n = 50

Given that the histogram data of the mean fill weight samples for both lines at repetitions using n = 720 and n = 50 appear to be normally distributed, the decision was made to move ahead with the Student's t-test comparing the mean fill weight of both production lines.

Two repetitions of the t-test were conducted. The first test was conducted comparing the mean fill weight of both lines using n = 720 samples, the second was conducted using n = 50 samples. The choice was made to run the test at the full sample size of n = 720 and a smaller sample size of n = 50 to determine if the larger sample size results may be skewed as a result of diminishing returns.

Table 1 displays the results for conducting a two tail, unpaired, unequal variance t-test at n = 720 samples for the mean fill weight on both production lines. The t-stat returned by running the analysis at a confidence level of $= 0.05$ was found to be -4.59810 and the two tailed critical value was found to be 1.9616.

Table 1

t-Test results for n = 720

	Line 1	Line 10
Mean	22.60625	22.72514
Variance	0.249821801	0.231509
Observations	720	720
Hypothesized Mean Difference	0	
df	1436	
t Stat	-4.598176951	
P(T<=t) one-tail	2.31835E-06	
t Critical one-tail	1.645915437	
P(T<=t) two-tail	4.63669E-06	
t Critical two-tail	1.931617354	

Table 2 displays the results for conducting a two tail, unpaired, unequal variance t-test at n = 50 samples for the mean fill weight on both production lines. The t-statistic returned by running the analysis at a confidence level of □ = 0.05 was found to be -1.9800 and the two tailed critical value was found to be 1.9852.

Table 2

t-Test results for n = 50

	Line 1	Line 10
Mean	22.57	22.688
Variance	0.198061224	0.286384
Observations	50	50
Hypothesized Mean Difference	0	
df	95	
t Stat	-1.198794706	
P(T<=t) one-tail	0.116794792	
t Critical one-tail	1.661051817	
P(T<=t) two-tail	0.233589584	
t Critical two-tail	1.985251004	

In both repetitions for the Student's t-test on the mean fill weights for production line 1 and production line 10 the t-stat is found to be less than the critical value for a two tailed test. This criterion indicates that we cannot reject the null hypothesis that the mean fill weights are statistically different. There appears to be no statistical difference between the mean fill weight of production line 1 and production line 10. As tested in this study, the powder flow device on line 1 does not cause the mean fill weights to statistically differ from the mean fill weights on line 10.

Chapter V: Discussion

For most high speed production and packaging operations the gain or loss of material while moving through the production stream is a difficult problem to tackle. The problem can equate to significant volumes having a substantial financial impact on the operation. The process used to manufacture and package individual single serve drink mix envelopes at the GAC facility is not without yield loss issues. This research project attempted to gain a better understanding of yield loss on a packaging process involving the handling of bulk powders.

Research was conducted to develop further knowledge on how and why bulk solids, specifically powders, acts under various conditions that are present in the GAC facility. GAC took action by installing a device on one of the productions lines with the intention to improve the powder handling characteristics in an effort to combat a known yield loss issue. The purpose of this study was to determine if the decision to install the device delivered positive results.

Discussion of the Findings

A two-step approach was used to determine if the vibratory powder feed device used on production line 1 was effective in delivering better control from the stand point of mean fill weight. A graphical analysis was conducted to visually show how the mean fill weight reacted to fluctuations in powder flow to the filler. Historical knowledge obtained from the plant operational staff indicated the discharge of a full canister caused the fill weight control to fluctuate significantly. The phenomena had never been documented to the extent that it was for the purposes of this study. A visual representation was conducted on production line 1 and production line 10. The envelope filling machine is identical on both lines. The second phase of the study involved statistical analysis to determine if there was a difference in the mean fill weight on the production line with the vibratory flow device and an identical production line without a flow device.

Conclusions

As stated earlier, the production operators gave strong indication that the fill weights fluctuate greatly as a result of increased powder flow generated by the discharge of a full intermediate canister of material. The graphical analysis conducted on both production line 1 and production line 10 did in fact show this to be the case. By evaluating the graphs generated in this study the researcher was easily able to show the effect of a full canister discharge. Examples are given within the body of this research to show the results. However, the impact was not repeatable or reliable. The graphical analysis did show a direct impact related to this event, but it did not show a direct impact on each sample set. More so, the results obtained from production line 1 did not show any drastic improvement over the line with a flow device. In fact, the visual analysis of production line 1 appeared to exhibit a slightly greater impact to the mean fill weight as a result of the canister discharge.

The second tool used to determine the effect of the powder flow device was the use of the Student's t-test to show if the mean fill weight of the line with the flow device was any different than the line without a vibratory flow device. Two repetitions were conducted on the mean fill weights of both lines. One repetition using all of the samples gathered on each of the lines and second repetition using 50 randomly selected mean fill weight samples. Both repetitions yielded a t-value that was less than the critical statistic for the degrees of freedom in each repetition. The results obtained indicate there was no significant difference between the mean fill weight of the production line using the vibratory feed device and line that does not.

Recommendations

Based on the analysis of data obtained in this experiment, the researcher concludes that no further capital should be invested in vibratory feed devices on any of the other production lines at the GAC facility.

It is also the researcher's opinion that the major limitations present in this experiment could have had an impact on the results. This study was a side by side comparison of the mean fill weight on two separate production lines. While the specific name brand and model of the filling machine was the same, there were still many subtle differences present that may or may not have had an effect on the outcome. Slight variations in the surface roughness and angles of the connecting tubes between the intermediate canister and the filler could cause issues with the results. It would be in GAC's interest to repeat the study by conducting a before and after analysis of a single production line. Repeating the study on the same line by conducting detailed measurement of the mean fill weight before the vibratory feed device is installed and then repeating the study after installing the device may deliver more conclusive evidence as to the true effect of the device. Executing the experiment under these conditions would eliminate almost all of the major limitations experienced in this study.

References

Akkerman, R., & van Donk, D. (2006). Development and application of a decision support tool for reduction of product losses in the food-processing industry. Journal of Cleaner Production, 16, 335-342. doi: 10.1016/j.jclepro.2006.07.046

Carson, J. W., & Petro, G. (n.d.). How to design efficient and reliable feeders for bulk solids. Retrieved from http://www.jenike.com

de Jong, J. A., Hoffmann, A. C., & Finkers, H. J. (1999). Properly determine powder flowability to maximize plant output. Chemical Engineering Progress, 95(4), 25-34.

Freeman, T. (2011). Characterizing powder flow. Chemical Engineering, 118(10), 66-72.

Mehos, G., & Kozicki, C. (2011). Consider wet agglomeration to improve powder flow. Chemical Engineering, 118(1), 46-49.

Roberts, A. W. (n.d.). Concepts of feeder design and performance in relation to loading bulk solids onto conveyor belts. Newcastle, New South Wales: The University of Newcastle.

Royal, T. A., & Carson, J. (2000). Fine powder flow phenomena in bins, hoppers and processing vessels. Retrieved from http://www.jenike.com

Tardos, G.I., & Lu, Q. (1995). Precision dosing of powders by vibratory and screw feeders: An experimental study. Advanced Powder Technology, 7(1) 51-58.

Mitchell, J. (2001). Vibratory feeders for powders. *Rubber World*, *223*(6), 22.

Vlok, P., & Fourie, C. (2010). A case study on maximizing the profitability of a form fill and seal machine by optimizing interruption intervals. *South African Journal of Industrial Engineering*, *21*(1), 179-191.

Wheatley, M. (2010). Manufacturing efficiency: Filling time. *Engineering & Technology, 13*(10), 54-56.

Yandrick, R. (2009). Vibratory feeders and conveyors: Useful selection tips. *Chemical Engineering*, *116*(6), 47-49.

Appendix A: Data Collected for Analysis of Production Line 1

Julian Date	Sample Set	Shift Sample	TIME	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	TARGET	AVE	TIME	Filler 1 Open	Filler 3 Open
295		1	5:16 PM	22.0	21.8	22.1	22.2	22.4	22.5	22.1	17:16		
295		2	5:31 PM	22.7	21.8	21.8	21.6	22.8	22.5	22.1	17:31		
295		3	6:00 PM	23.0	22.4	22.3	22.1	22.1	22.5	22.4	18:00		17:46
295		4	6:25 PM	22.4	22.9	22.4	22.4	22.3	22.5	22.5	18:25		
295		5	7:03 PM	22.9	23.0	22.5	22.5	23.0	22.5	22.8	19:03		
295		6	7:28 PM	22.6	22.0	22.3	22.7	22.7	22.5	22.5	19:28	19:19	
295		7	8:00 PM	23.2	22.1	23.2	22.7	22.5	22.5	22.7	20:00		
295	1	8	8:47 PM	22.8	22.0	21.6	22.4	22.1	22.5	22.2	20:47		
295		9	9:03 PM	21.9	21.7	21.8	21.9	22.6	22.5	22.0	21:03		
295		10	9:32 PM	23.0	22.0	22.4	22.2	22.4	22.5	22.4	21:32		
295		11	9:57 PM	23.3	22.6	22.9	22.3	22.7	22.5	22.8	21:57	22:11	
295		12	10:36 PM	22.2	22.6	22.9	22.1	22.8	22.5	22.5	22:36		22:45
295		13	10:57 PM	21.9	22.5	22.0	21.8	22.3	22.5	22.1	22:57		
295		14	11:28 PM	22.8	22.5	22.1	21.9	22.1	22.5	22.3	23:28		
296		15	12:01 AM	23.0	23.6	23.2	23.0	22.6	22.5	23.1	0:01		
296		16	12:25 AM	22.6	23.2	21.2	22.5	22.3	22.5	22.4	0:25		
Break													
296		1	2:46 PM	22.9	23.2	23.0	23.1	22.7	22.5	23.0	14:46		
296		2	3:29 PM	23.8	23.2	22.9	22.9	22.6	22.5	23.1	15:29	15:30	
296		3	3:59 PM	22.7	22.4	23.1	22.6	21.6	22.5	22.5	15:59		15:47
296		4	4:29 PM	23.5	23.1	23.3	23.1	22.7	22.5	23.1	16:29		
296	2	5	5:01 PM	23.6	22.8	21.5	23.1	22.1	22.5	22.6	17:01		
296		6	5:45 PM	22.2	22.6	22.0	22.3	22.4	22.5	22.3	17:45		
296		7	6:03 PM	21.3	22.0	22.8	22.2	21.9	22.5	22.0	18:03		
296		8	6:28 PM	23.3	22.2	23.1	22.9	23.2	22.5	22.9	18:28		
296		9	6:58 PM	22.6	22.1	22.7	22.5	22.1	22.5	22.4	18:58		
296		10	7:36 PM	22.9	22.4	22.5	22.7	22.5	22.5	22.6	19:36		

296		11	8:04 PM	22.6	23.1	22.4	22.3	21.8	22.5	22.4	20:04	20:10	
296		12	8:27 PM	24.1	23.8	24.0	24.2	24.1	22.5	24.0	20:27		
296		13	9:00 PM	22.9	22.1	22.3	23.2	23.1	22.5	22.7	21:00		
296		14	9:39 PM	22.3	23.0	22.2	22.6	22.6	22.5	22.5	21:39		
296		15	10:00 PM	22.9	22.1	22.4	22.5	22.3	22.5	22.4	22:00		
296		16	10:33 PM	23.3	22.9	23.1	23.1	23.2	22.5	23.1	22:33		
Break													
297		1	11:02 PM	22.4	22.4	22.4	22.4	22.3	22.5	22.4	23:02		
297		2	11:28 PM	22.8	22.3	22.7	22.5	22.5	22.5	22.6	23:28		
298		3	12:00 AM	22.0	22.8	23.0	21.8	22.3	22.5	22.4	0:00		
298		4	12:29 AM	22.4	22.4	22.1	22.3	22.2	22.5	22.3	0:29		
298		5	1:01 AM	23.0	22.8	22.8	22.3	23.0	22.5	22.8	1:01		
298		6	1:32 AM	22.6	22.8	23.4	23.0	22.4	22.5	22.8	1:32	1:17	
298		7	1:58 AM	21.9	21.5	21.7	22.1	22.7	22.5	22.0	1:58		
298	3	8	2:27 AM	22.9	22.6	22.7	22.4	22.5	22.5	22.6	2:27		
298		9	3:00 AM	22.1	22.5	22.7	22.3	22.4	22.5	22.4	3:00		3:04
298		10	3:30 AM	22.7	22.2	22.6	22.4	22.3	22.5	22.4	3:30		
298		11	4:05 AM	22.4	22.2	21.9	22.3	22.5	22.5	22.3	4:05		
298		12	4:28 AM	21.6	22.0	22.3	22.2	21.9	22.5	22.0	4:28	4:33	
298		13	5:07 AM	22.1	22.5	22.1	22.0	22.5	22.5	22.2	5:07		
298		14	5:32 AM	22.2	23.4	22.3	22.7	22.6	22.5	22.6	5:32		
298		15	5:59 AM	22.9	23.4	23.2	23.0	22.5	22.5	23.0	5:59		
298		16	6:30 AM	22.9	22.4	22.6	22.8	23.4	22.5	22.8	6:30		
Break													
298		1	3:01 PM	21.7	22.4	21.9	22.2	22.1	22.5	22.1	15:01		
298		2	3:32 PM	22.3	22.2	21.5	22.0	22.7	22.5	22.1	15:32		
298		3	4:03 PM	22.0	22.1	21.5	21.9	21.8	22.5	21.9	16:03	16:01	
298	4	4	4:36 PM	22.5	21.6	21.8	22.6	21.8	22.5	22.1	16:36		
298		5	5:03 PM	21.4	21.6	22.1	21.9	21.8	22.5	21.8	17:03		
298		6	5:40 PM	22.5	22.1	22.1	22.7	23.1	22.5	22.5	17:40		
298		7	6:05 PM	22.0	22.6	22.1	22.9	23.6	22.5	22.6	18:05		

298		8	6:29 PM	22.0	22.4	22.4	22.5	22.6	22.5	22.4	18:29		
298		9	6:59 PM	23.2	23.0	23.3	22.3	23.3	22.5	23.0	18:59		
298		10	7:41 PM	22.4	22.9	22.2	22.2	22.7	22.5	22.5	19:41		19:34
298		11	8:00 PM	22.0	22.5	22.8	23.0	22.4	22.5	22.5	20:00	20:05	
298		12	8:37 PM	22.9	23.3	23.3	23.2	23.0	22.5	23.1	20:37		
298		13	9:00 PM	21.9	21.9	22.2	23.8	23.1	22.5	22.6	21:00		
298		14	9:33 PM	22.5	23.0	22.6	23.8	21.4	22.5	22.7	21:33		
298		15	10:16 PM	23.3	23.2	23.2	23.2	22.4	22.5	23.1	22:16		
298		16	10:29 PM	22.7	22.7	22.7	22.2	21.9	22.5	22.4	22:29		
Break													
299		1	3:03 PM	22.8	23.1	22.1	21.9	22.6	22.5	22.5	15:03		
299		2	3:32 PM	22.2	23.5	23.7	22.7	22.7	22.5	23.0	15:32		
299		3	3:59 PM	22.5	22.6	21.7	23.0	22.7	22.5	22.5	15:59		
299		4	4:29 PM	23.1	24.1	22.7	23.3	22.8	22.5	23.2	16:29		
299		5	5:06 PM	23.3	22.9	22.5	22.5	22.5	22.5	22.7	17:06	17:11	
299		6	5:30 PM	22.8	23.1	22.5	22.8	22.7	22.5	22.8	17:30		17:43
299		7	6:10 PM	22.8	23.2	22.5	23.0	22.8	22.5	22.9	18:10		
299	5	8	6:29 PM	22.6	22.9	22.3	22.7	22.8	22.5	22.7	18:29		
299		9	7:22 PM	23.4	22.9	23.2	22.8	23.0	22.5	23.1	19:22		
299		10	7:31 PM	22.9	22.5	22.7	23.4	23.0	22.5	22.9	19:31		
299		11	8:19 PM	23.1	22.7	22.6	23.1	22.8	22.5	22.9	20:19		
299		12	8:28 PM	22.8	22.3	21.9	22.6	22.4	22.5	22.4	20:28		
299		13	9:07 PM	21.7	22.9	22.1	21.9	21.9	22.5	22.1	21:07	21:00	
299		14	9:39 PM	23.7	22.8	23.3	22.3	22.7	22.5	23.0	21:39		
299		15	9:59 PM	22.9	22.4	21.8	22.6	22.1	22.5	22.4	21:59		22:06
299		16	10:30 PM	22.2	22.4	22.0	22.8	23.0	22.5	22.5	22:30		
Break													
300		1	10:58 PM	22.8	22.9	22.1	22.8	22.0	22.5	22.5	22:58	22:50	
300	6	2	11:30 PM	22.2	22.0	22.8	22.0	21.8	22.5	22.2	23:30		
300		3	11:55 PM	22.7	21.8	22.3	21.9	22.4	22.5	22.2	23:55		
301		4	12:28 AM	22.9	22.9	22.4	22.5	22.4	22.5	22.6	0:28		0:00

301		5	1:00 AM	22.8	22.5	22.0	22.6	22.4	22.5	22.5	1:00		
301		6	1:29 AM	22.6	22.3	22.8	22.9	21.9	22.5	22.5	1:29		
301		7	2:01 AM	22.1	23.4	23.1	23.1	22.3	22.5	22.8	2:01		
301		8	2:34 AM	22.8	22.9	22.3	22.5	21.8	22.5	22.5	2:34	2:25	
301		9	3:00 AM	21.9	21.5	22.8	21.8	21.8	22.5	22.0	3:00		
301		10	3:27 AM	22.7	22.6	22.6	23.0	22.3	22.5	22.6	3:27		
301		11	4:01 AM	23.0	21.3	22.7	22.8	22.8	22.5	22.5	4:01		
301		12	4:26 AM	22.8	22.6	23.1	22.6	22.9	22.5	22.8	4:26		
301		13	5:15 AM	22.8	23.6	23.4	23.5	23.3	22.5	23.3	5:15		
301		14	5:38 AM	22.0	23.4	22.8	22.9	22.9	22.5	22.8	5:38	5:45	5:35
301		15	6:03 AM	22.6	22.3	22.5	22.6	22.7	22.5	22.5	6:03		
301		16	6:30 AM	22.4	23.1	22.0	22.4	22.6	22.5	22.5	6:30		
Break													
301		1	3:32 PM	23.0	21.9	22.4	22.8	22.1	22.5	22.4	15:32		
301		2	3:59 PM	22.1	22.7	22.3	22.2	23.1	22.5	22.5	15:59	16:04	
301		3	4:32 PM	22.4	22.6	22.3	23.3	21.9	22.5	22.5	16:32		
301		4	4:59 PM	23.5	22.7	22.3	22.6	22.6	22.5	22.7	16:59		
301		5	5:33 PM	23.1	22.1	22.7	22.3	23.0	22.5	22.6	17:33		
301		6	6:01 PM	22.2	22.4	22.5	22.9	22.4	22.5	22.5	18:01		
301		7	6:35 PM	22.3	22.3	23.2	22.3	22.9	22.5	22.6	18:35		
301	7	8	6:59 PM	22.2	22.6	23.8	22.6	22.3	22.5	22.7	18:59	19:13	
301		9	7:35 PM	22.1	22.8	22.5	22.4	22.5	22.5	22.5	19:35		19:23
301		10	7:59 PM	22.9	22.3	22.7	22.6	22.9	22.5	22.7	19:59		
301		11	8:31 PM	23.1	24.0	23.1	23.1	22.9	22.5	23.2	20:31		
301		12	9:02 PM	23.2	22.8	23.7	23.4	22.7	22.5	23.2	21:02		
301		13	9:35 PM	22.8	22.6	22.9	23.2	23.2	22.5	22.9	21:35		
301		14	10:08 PM	22.9	23.2	23.3	23.0	22.6	22.5	23.0	22:08		
301		15	10:31 PM	23.4	23.1	23.1	22.4	22.8	22.5	23.0	22:31	22:43	
301		16	10:53 PM	23.2	23.2	22.8	23.3	22.5	22.5	23.0	22:53		
Break													
302	8	1	2:58 PM	22.3	22.4	22.9	23.0	22.6	22.5	22.6	14:58		

302		2	3:38 PM	23.3	21.9	22.8	22.7	22.9	22.5	22.7	15:38		
302		3	3:57 PM	21.8	21.9	22.6	21.8	22.3	22.5	22.1	15:57		
302		4	4:00 PM	22.1	22.2	22.2	22.4	22.4	22.5	22.3	16:00		16:29
302		5	5:05 PM	23.1	23.1	23.2	22.4	22.6	22.5	22.9	17:05		
302		6	5:32 PM	22.2	22.3	22.0	22.5	22.3	22.5	22.3	17:32	17:38	
302		7	6:01 PM	22.4	23.0	22.1	22.3	22.5	22.5	22.5	18:01		
302		8	6:29 PM	22.9	22.6	23.5	23.4	23.1	22.5	23.1	18:29		
302		9	7:10 PM	22.3	22.4	22.8	22.9	22.8	22.5	22.6	19:10		
302		10	7:31 PM	22.9	22.5	23.6	22.9	22.7	22.5	22.9	19:31		
302		11	8:02 PM	23.3	22.3	22.7	23.1	22.2	22.5	22.7	20:02		
302		12	8:26 PM	22.3	22.7	22.1	22.2	22.3	22.5	22.3	20:26		
302		13	9:04 PM	23.5	23.0	23.4	22.6	23.2	22.5	23.1	21:04	20:58	
302		14	9:29 PM	22.4	22.4	22.5	22.4	22.7	22.5	22.5	21:29		21:35
302		15	10:04 PM	23.3	23.4	23.1	23.5	22.5	22.5	23.2	22:04		
302		16	10:27 PM	22.8	23.1	23.1	23.3	22.9	22.5	23.0	22:27		
Break													
303		1	2:59 PM	21.8	22.4	22.7	22.3	22.2	22.5	22.3	14:59		
303		2	3:34 PM	22.0	23.9	22.9	22.1	21.9	22.5	22.6	15:34	15:45	
303		3	3:59 PM	22.4	22.7	22.2	22.7	22.3	22.5	22.5	15:59		
303		4	4:29 PM	22.7	23.0	22.8	22.8	22.7	22.5	22.8	16:29		
303		5	5:00 PM	21.9	22.2	22.3	22.1	23.3	22.5	22.4	17:00		
303		6	5:35 PM	22.7	22.4	22.5	22.9	23.0	22.5	22.7	17:35		17:49
303		7	6:09 PM	23.7	22.8	22.2	22.8	22.1	22.5	22.7	18:09		
303	9	8	6:31 PM	22.2	22.3	22.6	22.8	22.8	22.5	22.5	18:31		
303		9	7:00 PM	22.5	23.4	22.9	22.5	22.5	22.5	22.8	19:00	19:10	
303		10	7:34 PM	23.2	22.7	23.4	23.1	23.0	22.5	23.1	19:34		
303		11	8:04 PM	22.1	23.1	22.3	22.8	22.7	22.5	22.6	20:04		
303		12	8:34 PM	22.8	22.5	23.6	23.3	23.5	22.5	23.1	20:34		
303		13	9:00 PM	22.7	23.1	22.3	23.6	23.6	22.5	23.1	21:00		
303		14	9:41 PM	22.8	23.1	23.4	22.2	22.7	22.5	22.8	21:41		
303		15	10:00 PM	22.7	23.0	21.5	22.3	22.6	22.5	22.4	22:00		

303		16	10:32 PM	21.9	22.2	22.8	22.7	22.6	22.5	22.4	22:32		

Appendix B: Data Collected for Analysis of Production Line 10

Julian Date	Sample Set	Shift Sample	TIME	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	TARGET	AVE	TIME	Filler 1 Open	Filler 3 Open
280		1	11:07 PM	22.4	22.9	23.1	22.4	22.7			23:07		
280		2	11:52 PM	22.8	22.3	22.9	23.0	23.1	22.5	22.8	23:52		
281		3	12:36 AM	22.9	22.2	23.0	23.2	22.7	22.5	22.8	0:36		
281		4	12:39 AM	23.0	22.5	23.3	22.5	23.5	22.5	23.0	0:39		
281		5	1:00 AM	22.5	21.8	22.1	21.9	22.2	22.5	22.1	1:00		1:08
281		6	1:38 AM	23.1	22.7	23.2	22.3	22.7	22.5	22.8	1:38		
281		7	2:00 AM	23.1	22.3	23.5	23.2	23.0	22.5	23.0	2:00		
281	1	8	2:35 AM	22.2	22.2	22.5	23.2	22.1	22.5	22.4	2:35		
281		9	3:02 AM	22.5	22.1	22.6	22.1	22.7	22.5	22.4	3:02		
281		10	3:35 AM	22.4	22.6	22.7	22.7	22.3	22.5	22.5	3:35	3:26	
281		11	4:01 AM	22.8	21.7	22.4	22.3	22.6	22.5	22.4	4:01		
281		12	4:31 AM	22.1	22.0	21.5	22.2	22.3	22.5	22.0	4:31		4:27
281		13	5:00 AM	23.6	23.4	24.4	22.3	22.8	22.5	23.3	5:00		
281		14	5:34 AM	22.7	23.5	22.8	23.3	22.8	22.5	23.0	5:34		
281		15	6:05 AM	22.2	21.9	22.3	22.1	22.4	22.5	22.2	6:05		
281		16	6:38 AM	22.5	22.6	22.0	22.4	22.1	22.5	22.3	6:38		
Break													
281		1	11:08 PM	22.8	23.8	23.0	23.0	23.7	22.5	23.3	23:08		22:54
281		2	11:30 PM	23.4	23.0	22.8	23.8	22.9	22.5	23.2	23:30		
282		3	12:20 AM	23.7	23.4	23.3	22.6	23.1	22.5	23.2	0:20		
282		4	12:35 AM	22.3	22.5	23.4	22.9	21.8	22.5	22.6	0:35		
282	2	5	1:00 AM	22.2	22.0	21.7	22.2	22.2	22.5	22.1	1:00	1:25	
282		6	1:40 AM	22.5	23.1	23.4	22.8	23.0	22.5	23.0	1:40		1:35
282		7	2:01 AM	24.1	23.4	23.6	23.4	23.6	22.5	23.6	2:01		
282		8	2:30 AM	22.9	23.4	23.6	23.2	23.6	22.5	23.3	2:30		
282		9	3:02 AM	23.4	23.0	23.5	22.5	22.3	22.5	22.9	3:02		
282		10	3:37 AM	22.5	22.5	22.9	22.8	23.1	22.5	22.8	3:37		

282		11	4:01 AM	22.7	23.4	22.9	22.7	22.6	22.5	22.9	4:01	3:56	3:46
282		12	4:33 AM	23.0	22.7	23.3	23.5	22.3	22.5	23.0	4:33		
282		13	5:01 AM	22.3	22.8	22.9	22.9	22.5	22.5	22.7	5:01		
282		14	5:34 AM	22.7	22.4	22.7	22.6	22.5	22.5	22.6	5:34		
282		15	6:01 AM	22.6	22.8	22.7	22.7	22.7	22.5	22.7	6:01		5:54
282		16	6:33 AM	22.4	21.9	22.2	22.7	22.0	22.5	22.2	6:33		
Break													
282		1	10:53 PM	22.5	22.4	23.3	21.8	22.4	22.5	22.5	22:53	22:30	22:42
282		2	11:30 PM	22.9	22.3	22.5	22.9	23.0	22.5	22.7	23:30		
283		3	12:03 PM	22.4	22.2	22.4	22.7	23.1	22.5	22.6	0:03		
283		4	12:32 AM	21.9	22.0	22.3	22.5	23.1	22.5	22.4	0:32		
283		5	12:57 AM	22.1	22.4	21.9	22.8	22.3	22.5	22.3	0:57		
283		6	1:35 AM	22.3	22.7	21.5	23.1	21.5	22.5	22.2	1:35		
283		7	1:58 AM	22.6	22.6	22.2	22.3	23.0	22.5	22.5	1:58		
283	3	8	2:26 AM	22.1	22.4	21.9	22.3	22.1	22.5	22.2	2:26		
283		9	3:05 AM	22.0	22.0	22.8	22.4	22.4	22.5	22.3	3:05		
283		10	3:34 AM	23.0	22.2	22.2	22.9	22.5	22.5	22.6	3:34		3:21
283		11	4:01 AM	22.8	23.1	22.6	24.2	22.5	22.5	23.0	4:01	3:46	
283		12	4:30 AM	22.4	21.7	22.6	21.7	22.5	22.5	22.2	4:30		
283		13	5:00 AM	22.9	21.9	22.6	22.5	22.5	22.5	22.5	5:00		
283		14	5:33 AM	22.8	22.3	22.3	22.3	22.4	22.5	22.4	5:33		
283		15	6:00 AM	22.4	22.6	22.6	22.0	22.4	22.5	22.4	6:00		
283		16	6:34 AM	22.7	22.7	22.9	22.2	22.1	22.5	22.5	6:34		
Break													
283		1	11:03 PM	23.2	23.5	23.5	22.2	23.0	22.5	23.1	23:03		
283		2	11:30 PM	23.3	22.6	22.8	22.3	22.6	22.5	22.7	23:30		
284		3	12:05 AM	23.2	22.5	22.8	22.6	23.0	22.5	22.8	0:05	23:42	23:33
284	4	4	12:34 AM	23.1	22.4	22.7	22.8	23.4	22.5	22.9	0:34		
284		5	1:06 AM	23.1	22.9	22.8	23.0	23.4	22.5	23.0	1:06		
284		6	1:34 AM	23.0	23.3	22.9	23.2	23.4	22.5	23.2	1:34		
284		7	2:00 AM	22.9	22.8	23.4	22.5	22.9	22.5	22.9	2:00		

284		8	2:30 AM	22.7	22.9	22.2	22.8	23.1	22.5	22.7	2:30		
284		9	3:02 AM	22.3	22.9	22.7	22.6	23.1	22.5	22.7	3:02		
284		10	3:34 AM	22.8	22.9	22.7	22.7	23.0	22.5	22.8	3:34		3:12
284		11	4:01 AM	23.3	22.9	22.7	22.8	22.9	22.5	22.9	4:01		
284		12	4:31 AM	22.9	22.5	22.9	23.0	22.5	22.5	22.8	4:31	4:33	
284		13	5:04 AM	22.6	22.8	22.6	22.8	23.2	22.5	22.8	5:04		
284		14	5:35 AM	22.8	23.3	23.4	22.7	22.4	22.5	22.9	5:35		
284		15	6:00 AM	23.2	23.6	22.9	23.0	22.6	22.5	23.1	6:00		
284		16	6:30 AM	22.4	23.2	22.8	22.8	22.8	22.5	22.8	6:30		6:09
Break													
284		1	11:03 PM	22.5	23.6	22.8	23.1	22.5	22.5	22.9	23:03		
284		2	11:37 PM	23.0	22.6	23.0	22.7	22.3	22.5	22.7	23:37	23:50	
285		3	12:24 AM	23.2	22.6	22.3	22.5	22.6	22.5	22.6	0:24		
285		4	12:30 AM	22.7	22.0	22.9	22.4	23.3	22.5	22.7	0:30		
285		5	1:00 AM	21.8	22.2	22.5	22.7	22.6	22.5	22.4	1:00		0:55
285		6	1:34 AM	24.1	23.2	22.9	22.6	23.1	22.5	23.2	1:34		
285		7	2:00 AM	23.0	22.3	22.7	22.9	22.4	22.5	22.7	2:00		
285		8	2:33 AM	22.7	23.4	22.2	22.8	22.6	22.5	22.7	2:33		
285	5	9	3:07 AM	22.2	22.4	22.5	21.9	22.2	22.5	22.2	3:07	2:57	3:07
285		10	3:12 AM	23.0	23.2	22.4	22.7	22.6	22.5	22.8	3:12		
285		11	3:36 AM	23.3	23.0	22.4	23.0	23.2	22.5	23.0	3:36		
285		12	4:02 AM	24.1	24.5	24.6	25.1	23.2	22.5	24.3	4:02		
285		13	5:07 AM	23.5	23.6	23.7	24.0	22.7	22.5	23.5	5:07		
285		14	5:38 AM	22.9	22.7	22.7	22.8	22.2	22.5	22.7	5:38	5:41	5:35
285		15	6:02 AM	23.0	23.3	23.0	23.0	22.7	22.5	23.0	6:02		
285		16	6:35 AM	23.1	23.8	23.2	23.2	23.2	22.5	23.3	6:35		
Break													
287		1	11:00 PM	22.7	22.8	22.8	23.0	23.5	22.5	23.0	23:00		
287	6	2	11:39 PM	23.2	23.4	22.9	23.6	22.9	22.5	23.2	23:39		
288		3	12:34 AM	22.7	23.6	23.1	23.6	22.8	22.5	23.2	0:34		
288		4	12:40 AM	22.4	23.0	23.0	22.9	23.0	22.5	22.9	0:40		

288		5	1:04 AM	22.7	23.3	22.9	23.0	23.1	22.5	23.0	1:04		
288		6	1:39 AM	22.3	22.5	22.1	22.8	22.8	22.5	22.5	1:39		
288		7	2:00 AM	22.6	22.9	22.5	22.8	22.1	22.5	22.6	2:00	1:52	
288		8	2:28 AM	22.5	23.0	22.3	22.7	22.6	22.5	22.6	2:28		2:20
288		9	3:05 AM	22.7	22.9	22.4	23.0	23.0	22.5	22.8	3:05		
288		10	3:30 AM	23.3	22.5	22.8	23.4	22.7	22.5	22.9	3:30		
288		11	4:13 AM	22.5	21.7	22.8	22.0	22.5	22.5	22.3	4:13		
288		12	4:32 AM	22.1	22.6	22.1	22.1	22.2	22.5	22.2	4:32	4:35	
288		13	5:03 AM	22.7	23.4	22.2	22.2	22.1	22.5	22.5	5:03		4:40
288		14	5:34 AM	22.8	22.3	21.6	23.0	22.3	22.5	22.4	5:34		
288		15	6:03 AM	22.4	22.0	22.2	22.4	22.3	22.5	22.3	6:03		
288		16	6:33 AM	22.2	22.8	22.0	22.2	22.3	22.5	22.3	6:33		
Break													
288		1	11:09 PM	22.7	23.0	23.1	22.1	23.0	22.5	22.8	23:09	22:57	
288		2	11:35 PM	22.9	23.3	22.7	22.7	22.7	22.5	22.9	23:35		
289		3	12:10 AM	22.8	23.2	22.9	22.4	22.9	22.5	22.8	0:10		
289		4	12:34 AM	22.1	22.3	22.6	22.7	22.7	22.5	22.5	0:34		
289		5	1:03 AM	21.8	22.2	22.4	23.0	23.1	22.5	22.5	1:03		0:50
289		6	1:31 AM	22.3	22.4	22.8	22.3	22.2	22.5	22.4	1:31		
289		7	2:03 AM	22.6	22.9	23.0	22.4	22.6	22.5	22.7	2:03	1:54	
289	7	8	2:30 AM	22.0	22.5	22.9	23.0	22.6	22.5	22.6	2:30		
289		9	3:05 AM	22.5	22.5	22.8	22.8	22.7	22.5	22.7	3:05		3:00
289		10	3:35 AM	22.9	22.6	22.4	22.8	22.6	22.5	22.7	3:35		
289		11	4:16 AM	23.2	22.7	22.0	22.8	22.5	22.5	22.6	4:16		
289		12	4:32 AM	22.8	23.0	22.2	22.8	22.2	22.5	22.6	4:32		
289		13	5:02 AM	22.6	23.3	22.9	23.1	22.9	22.5	23.0	5:02	4:36	
289		14	5:37 AM	22.7	23.6	23.5	23.3	23.6	22.5	23.3	5:37		5:29
289		15	6:14 AM	22.4	22.8	23.6	23.0	23.0	22.5	23.0	6:14		
289		16	6:45 AM	22.7	23.2	23.2	22.5	22.7	22.5	22.9	6:45		
Break													
289	8	1	11:00 PM	22.6	23.4	22.9	22.4	22.5	22.5	22.8	23:00		

289		2	11:30 PM	22.2	22.2	22.8	22.8	22.6	22.5	22.5	23:30		
290		3	12:21 AM	22.7	22.5	22.7	22.6	22.8	22.5	22.7	0:21		
290		4	12:38 AM	23.3	22.7	23.4	22.3	22.5	22.5	22.8	0:38	0:32	0:26
290		5	1:00 AM	23.0	23.2	23.2	23.0	23.4	22.5	23.2	1:00		
290		6	1:36 AM	23.3	23.0	22.6	23.0	22.8	22.5	22.9	1:36		
290		7	2:00 AM	22.6	22.8	22.2	22.7	23.5	22.5	22.8	2:00		
290		8	2:28 AM	22.4	22.7	22.3	22.7	23.0	22.5	22.6	2:28		
290		9	2:59 AM	22.1	22.6	22.4	22.7	22.4	22.5	22.4	2:59		2:44
290		10	3:34 AM	22.5	22.2	22.9	22.7	22.3	22.5	22.5	3:34	3:23	
290		11	4:12 AM	22.2	24.1	22.6	22.1	22.7	22.5	22.7	4:12		
290		12	4:31 AM	22.6	21.2	22.0	22.5	22.5	22.5	22.2	4:31		
290		13	5:03 AM	22.9	22.9	22.0	22.0	22.5	22.5	22.5	5:03		
290		14	5:37 AM	22.1	22.5	22.3	23.2	22.6	22.5	22.5	5:37		
290		15	5:57 AM	22.4	22.3	22.2	23.0	22.4	22.5	22.5	5:57		5:43
290		16	6:35 AM	22.6	22.0	22.0	22.7	22.1	22.5	22.3	6:35		
Break													
290		1	11:04 PM	22.0	22.7	22.4	22.2	22.4	22.5	22.3	23:04		
290		2	11:37 PM	22.9	22.6	22.0	22.7	23.1	22.5	22.7	23:37	23:21	
291		3	11:59 PM	22.7	22.8	22.6	23.0	22.6	22.5	22.7	23:59		
291		4	12:24 AM	22.5	23.0	23.2	23.2	22.5	22.5	22.9	0:24		
291		5	1:08 AM	22.9	22.8	23.2	23.1	22.9	22.5	23.0	1:08		
291		6	1:33 AM	23.1	23.3	22.6	23.8	23.4	22.5	23.2	1:33		
291		7	2:03 AM	22.0	22.6	22.8	23.0	22.6	22.5	22.6	2:03		
291	9	8	2:31 AM	22.7	21.9	22.4	21.8	22.2	22.5	22.2	2:31		
291		9	3:01 AM	23.4	22.2	23.0	23.3	22.5	22.5	22.9	3:01	2:42	2:47
291		10	3:34 AM	24.0	22.0	23.0	22.6	23.5	22.5	23.0	3:34		
291		11	4:03 AM	22.1	22.3	23.2	22.1	23.4	22.5	22.6	4:03		
291		12	4:30 AM	22.7	22.0	23.5	22.3	22.3	22.5	22.6	4:30		
291		13	5:06 AM	23.0	23.0	23.6	23.4	22.6	22.5	23.1	5:06	5:08	4:57
291		14	5:36 AM	23.0	22.7	23.0	22.9	22.6	22.5	22.8	5:36		
291		15	6:01 AM	22.2	22.9	22.8	23.4	23.1	22.5	22.9	6:01		

291		16	6:41 AM	22.8	22.7	22.9	22.9	22.7	22.5	22.8	6:41		