Spring 2021

Statistical Study of the Effect of Implementing an Airveyor System on the Warpage of Injection Molded Closures

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STATISTICAL STUDY OF THE EFFECT OF IMPLEMENTING AN AIRVEYOR SYSTEM ON THE WARPAGE OF INJECTION MOLDED CLOSURES

A Thesis
Presented to
The Faculty of the School of Engineering and Applied Sciences
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Wes Bozarth

May 2021

STATISTICAL STUDY OF THE EFFECT OF IMPLEMENTING AN AIRVEYOR SYSTEM ON THE WARPAGE OF INJECTION MOLDED CLOSURES

Date Recommended April 9th, 2021

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This thesis is dedicated to my wife, Amanda. Without whom I would not be the man I am today. Through her example I am inspired to work hard and reach for more; not out of greed, but because it is the right thing to do, and we only have this one life in which to do the right thing. I would also like to dedicate this thesis to my parents Chuck and Jill, as well as my step-parents Stacy and Wayne. Each of you have never let me feel anything less than unwavering love and support. You have made it easy for a kid like me to believe I was capable of more, and provided the encouragement necessary to take the risks required to see where that ceiling is. I'm still looking for it.

ACKNOWLEDGMENTS

I would like to acknowledge and thank Dr. Orooji and Dr. Rezasoltani for agreeing to take time out of their schedule to serve on this thesis committee. I would especially like to thank Dr. Revels for his time and guidance in serving as the committee chair. From my first course in the MSETM program and throughout we have been connected, and he has been such an asset in my education as a student and development as a professional.

Additional thanks go out to Berry Global, Bowling Green, KY production facility for allowing me to use this project as a source for my thesis. I would like to acknowledge all the team members that were a part of this Six Sigma project. Your expertise and support have been a tremendous asset in the completion of this project and thesis.

Lastly, I would like to acknowledge and thank the mentors I have had throughout my professional career: Wayne Thomas, Mike Gross, Kevin Autry, Wayne Highsmith, and Jeremy Brooks. We have been through a lot of ups and downs serving alongside each other in the trenches. Through it all I have tried to learn and grow from your example. Without the trust you put in me and the effort you expended in my development, I would not be the professional I am today. Thank you.

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Berry Global in Bowling Green, Kentucky produces predominantly polypropylene container closures. One variant, the 83mm lined jar closure, is produced by first being injection molded, placed in work-in-progress (WIP) hold for 24 hours to cool, and then finished through the auxiliary liner operation into a final product. While this process is an effective method to produce a quality large-diameter closure and allows the polypropylene adequate time to cool without warping out of shape, the 24-hour WIP time and the manpower needed to accomplish this can negatively impact several business metrics as well as employee safety.

The purpose of this thesis was to document the application of Six Sigma to improve the process of manufacturing 83mm lined jar closures. This was completed by executing the define, measure, analyze, improve, and control (DMAIC) process at the heart of Six Sigma to define the process, measure current WIP and desired airveyor continuous flow process metrics to analyze any impact to the closure, and put controls in place to ensure the improved process was stable. The project resulted in a successful application of the Six Sigma methodology and positive variable data results supporting a recommendation for the change to a continuous flow airveyor process.

Introduction

The largest capacity polypropylene closure mold at Berry Global in Bowling Green, KY (BG-BGKY) is 120 cavities and has the capability of producing over 1.2 million bottle closures per day. The 18mm tamper evident, liner-less bottle closure finished product from this mold and subsequent auxiliary operations is just a single product type of the multitude of variations of closure that Berry Global can produce in Bowling Green alone. Characteristics that can differentiate one closure from another can be: resin type, diameter, height, color, tamper evident (TE) feature, lined or not, liner type, ribbed exterior or smooth, and so on. Some of these variations are made by the press recipe or design features of the mold itself; others are added through auxiliary processing which may cut the TE band and fold the tabs that secure around the bottle neck seal, cut and insert the liner, apply artwork, or any combination of these options as required by the closure design.

The extensive range of variants coupled with high demand volumes, quality requirements, and lengthy changeover timing means that BG-BGKY processes must produce at an optimal level to avert missed deliveries, quality concerns, and increased cost of quality (COQ). In order to mitigate these risks most closures are produced in a continuous operation from the injection molding press, transported to auxiliary operations by airveyor tubes and processed into finished goods ready for shipment to the customer, all while having quality checks conducted at defined frequencies. However, there are still some closure variants that are not produced in this manner.

The 83mm closure is the largest diameter closure produced at BG-BGKY (Figure 1). It is used to seal jars containing condiment and food products such as mayonnaise, marshmallow cream, and peanut butter. Produced in a 24-cavity mold, quantities coming out of the press can exceed 150,000 closures per day. These closures are then placed into a 24-hour WIP hold before being processed through the auxiliary lining operation into finished good packaging. This process of running mold production into a gaylord and then transported to a hold area or to the auxiliary operation is an antiquated method of production from which most closure types have ameliorated.

Figure 1. Example of 83mm Lined Closure

Local tribal knowledge has imparted that the design and/or size of the 83mm closure can cause it to warp out of design form due to heat retention when processed straight from the molding process through auxiliary into finished goods packaging. Because of this, improvements that have been made to the production of other closure types, nor other unexplored alternatives to optimize process flow, reduce inventory on hand, and add agility to the facility have been applied to the 83mm mold and auxiliary production method.

Project Goal

Producing a product that meets customer requirements as efficiently and safely as possible, while keeping costs low is a prime objective of any manufacturing organization. Management is continually searching for ways to improve processes, eliminate waste, reduce overhead costs, make existing manual operations safer for employees, increase throughput, and so on. Berry Global (Berry) is no exception. In fact, Berry places such an emphasis on continuous improvement, that it has adopted the Six Sigma philosophy into its organization as the methodology it utilizes to execute their continuous improvement directive. In fact, Six Sigma, by its own nature, fosters this directive to meet these management objectives. According to Pyzdek and Keller, “The opportunities meet the goals at the Six Sigma project, whose selection and development become critical aspects of meeting organizational objectives” (2014, p. 11).

The goal of this project is to apply the Six Sigma methodology to improve the 83mm lined closure production method by investigating a way to eliminate the WIP hold time and instead process straight from injection molding through the auxiliary lining operation into finished goods packaging, staged and ready for shipment to the customer.

While the current technique of processing injection molded closures into a gaylord and held for 24 hours is believed to be the best method to allow for cooling with reduced warping and cracking occurrence, it does require manual transportation of the gaylords through the production floor to the warehouse, which presents safety hazards, as well as increase the WIP inventory on hand. Excessive on-hand inventory, whether it is raw materials, WIP, or finished goods is a source of waste; as indicated by Munro, Ramu, and Zrymiak, "Production or administrative functions that use more space or other resources than necessary increase costs without adding value" (2015, p. 42).

Statement of Purpose

The intent of this project is to utilize the Six Sigma methodology and statistical tools to attempt to improve the current 83mm closure production process resulting in reduced costs related to processing and inventory on hand as well as safety incident occurrence potential.

Expected Results

Application of Six Sigma to the 83mm closure production process is expected to result in an improved manufacturing method that removes the 24-hour WIP hold time and produces a closure that meets customer requirements with an improved process capability. The metrics by which the success of this project will be measured include:

- Cracked closure occurrence: The target for this metric will be that the continuous flow production process will be equal to or less than the baseline established in the current WIP hold process.

- Severity of Warpage: The target for this metric will be that the continuous flow production process will be equal to or less than the baseline established in the current WIP hold process.
- WIP closures in inventory: The target for this goal is to eliminate the WIP hold material from the warehouse level. A baseline will be established by reviewing historical stock levels.

It is important to note, at this point, that while sigma levels are the foundational metric of the Six Sigma philosophy, they are not considered a metric by which this project will be measured. The reason for this is that BG-BGKY does not have a system in place to identify and quantify warpage as a scrap reason for closures at this time. This may be a CI project itself in the future.

Assumptions

This project will be conducted under the following assumptions:

1. Functional experts that are requested to be a part of this Six Sigma project agree, actively participate, do not undergo an extended absence from the plant for any reason, and do not terminate employment during the span of the project.
2. Requested line time to run sample builds is permitted.
3. All functional areas, including leadership will not make assumptions based on tribal knowledge and instead be open to any improvement ideas proposed and support trial efforts.
4. If the continuous flow process results in an increased occurrence of warped or cracked closures, there exists a reasonable improvement that can be made to the new process to reduce occurrence to or below baseline.

5. Demand will allow for adequate production of this closure during the span of this project so that type changes or other wasteful actions are not required to run trials.
6. Metrology equipment necessary to measure inspection data remains functional.
7. No information technology infrastructure will fail in the preservation of project material including: Six Sigma tools, data, presentation, etc.

Limitations

Any proposed improvement sample trials would be running on the same injection mold press and auxiliary lining machines as normal production. Therefore, any process improvement downtime or sample runs will need to be negotiated with production planning and may require an excess amount of inventory on hand to allow for the time needed as risk mitigation.

Based on interviews with personnel possessing tribal knowledge, it is anticipated that the removal of the 24-hour WIP hold time will result in an increased degree of warp severity and/or cracked closures from a continuous flow production process. This phenomenon is expected to be a result of compacting warm closures tightly together in a finished goods box, causing excessive heat that affects the closure form. This will need to be confirmed or disproved during the Measurement step of the DMAIC process. If confirmed, additional improvements will be required as a part of the project to alleviate this condition. Improvement measures may be constrained by the physical area of the productions process and limit equipment installation options.

Delimitations

The following delimitations have been identified:

1. This project will only evaluate the 83mm jar closure, which is the largest diameter closure produced at the BG-BGKY facility. No other closures style will be evaluated as a part of this project.
2. This project will only seek to apply improvements to injection molding press MI2358 and auxiliary lining machine CLN2303 as this is the only combination currently producing and processing the 83mm closure.
3. The results from this project will only apply to the 83mm closure analyzed during this project. An 83mm closure product with different design characteristics from the same customer or new customer will not assume the same results from this project.
4. Similarly, any new combination of press, mold, or auxiliary line will not assume the same results from this project.

Definition of Terms

- Airveyor – A system consisting of tube and air pressure to move closures from the injection molding operation to auxiliary lines for final processing into finished good boxes. This system is also referred to as blow-tubes at BG-BGKY.
- Closures – Devices whose purpose is to provide a seal on various types of containers. Commonly known as caps or lids.
- Cost of Quality (COQ) – Any cost that would not have been expended if quality were perfect (e.g., rework, retesting, sorting). (Christensen, Betz, & Stein, 2014, p. 8)
- DMAIC – Structure providing a useful framework for creating a "gated process" for project control. Applied for performance improvement of an existing product, process, or service. (Pyzdek & Keller, 2014, p. 213)

- Gaylord/Ropak – Used interchangeably at Berry and in this thesis. Both represent a large vessel into which closure WIP is processed. Ropak is a brand name of gaylord, which is the term for the vessel.
- Injection Molding - Shape-forming process in which molten metal or plastic is injected into aluminum, ceramic, or steel molds (shaped like the end product) and squeezed under high pressure. Injection molding is employed mainly in the production of solid objects. (Injection Molding, 2020)
- Metrology – That portion of measurement science that is often used to provide, maintain, and disseminate a consistent set of units, to provide support for the enforcement of equity in trade by weights and measurement laws, or to provide data for quality control in manufacturing (Simpson, 1981, as cited in Borror, 2009); more simply, "The science of precision measurement" (Borror, 2009, p. 245).
- Project Charter – A document stating the purposes of the project. It serves as an informal contract that helps the team stay on track with the goals of the organization. (Munro, Ramu, & Zrymiak, 2015, p. 95)
- Six Sigma – The application of the scientific method to the design and operation of management systems and business processes which enable employees to deliver the greatest value to customer and owners. (Pyzdek & Keller, 2014, p. 6)
- Tamper Evident (TE) – A security feature design characteristic of the closure that notifies the end-user of the security state of the container.
- Tribal Knowledge – Any unwritten information that is not commonly known by others within a company. This term is used most when referencing information

that may need to be known by others in order to produce quality product or service. The information may be key to quality performance but it may also be totally incorrect. Unlike similar forms of artisan intelligence, tribal knowledge can be converted into company property. It is often a good source of test factors during improvement efforts. (Tribal Knowledge, 2020)

- Value Stream Map (VSM) – The [illustration of the] series of activities that an organization performs, such as order, design, produce, and deliver products and services. (Munro, Ramu, & Zrymiak, 2015, p. 44)
- Work-in-Progress (WIP) – Partially processed product. WIP does not automatically imply the product is held for a period of time in between processes; any product at any stage between raw material and finished good is considered WIP.

Review of Literature

While Six Sigma is as relevant today as it has ever been, the literature available on the topic appears to be dated, the majority of which comes from the 1990s and 2000s, when the methodology craze was at its peak. However, this is not to say that the literature available from that era is irrelevant, or that the literature being published today contradicts the earlier information. The fact is that the core philosophy of Six Sigma and the DMAIC process has not changed or evolved significantly since its foundation was laid. That being said, as new tools are developed, or existing tools improved, they can be utilized in the Six Sigma DMAIC process where appropriate.

Six Sigma, at its core, is a set of principles and a central process. The majority of the literature available covers the key principles of Six Sigma, its history, the DMAIC process, implementation techniques & obstacles, and the core tools available for each step of the process. Six Sigma literature also often pays homage to the quality pioneers that laid the foundation on which the philosophy was built, and whom developed the tools which are used in the DMAIC process. This review of literature attempts to summarize these topics, without diving too deep into them, as there is an abundant amount of source material available for review.

Definition

Six Sigma is a philosophy for continuous improvement. Organizations that adopt this philosophy take a pledge to continuously improve their processes by viewing them through the lens of the customer, understanding what they value, and bringing the product in line with these values while eliminating waste to increase profits. This definition is supported by Harry & Shroeder (2000, p. VII). They define Six Sigma as "A business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction".

Six Sigma History

Six Sigma's mainstream popularization began in the mid-1980's, but the foundation of the philosophy was laid in the 1970's when a Japanese firm took over a Motorola factory in the US that produced televisions. Under the new management regime, the factory began producing only one defect for every twenty that was produced prior to the Japanese firm acquisition. "They did this using the same workforce, technology, and designs, and did it while lowering costs, making it clear that the problem was Motorola's management" (Pyzdek & Keller, 2014, p. 4). For its improved quality as a result of the Six Sigma methodology, Motorola was the first recipient of the Malcolm Baldridge National Quality Award (MBNQA). From this recognition, success stories of companies who followed in Motorola's footsteps, and advocation by reputable quality pioneers, Six Sigma has become synonymous with continuous improvement and a standard term in any industry's dictionary.

The Six Sigma Process

The bones of the Six Sigma process are common across the reputable literature available on the subject and a good overview is put forth by Munro, Ramu, & Zrymiak (2015, p. 23):

1. Recognize that variation exists in everything that we do; standardize your work.
2. Identify what the customer wants and needs. Reduce variation.

3. Use a problem-solving methodology to plan improvements.
4. Follow the DMAIC model to deploy the improvement.
5. Monitor the process using process behavior charts.
6. Update standard operating procedures and lessons learned.
7. Celebrate successes.
8. Start over again for continual improvement – PDSA/SDCA.

Internal Barriers to Implementation

As with any change, there is resistance, and Six Sigma implementation is no different. Many organizations that choose to adopt the Six Sigma philosophy and make it a part of their culture have existed for a long time and have employees who are accustomed to doing things a certain way, and will resist this change or write it off as a fad that will pass. Therefore, it is important that management is organized in its implementation efforts and ensures everyone is on the same page for what is to come.

Beyond the employee culture implementation barriers, however, exists procedural barriers. As Pyzdek & Keller (2014, p. 198) note, "In an organization that is serious about its written rules even senior leaders find themselves helpless to act without submitting to a sometimes burdensome rule-changing process" and "Projects almost always require that work be done differently, and such procedures prohibit such change". This requires a detailed effort by the organization to review its established policies and procedures and bring them in line with their new Six Sigma culture. This effort will only help reinforce the commitment to change the organization is making and aid in receiving employee buy-in.

External Barriers to Implementation

In addition to internal barriers of implementation there exists external barriers. One of the most common external barriers an organization must realize and address is any requirements put forth by external governing or industry certifying agencies. Different industries have unique requirements put forth by these entities that if not met, can result in loss of certification or legal penalties. In recognition of this reality, Pyzdek & Keller (2014, p. 199) advise that “These agencies [for example, the Food and Drug Administration (FDA)] must often be consulted before undertaking projects”.

Management Commitment

As previously mentioned, but a point that cannot go understated, management commitment is a crucial element in the implementation and ongoing success of Six Sigma in any organization. Six Sigma is not a job description for a single member of your organization, but a culture that is realized through the efforts of everyone, perhaps most importantly, members of management. Pyzdek & Keller (2014, p. 197) make the following observations regarding management’s role in Six Sigma:

- Management sponsors provide the management interface necessary to ensure the project remains on course relative to its objectives, or to change objectives if necessary given new information discovered by the project team
- At times, it will be necessary for management to reiterate its project support to clear roadblocks
- Management must also evaluate the project results, as well as the team performance, to provide feedback to the management systems for identifying improvement opportunities

Quality Pioneers

"Most of the techniques found in the Six Sigma toolbox have been available for some time thanks to the groundbreaking work of many professionals in the quality sciences" (Munro, Ramu, & Zrymiak, 2015, p. 8). These pioneers are identified in Table 1 along with their contribution to the Six Sigma philosophy and/or toolbox (Munro, Ramu, & Zrymiak, 2015, pp. 8-15).

Quality Pioneer	Key Contributions
Subir Chowdhury	• Work with top-level management teams to recognize the need for quality
Philip Crosby	• Management theory for quality • Engaged business executives in quality
W. Edwards Deming	• Japan's reconstruction in the 1950s and 1960s; development of the Deming Prize • Developments in sampling techniques—applied to census applications • Management principles: Fourteen Points and Seven Deadly Diseases • Red bead experiment • Transformation of American Industry
Armand Feigenbaum	• Quality planning—became AQP • Quality costs—the hidden factory
Kaoru Ishikawa	• Japanese quality circles • Ishikawa diagram (cause-and-effect diagram, fishbone diagram)
Joseph M. Juran	• Pareto principle—"the vital few and trivial many" • Management theory for quality
Dorian Shainin	• Red "X" –collection of industrial statistical tools that's collectively have become known as the Shainin System for Quality Improvement
Walter Shewhart	• Father of statistical quality control • Shewhart cycle—PDCA
D.H. Stamatis	• First handbook dedicated to understanding and practical applications of FMEA
Genichi Taguchi	• Taguchi loss function • The philosophy of off-line quality control • Innovations in the statistical design of experiments

Table 1. Quality Pioneers and Six Sigma Contributions

Methodology

The purpose of this project is to utilize the Six Sigma methodology and statistical tools to attempt to improve the current 83mm closure production process. This project will be performed at the BG-BGKY facility. Prior to the start, the project leader completed a Project Feasibility Screening (Appendix 1) to qualify it as a project worth completing. This project will be accomplished by executing the define, measure, analyze, improve, and control (DMAIC) process at the heart of the Six Sigma methodology.

Define Stage

During the define stage, the Continuous Improvement (CI) Leader will draft the Project Charter (Appendix 2) to define the problem, goal, scope, and team roles and responsibilities. A defined scope is important to any Six Sigma project "to ensure a common understanding of what the project team and its associated resources will work on, and what is outside those defined boundaries" (Munro, Ramu, & Zrymiak, 2015, p. 96). Concurrently, and as an input to the project scope, the CI Leader will work with the team and available resources to create the SIPOC diagram associated with the project scope (Appendix 3). The deliverables to pass the define stage milestone and enter the Measure stage will be the completed and agreed to SIPOC diagram and Project Charter.

Measure Stage

The objective of the measure stage will be to define the key process metrics associated with the project and complete baseline measurements from which intended improvements can be compared. In order to define and document the metrics that will be used to measure improvements, the CI Leader will brainstorm and propose potential metrics to the team and look for their input to validate the proposed, or pivot to more suitable options proposed by the team. Once established, an organized plan will be developed and executed to gather and document baseline measurements of the process in its current state. This plan will define who will be collecting the measurements, when they will be collected, how, and a documentation method. It is important to have a clear process that the entire team, and those conducting the work understand when gathering measurements. If measurements are not gathered as directed, the resulting data can be meaningless, or paint an incorrect picture of the process. If this occurs, it can jeopardize the rest of the DMAIC process. "Only when quality is [accurately] quantified, can meaningful discussion about improvement begin" (Pyzdek & Keller, 2014, p. 271).

Analyze Stage

The goal of analyze stage of the DMAIC process will be to compare baseline measurement data collected during the measure stage to the data from the same metric on closures produced using the desired continuous flow airveyor process. This will be achieved by utilizing statistical tools to show correlation between current baseline WIP processing and proposed airveyor change with samples measured immediately and after a 2-week hold time in finished good boxes. If the data analysis results in a higher degree of severity in warpage or cracking occurrence, additional work will be needed to investigate additional measures to be taken and analysis to move on to the improve stage.

Improve Stage

During the improve phase of the DMAIC process, the team will make improvements to the 83mm closure production process. These improvements will be supported by the analysis of the measurement data that prove a reduction in the severity of warpage and cracking as a result of switching to the continuous flow process. If no significant increase in the severity of warpage and cracking occurrence when comparing new continuous flow processing to the baseline current WIP process with no additional changes to the line, this will be the only improvement made to the process.

Control Stage

To finalize the DMAIC process the control phase will be completed. During this phase the new process will be verified by conducting pilot runs and taking new measurements of the key metrics and comparing them to the baseline figures. If any issues are observed during the pilot run, the DMAIC will revert back to the improve phase for additional work. It's not uncommon to observe issues during a pilot run following a process change. As stated by Pyzdek and Keller (2014, p. 585), "unanticipated problems are nearly always discovered during pilot runs and they should not be overlooked." Providing the results are favorable, the CI team will standardize the new process by documenting and controlling it through procedures, work instructions, forms, and references as necessary or required by regulatory, and statutory requirements.

Participants

All team members chosen to participate in the Six Sigma project will be area experts, capable of contributing to the successful evaluation and subsequent improvement to the 83mm WIP process. All members are knowledgeable on the topics of closure manufacturing, quality inspection requirements, metrology, and Six Sigma project team member expectations. To help keep to the established schedule for project completion, an initial meeting will be held with all team members to review the schedule and important milestones. Additionally, periodic meetings will be held to review project status.

Instrumentation and Materials

An optical comparator (Figure 2) will be used to measure the severity of warpage in concerned samples from each sample run. The optical comparator works by using a light to create a shadow of the concerned part area on the work stage. Then, using a static cross-hair on the work stage along with a joystick and coordinate measurements on the computer, the inspector is capable of measuring a dimension to a high degree of resolution. The challenge for this process as discovered during the brainstorming of the best way to measure warpage is effectively reviewing samples to qualify them as possessing warpage, and then to determine at what alignment the closure so the highest degree of warpage was measured for each closure sample. The tried and decided upon method is to place the closure on a flat surface open-side-down, then tap around the circumference of the closure, inspecting for rocking. Then, if judged to be significant, tap to find the point around the circumference where the rocking is the most extreme. At this point a mark was made on the closure to identify the pivot point for the warped closure. Each closure is then placed on the optical comparator in the same orientation as described above with the pivot line perpendicular to the measuring apparatus and a static weight placed on one side to pivot the closure, allowing the inspector to measure the area of concern.

Figure 2. Starrett HB400 Horizontal Benchtop Optical Comparator

WIP on-hand historical baseline data will be extracted from the JD Edwards (JDE) Enterprise Resource Planning (ERP) system utilized at BG-BGKY. This system is used for production planning, inventory tracking, and financial tracking, among other things. By using this system, a one-month average inventory of the 83mm WIP parts will be calculated to use as the baseline figure for this project metric.

Microsoft Excel and especially Minitab will be used for data analysis and presentation. Minitab describes itself as a comprehensive suite of statistical, data analysis, and process improvement tools. It is heavily utilized at BG-BGKY for analysis and reporting as it is incredibly user-friendly and contains a multitude of tools and features to aid in statistical data analysis. Microsoft PowerPoint will be used to generate the overall presentation of the Six Sigma project for presenting to BG-BGKY management and the thesis committee.

Threats to Validity

While brainstorming threats to validity for this project the following question was asked - What is he confidence level that the cause and effect relationship of the continuous flow process and warpage severity or cracking is not caused by some other factor? This is the main source of concern for veteran team members in changing to the continuous flow process. However, this concern is driven by past experience and tribal knowledge and no documented proof exists that warpage to harmful degree in the vein of form, fit, and function has resulted from the continuous flow processing of 83mm closures. For this reason, as part of the measure step in the DMAIC process, it will be an objective to observe if there is any such correlation between the continuous flow process and severity of warpage or cracking occurrence.

Results

Define – Project Charter

The Project Charter followed a standard format to organize and document the Project Champion, team members, project name, details and description, objective, customer definition, benefits, metrics, and indication of savings type.

The Project Champion for this improvement activity was the Plant Manager. The Project Champion's role was to provide support in form of resource delegation. As all team members had primary responsibilities outside of this project, and as with any new mandate outside of normal responsibilities, it is important that the Project Champion be a person who has the authority to redirect normal tasks when needed and express the importance of the project so that all team members feel comfort in dedicating their time and decision-making authorities to the objectives needed to complete the project in an efficient time frame.

Team members for this project served as a cross-functional representation of the areas of the facility that were needed to provide knowledge and resource allocation. These included:

- CI Leader to coordinate and organize actives, serve as the resource for the Six Sigma DMAIC process, keep focus, host meetings and conduct measurements and analysis to provide recommendations based on these analyses.
- The Engineering Manager is the authority over the injection molding processes and served to provide production line time, resource allocation, and area expertise.

- The Auxiliary Engineering Supervisor served as a resource for the auxiliary lining processes. As an internal customer to the injection molding process and susceptible to affects by any change in the current WIP process it was important to keep this person involved and informed.
- The Manufacturing Supervisor was primarily responsible for providing line time for trials and direction to production employees to keep samples organized and segregated from normal production.
- The Auxiliary Preventive Maintenance Specialist was the point person on performing any airveyor work. As airveyor routes are redirected from time to time to flow an injection molding press to a particular auxiliary line, this person was key to make sure the route was correct and the system had no issues at sample production timing.
- The Metrologist is a key member of the Quality department and served to provide recommendations at the Measurement stage of the process and direction on how to use the optical comparator measurement device.

As mentioned in the Methodology-Define section of this thesis, it is important to have a well-defined summary description of the current process and the project objective documented on the Project Charter. With that in mind, the Process Description and Project Objective defined as shown in Figure 3.

2) Process Description	83mm is processed from P58 into Ropak for a minimum 24-hour hold and then brought to CLN03 for lining instead of taking advantage of continuous flow blow over infrastructure.
3) Project Objective	The team's objective is to implement airveyor continuous flow process from P58 to CLN03 while maintaining or reducing current defect rate and lining process efficiency.

Figure 3. Project Charter - Process Description and Project Objective

The lens in which all Six Sigma projects should be viewed is through is that of the customer. Customers are segregated into two groups: internal and external customers. As the names suggest, internal customers are those inside the organization that are down-stream from currently considered process. They are those who will receive a partial or WIP product for further processing. External customers are those outside the organization that receive either a finished good product or a WIP product that is as complete as the organization can make it before sending it to the next organization for further processing. The external customer was defined on the Project Charter and is the external company the closure is sold to for use in packaging food products. The internal customer, the one that has the potential to be affected by the improvement of this project is the auxiliary lining process at CLN2303.

The savings type that will be realized through the benefits of the process improvement were defined on the Project Charter as a cost reduction through elimination in WIP inventory on hand as well as a cost avoidance in the elimination of potential safety incidents from having excess forklift traffic on the production floor. Additionally, it is worth noting that by eliminating the 24-hour WIP hold time requirement, BG-BGKY will increase its agility in responding to customer order changes.

As mentioned, the customer is kept in mind throughout the Six Sigma project. The objective is to make improvements that benefit internal and external customers. Therefore, decisions that affect the customer will be made at the improve stage of the project based on measurement data. In order to make good decisions and improvements, it is important to have accurate measurement data based on correct metrics that affect the customer(s). For the project, as a gauge by which to decide whether or not to change to the airveyor process in lieu of the 24-hour WIP process, the following metrics were decided upon and documented on the project charter:

- closure warpage
- cracked closure occurrence
- WIP closures in inventory

These metrics are explained further as well as their baselines defined below in the results sub-sections.

Define – SIPOC & Process Flowchart

The SIPOC diagram was completed during the define stage to define the scope as well as document important information related to the continuous improvement project. This was completed using the following steps as described in *The Certified Six Sigma Green Belt Handbook* (Munro, Ramu, & Zrymiak, 2015):

1. First, define the process and its boundaries (center of the diagram shown in Figure).
2. Next, identify the outputs of the process, including data, services, products, information, records, and so on.
3. For each identified output, identify all of the associated inputs.

4. Then, move on to the internal and external customers – those that receive the identified outputs.
5. Finally, move back to the supplier column to identify the internal and external suppliers for each identified input.

The resultant SIPOC is shown in appendix C and serves as an agreement of the scope of the project and a common language for all team members throughout the project. The SIPOC provides a base by which a VSM or process flowchart can be generated. For this project it was judged that a VSM would be overkill and the team opted for a process flowchart (Appendix D) to illustrate the current process and the desired resultant improvement process.

Measure – Baseline WIP Process

To measure the baseline of warpage severity and cracking occurrence for current WIP process parts two finished goods boxes were taken from current production on February 8th, 2021. One box was inspected and suspect parts measured immediately, and one box was held for two weeks and then inspected and measured to allow for observation in any increase in warpage as a result from the extra time in an enclosed environment.

Each finished goods box of 83mm closures contains 400 closures. Each closure was placed on a flat surface and tapped in four points to judge if any warpage exists (Figure 4). If judged to contain a degree of warpage out of the norm, the sample was marked at the pivot point on the circumference and identified with a sample ID and placed to the side. 39 out of 800 WIP processed closures were judged to contain a degree of warpage worth measuring at the next step. During this inspection each closure was also examined for cracking as this characteristic was also identified as a project metric. Cracking in a closure is a functional failure mode that is considered much more severe as it likely could result in a food product spoilage issue and a product recall, whereas warpage is considered a fit failure mode that can present assembly issues for the customer. Fortunately, zero occurrences of cracking were observed in the current WIP process baseline sample closures.

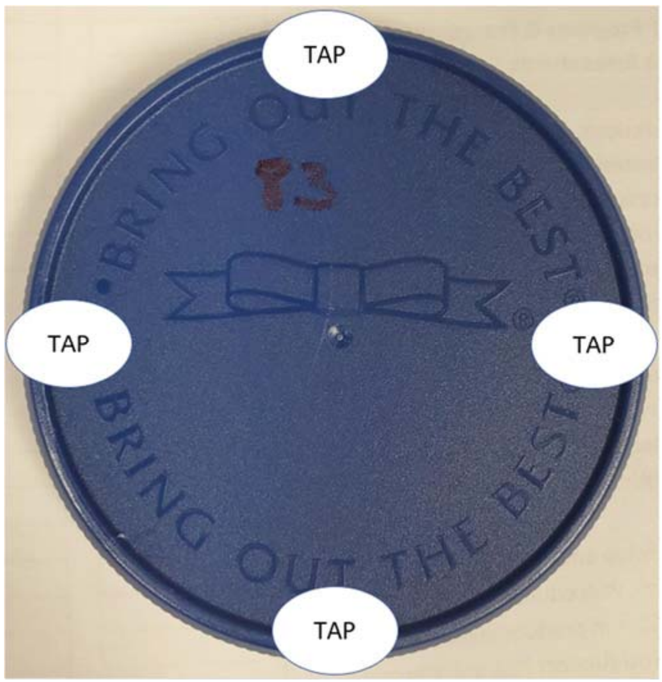


Figure 4. Tap Inspection Visual

The “suspect” samples were then placed on the optical comparator to have the degree of warpage measured to a 0.0000” precision (Figure 5). This was executed by orienting the closure so that the marked pivot point was placed at nine o’clock in relation to the person conducting the measurement. Then, a 287.204g block was placed on this marked pivot point on the circumference of the closure to apply a static weight on each closure and reduce any variability in the measurement technique. Next, the optical comparator was used to measure the gap between the flat surface and the bottom of the closure opposite the pivot point. This measurement was used to indicate the severity of warpage and served as the variable data by which analysis was completed to judge differences between the current WIP production process and proposed airveyor production process closures.

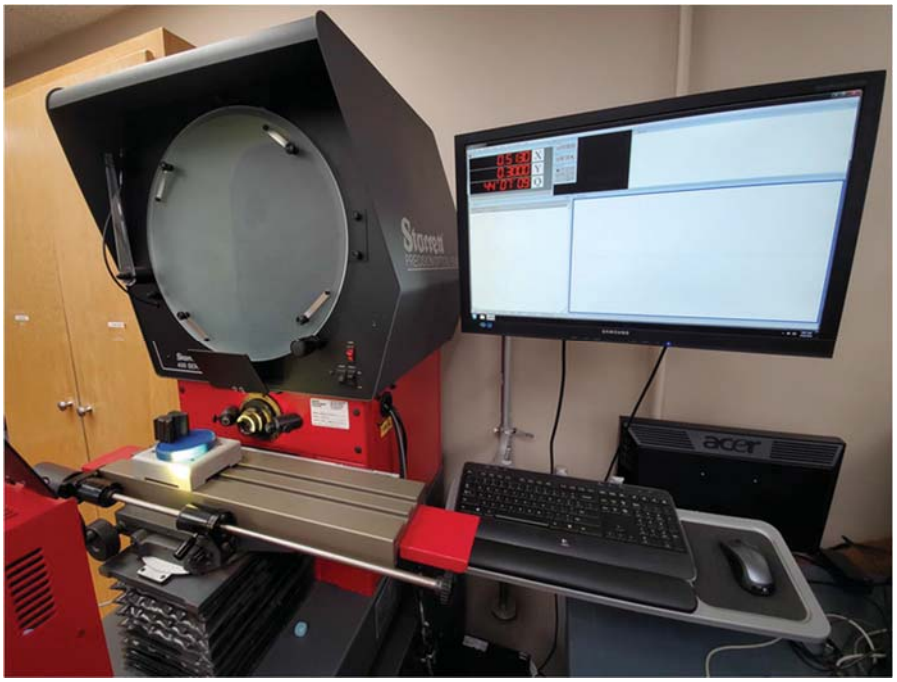


Figure 5. Optical Comparator Measurement

Measure – Airveyor Process

To collect continuous flow airveyor sample closures both the injection molding machine and the auxiliary lining line were shut down and the Auxiliary Preventive Maintenance Technician confirmed the airveyor tubes were properly routed and the injection molding machine was setup to route its WIP closures to the airveyor instead of the gaylord. Following these confirmations and checks at both processes, the injection molding line was restarted, closures were produced and airveyed over to the auxiliary lining operation where they were immediately processed into finished good boxes.

Four boxes were produced on 10/30/2020 with the original intent to inspect and measure two boxes on 11/2/2020 and two boxes 2 weeks later. However, all four of these boxes were inspected more than four months later due team member absence from the facility due to COVID-19 work-from-home requirements. These samples were judged to still be applicable as the intent of the samples was to understand a worst-case warpage condition, and the assumption, based on tribal knowledge, was that the direct processing into finished good boxes where they are tightly packed while warm from the injection molding processes and sealed will result in a higher probability and degree of warpage.

The same inspection and measurement technique as previously described for the current WIP process baseline closures were used for the sample airveyor closures. Likewise, as with the baseline samples, these were checked for cracks during the inspection and out of 1600 closures inspected, zero were found to contain cracks.

Measure – WIP Closures in Warehouse Inventory

The final metric by which this project was to be measured was the elimination of WIP closures stored in the warehouse. As previously discussed, inventory-on-hand is considered waste and reduction or elimination efforts are commonly a focus of Six Sigma projects. In order to establish a baseline for this metric, the JDE ERP system employed by BG-BGKY was used to log a 30-day history of 83mm WIP inventory-on-hand in the warehouse. A summary of the data is provided below in Figure 6. At any given time on average, 32.7 Ropak gaylords had the potential to be eliminated from warehouse inventory with the successful completion of this project.

30 Day Avg Qty Closures in WIP	384216.2
Closures Per Ropak	11750
30 Day Avg Qty Ropaks in Warehouse	32.7
Ropaks per Stack in Warehouse	3
30 Day Avg Number of Stacks in Warehouse	10.9
SqFt of Ropak Footprint (5'x5' Footprint)	25
SqFt of Space in Warehouse	272.5

Figure 6. WIP Closure Inventory 30 Day Average

Analyze

The primary analysis conducted with this project was concerned around the degree of warpage of closures from the current WIP process compared to closures produced using the new airveyor process sample run. While two other metrics in the form of cracking occurrence and warehouse inventory space utilized by WIP closure stock were put forth, these did not require in-depth analysis—only observation and documentation. To reiterate, the three sample groups analyzed included: current WIP process closures inspected and measured immediately; current WIP process closures inspected and measured after a two-week hold in finished good boxes; and desired new continuous-flow airveyor closures that were held in finished good boxes for over four-months.

The variable data captured for the suspect samples belonging to each one of these groups was the degree of warpage, measured in inches using an optical comparator. The individual measurements for each group was compared against the data in its own group, as well as the data belonging to the other two groups. When comparing the data in each individual group, the analysis involved confirmation that the data set resulted in a normal distribution and that no outliers existed. To check for normality, beyond a visual review of the data distribution using the summary report generated in Minitab, the Anderson-Darling (AD) Normality test was ran to statistically confirm normality in the data set. "The AD test starts by assuming that your data was normally distributed and then checks for lack of normality" (Khan, 2019, p. 50). The AD test, shown in the probability plot for each group in the appendix, plots the data along with a trend line, and generates the P-Value based on the data set. A P-Value above 0.05 is an indicator that the data comes from a normally distributed population. Outlier analysis for each sample group utilized the Grubbs' Test. An outlier significance level of $\alpha = 0.05$ was used to identify any outliers outside of a 5% significance level. The Minitab generated statistical reports that were used for analysis are located in Appendix E through H. A breakdown of each step of the analysis is shown in subsequent Analysis sections below and follows a standard reporting style format with some additional commentary.

Analysis – WIP Process Closures, Immediate

A sample size of $n = 21$ closures was identified during the inspection phase of the measurement process and taken to the optical comparator for measurement. The summary report for the sample group produced using Minitab shows, at first glance, a normally distributed data set and that no significant outliers exist. To confirm the normality of the data set and lack of any outliers, the AD Normality test resulted in a P-Value of 0.224, and the Grubbs' Outlier test proved there were no outliers at the 5% level of significance.

Based on this analysis, the following statement was generated to summarize the data set and qualify it for additional examination and as reputable data from which any improvement decisions can be made: The sample data set comprised of 21 current WIP process closures showed a normally distributed trend with no outliers, and therefore the mean for the sample group of 0.079448” inches of warp can be considered an accurate representation of the population, when inspected immediately.

Analysis – WIP Process Closures, 2 Week Hold

A sample size of n = 15 closures was identified during the inspection phase of the measurement process and taken to the optical comparator for measurement. The summary report for the sample group produced using Minitab shows, at first glance, a normally distributed data set and that no significant outliers exist. To confirm the normality of the data set and lack of any outliers, the AD Normality test resulted in a P-Value of 0.803, and the Grubbs’ Outlier test proved there were no outliers at the 5% level of significance.

Based on this analysis, the following statement was generated to summarize the data set and qualify it for additional examination and as reputable date from which any improvement decisions can be made: The sample data set comprised of 15 current WIP process closures showed a normally distributed trend with no outliers, and therefore the mean for the sample group of 0.082787” inches of warp can be considered an accurate representation of the population, when inspected after a 2-week hold period.

Analysis – WIP Process Closures, Combined

Analysis of the WIP process closures, inspected and measured immediately as well after a 2-week hold period showed comparable results, indicating that the additional hold time in a finished good box has little effect on the closure. To test this hypothesis, the data from the two individual sample sets were combined and the same analysis that was conducted on each independent data set was conducted on the combination data. The summary report for the combination group produced using Minitab shows, at first glance, a normally distributed data set and that no significant outliers exist. To confirm the normality of the data set and lack of any outliers, the AD Normality test resulted in a P-Value of 0.198, and the Grubbs' Outlier test proved there were no outliers at the 5% level of significance.

Based on this analysis, the following statement was generated to summarize the data set and qualify it for additional examination and as reputable data from which any improvement decisions can be made: The combination data set comprised of 36 current WIP process closures showed a normally distributed trend with no outliers, and therefore the mean for the combination group of 0.80839" inches of warp can be considered an accurate representation of the current WIP process population, independent of inspection timing. For further comparison analysis between the current WIP process and the desired airveyor process this combination data set will be used.

Analysis – Airveyor Process Closures, 4 Month Hold

An identical sample size to the combination WIP process analysis of n = 36 closures was identified during the inspection phase of the measurement process and taken to the optical comparator for measurement. The summary report for the sample group produced using Minitab shows, at first glance, a normally distributed data set and that no significant outliers exist. To confirm the normality of the data set and lack of any outliers, the AD Normality test resulted in a P-Value of 0.531, and the Grubbs' Outlier test proved there were no outliers at the 5% level of significance.

Based on this analysis, the following statement was generated to summarize the data set and qualify it for additional examination and as reputable data from which any improvement decisions can be made: The sample data set comprised of 36 desired airveyor process closures, inspected after a 4-month hold time in finished good boxes to simulate a worst-case-scenario, showed a normally distributed trend with no outliers, and therefore the mean for the sample group of 0.047153" inches of warp can be considered an accurate representation of the population.

Analysis – Comparison and Conclusion

After vetting the current WIP process combination as well as the desired airveyor data independently, the two were compared for analysis (Figure 6).

Descriptive Statistics: WIP Baseline, Blowover - 4 Months

Statistics

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
WIP Baseline	36	0	0.08084	0.00383	0.02300	0.03970	0.06237	0.07740	0.09580
Blowover - 4 Months	36	0	0.04715	0.00396	0.02376	0.00490	0.02915	0.04170	0.06625

Variable	Maximum
WIP Baseline	0.12750
Blowover - 4 Months	0.09890

Figure 7. WIP & Airveyor Descriptive Statistics

From this comparison the following statements can be made based on an identical sample size of n = 36:

- The two data sets contain an almost identical standard deviation, indicating consistency inside each data set as well as when compared to each other, which gives confidence that if the improved airveyor process is implemented, no additional variability will be observed;

- The maximum degree of warp observed on airveyor process samples is 0.0286” less than current WIP process samples;
- The degree of warp is less in airveyor process parts across all quartiles; and
- The desired airveyor process closures show on average a 41.7% reduction in warp severity.

Based on this analysis, the recommendation to make the change to the airveyor process was presented to management.

Improve

As a result of previous improvements at the facility, including airveyor networks from injection molding presses to auxiliary operations, the infrastructure for the recommended processes improvement to switch the 83mm closure from 24-hour WIP processing to a continuous flow airveyor processing method was already in place and required no additional capital or resource investment.

Control

The project has now made it to the control phase and the next steps are to work with the customer on some extended run special shipment sample to verify the results realized during the measure and analyze stages of this project and to confirm there is no issue with the closures produced from the continuous flow process in the customers manufacturing operation. If there are no issues experienced with this final step, the change will be made permanent.

Currently there exists no documentation in the form of procedures or work instructions that mandate the 24-hour hold WIP processing of 83mm closures. However, once the change has been validated through the external customer and been permanently implemented, there will be a requirement for training across all crews on the production floor as well as material handlers so that they are aware of the change point. Additionally, and as a part of this training, the contents of the batch record will be modified to reflect the continuous flow operation.

Conclusion

The goal of this project was to apply the Six Sigma methodology to improve the 83mm lined closure production method by investigating a way to eliminate the WIP hold time and instead process straight from injection molding through the auxiliary lining operation into finished goods packaging, staged and ready for shipment to the customer. However, the purpose of this project was to explore the methodology of Six Sigma, its history, its purpose, the quality pioneers whose contributions to the field have been the bedrock by which the methodology is built upon, and apply it to a real-world scenario to validate its utility. Both the goal and the purpose of this project was realized in this endeavor through the hard work and cooperation of an excellent team of experts in their trade.

Through the research conducted and the efforts put forth in this project, the researcher was able to validate the utility of the Six Sigma methodology as a continuous improvement instrument. Additionally, analysis of the quantitative data gathered on current 24-hour hold WIP process closures, as well as closures produced using the desired continuous flow airveyor process, the continuous improvement Project Leader was able to recommend changing to the desired method to the Project Champion.

Any continuous improvement philosophies including Six Sigma state that the process is never ending, and that the success from one project should be applied to similar projects through what is known by the Japanese as yokoten or sometimes referred to as a look-across. This project's scope was the 83mm lined closure, but there are other closures at Berry-BG that still utilize the 24-hour hold WIP process. Through the work of this project, the same techniques can be used to validate other closure types to qualify them for an airveyor continuous flow process. Additionally, Berry-BG is always looking for ways to improve its measurement techniques and investigation methods to gather additional data to make an even more informed decision. Some of these in development at the time of this project is the implementation of a coordinate measurement machine (CMM) and temperature studies using data loggers. As these and other tools are developed and implemented at Berry-BG, future projects can utilize them, as well as past project such as this can be revisited to confirm the results.

Appendix

Appendix A — Project Feasibility Screening

#	Project Approval Key Criteria	Yes	No	Evidence
1	In-line with strategy	✓		Process/product improvement in line with Quality Vision Statement (CORPSOP-0226) Ongoing automation initiative Reduce costs and safety incident potential
2	Significant impact (customer and/or $s)	✓		P58 Internal customers CL03 auxiliary lining Eliminates wait time for gaylord change Forklift drivers Eliminates the need to move gaylords from P58 to 24-hour hold area and from hold area to CL03 Plant floor workers Eliminates safety risk of this forklift traffic Berry Global (both Bowling Green facility and Corporate as a whole) Potential reduction in scrap loss while running during gaylord changeover Lost production time elimination through continuous flow implementation External Customers Increases Berry's agility to respond to changes in customer orders Potential future price savings as a result of cost reduction to Berry
3	Committed "Sponsor"	✓		Plant Manager is project sponsor and has the authority to allocate resources for completing projects and to remove roadblocks that may arise.
4	Right team (right members, sufficient dedication)	✓		Auxiliary area Supervisor Metrologist Manufacturing Supervisor Engineering/Tooling Manager
5	Existing process with many occurrences	✓		Existing process of gaylord/24-hour hold Infrastructure in place to airvey closures from molding to auxiliary process
6	Clear process boundaries (start/end)	✓		MI2358 & CLN2303

7	Customers are identified and their needs can be understood	✓		See #2
8	Data available or easy to obtain	✓		Potential metric data that will need to be collected and how it can be collected Scrap quantity Can be measured by placing scrap gaylord at CLN03 Scrap cost Can be calculated based on quantity and cost info from JDE Scrap loss at MI Ropak change timing Collect the quantity of overflow by not turning off MI during Ropak change Production loss at Aux Ropak change timing Time the time it takes to change Ropak at CLN03 and figure how many parts we make during that time. Get with Finance to learn our sales price per part on 83mm Warp/crack of base airveyor operation (i.e., no cooling counter measures) Run X boxes Inspect half of X boxes immediately for cracks/warpage Let half of X sit for N number of days and then inspect for cracks/warpage
9	Chronic known problems/defects	✓		Cracks and/or warpage
10	The project is not the implementation of a known solution	✓		While the transition from the manual 24-hr WIP process to the airveyor continuous flow is a known solution, the actions needed to counter the warpage and cracking we anticipate is not yet known, if at all possible. This project will determine that.
11	Feasible with the time and resources available	✓		Feasible, but the 83mm mold will be pulled near the end of October, 2020 to be refurbished. It would be nice to gather baseline measurements prior to this so we can understand if the refurbished mold has any effect on the airveyor continuous process flow.
12	Not in conflict with other existing	✓		On the contrary, another CI project is underway to improve color loss for this

	initiatives			product. A potential source for color loss is the product loss at MI during Ropak change. If we eliminate this source as a result of this project, it will compliment the results of the other project.

Appendix B — Project Charter

CI Project Charter

Business Unit	Consumer Packaging Division		
Site/Location	Bowling Green, KY		
Project/Event Start Date	1-Oct-20	**Tgt Completion Date:**	1-Apr-21
Project Champion	<Hidden>	Title/Position:	Plant Manager
CI Lead	Wes Bozarth	Title/Position:	QE/CI Coordinator
Team Members	<Hidden>	Title/Position:	Auxiliary PM Spec.
	<Hidden>	Title/Position:	Engineering Mgr
	<Hidden>	Title/Position:	Metrologist
	<Hidden>	Title/Position:	Auxiliary Eng Supv
	<Hidden>	Title/Position:	Mfg Supv

Element	Description	Details
1) Project/Event Name	P58/CLN03 83mm Blow Over	Implement blow over of 83mm closure while minimizing warpage/cracking as a result of the continuous flow process
2) Process Description	83mm is processed from P58 into Ropak for a minimum 24-hour hold and then brought to CLN03 for lining instead of taking advantage of continuous flow blow over infrastructure.	
3) Project Objective	The team's objective is to implement airveyor continuous flow process from P58 to CLN03 while maintaining or reducing current defect rate and lining process efficiency.	
4) Customer	The external customer that will benefit from this improvement is <Hidden>.	
5) Process Benefits	Elimination of WIP, reduced process time, added agility to meet sudden demand changes by our customers.	

6) Project Metrics/Cost Improvement	Metric	Baseline	Target
	Warpage	.080" Mean @ ≥ 2 Weeks Hold Time	Severity ≤ Baseline
	Cracked Closure Occurrence	0	Occurrence ≤ Baseline
	WIP Closures in Inventory	32.7 Ropaks	0

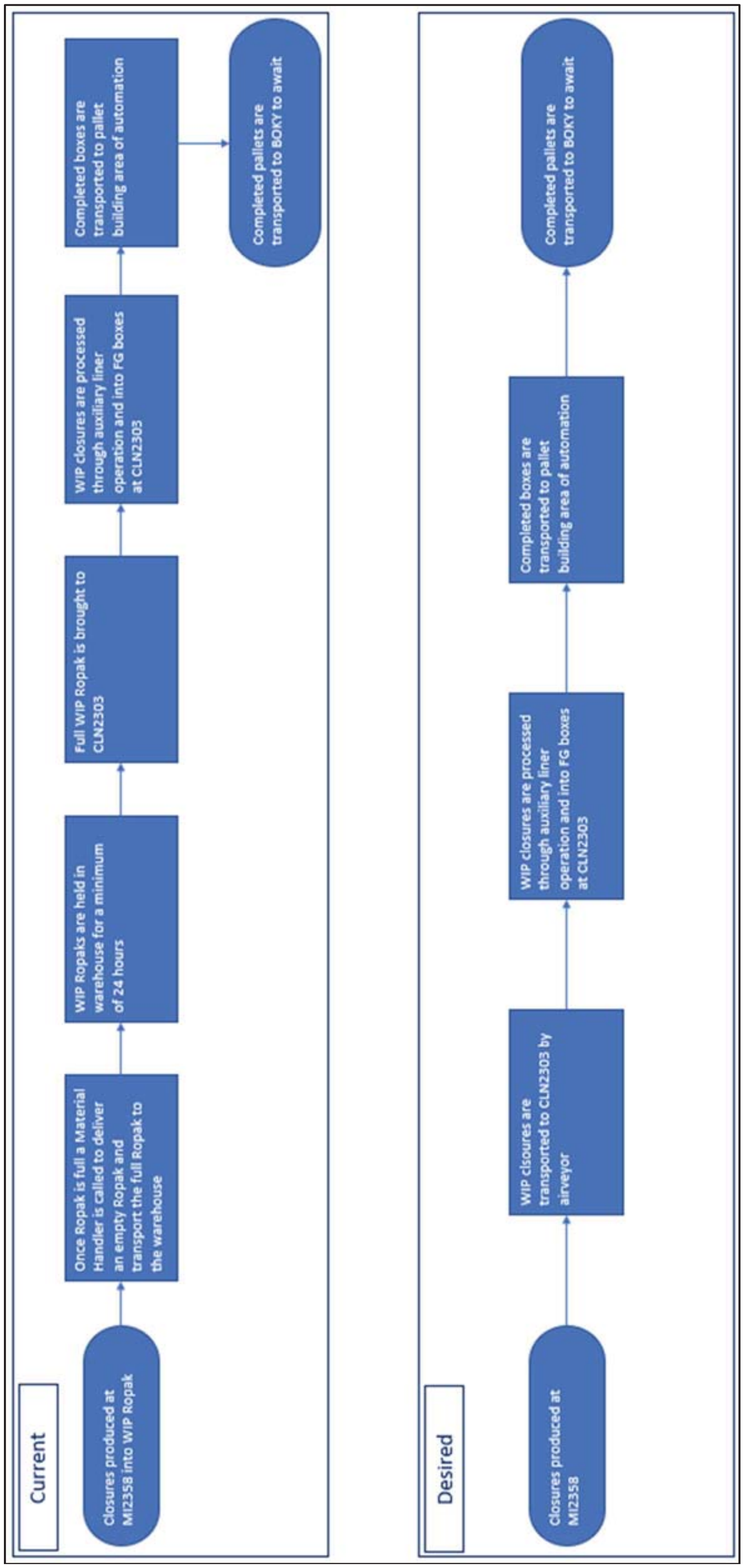
7) Savings Type	Cost Reduction	Wip / Inventory Reduction	Cost Avoidance	Cash Flow	Labor	Incremental Sales

Appendix C — SIPOC

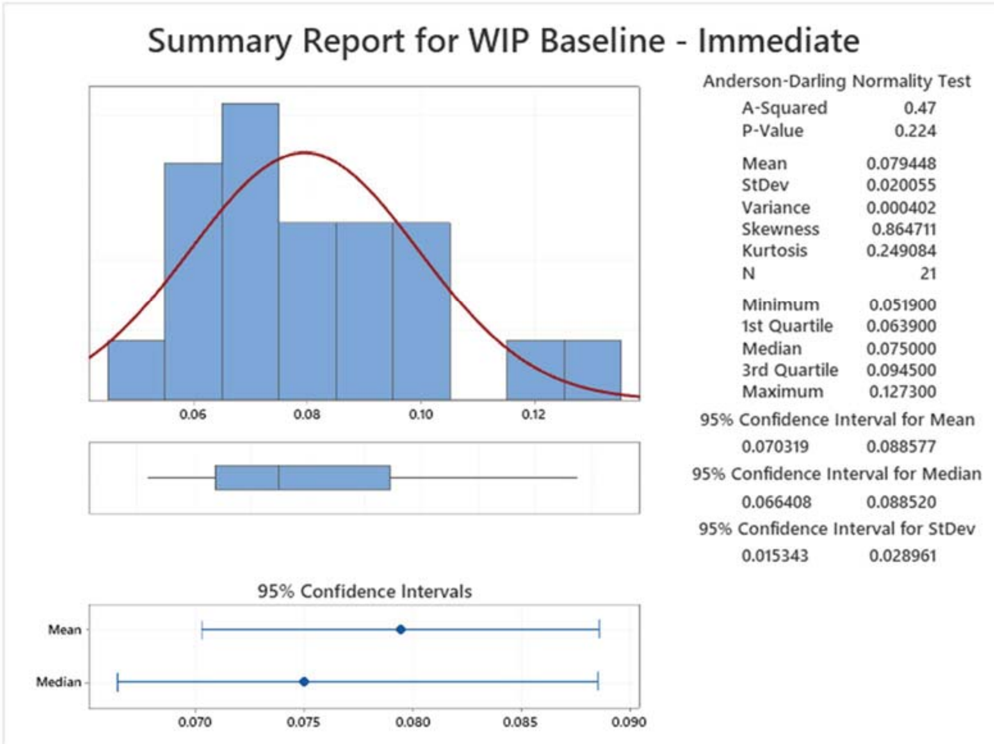
SIPOC
(Suppliers, Inputs, Process, Outputs, Customers)

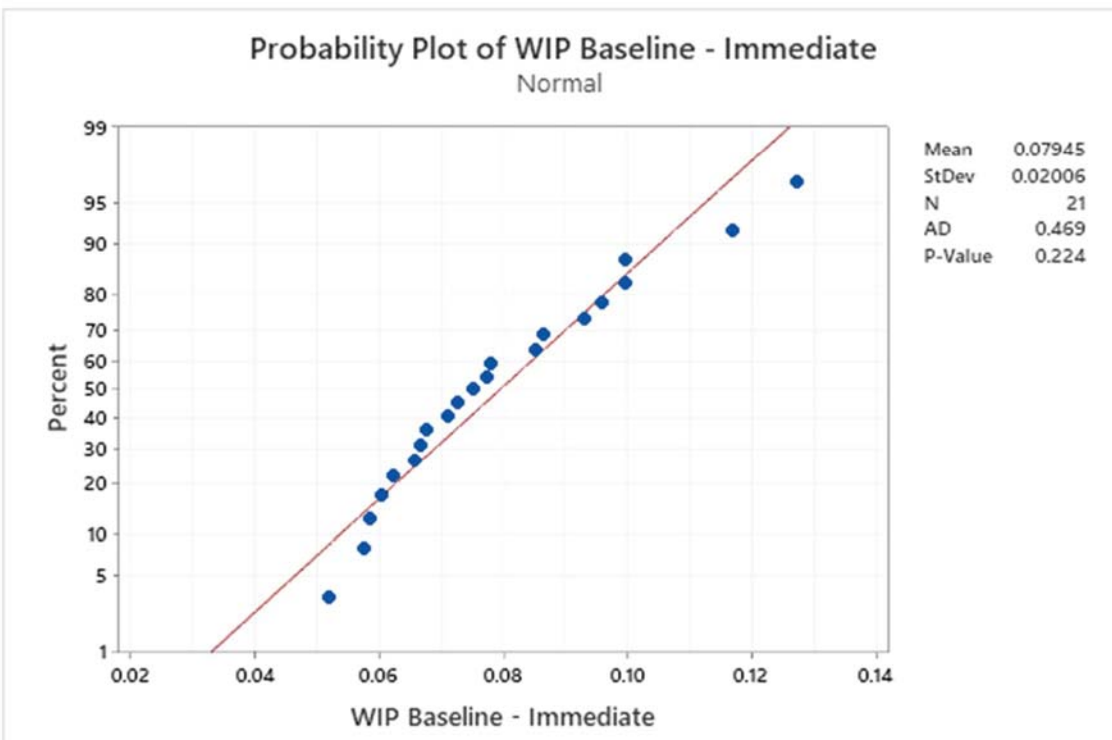
Suppliers	Inputs	Process	Outputs	Customers
Providers of the required inputs / resources to ensure the process executes as planned.	Resources required by the process to obtain the intended output.	Top-level description of activity.	Deliverables from the process. Note: Deliverables can be hardware, software, systems, services, data, information, etc.	Any organization that receives an output or deliverable from the process. Note: Can also capture systems/databases that receive outputs, information, data, etc.
Resin – <Hidden>	426546 Resin } WIP } FG	**Input boundaries** **Receipt of Raw Materials** ↓ **Process being reviewed** **83mm Closure Production** ↓ **Output boundaries** **Transfer of FG pallets to BOKY**	FG 83mm Closure	<Hidden>
Color – <Hidden>	1568669 Color		Batch Record	
Liner – <Hidden>	522326 Liner		• 1578447 WIP	
			• 1579982 FG	
	WIP Batch Record			
	• Traveler			
	• Line Clearance Checklist			
	• Injection First Shot Sheet			
	• OP & QA Inspection Form			
	FG Batch Record			
	• Traveler			
	• Line Clearance Checklist			
	• Camera Reject Verification			
	• OP & QA Inspection Form			
	• WIP & Liner Traceability Labels			

Appendix D — Process Flowchart



Appendix E — WIP Process Closures, Immediate





Outlier Test: WIP Baseline - Immediate

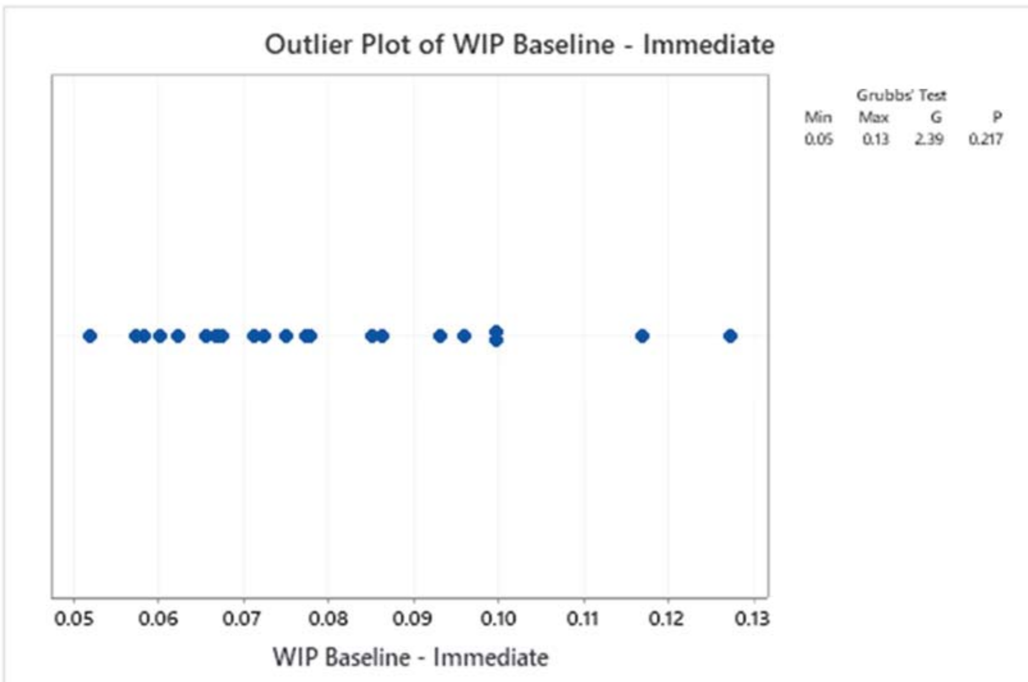
Method

Null hypothesis	All data values come from the same normal population
Alternative hypothesis	Smallest or largest data value is an outlier
Significance level	α = 0.05

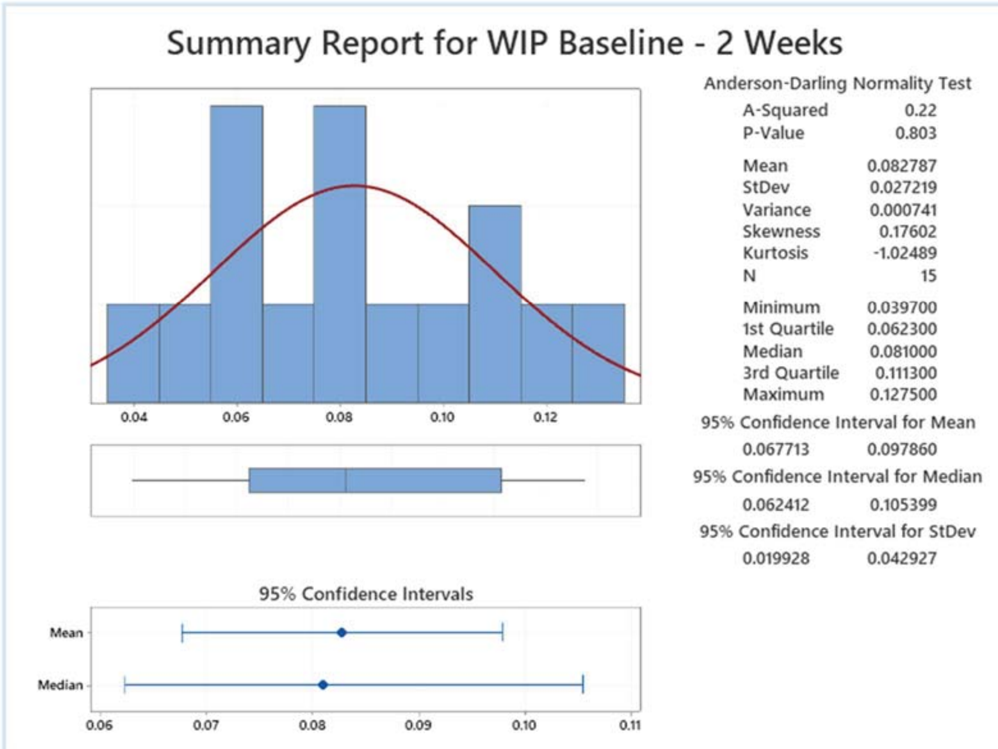
Grubbs' Test

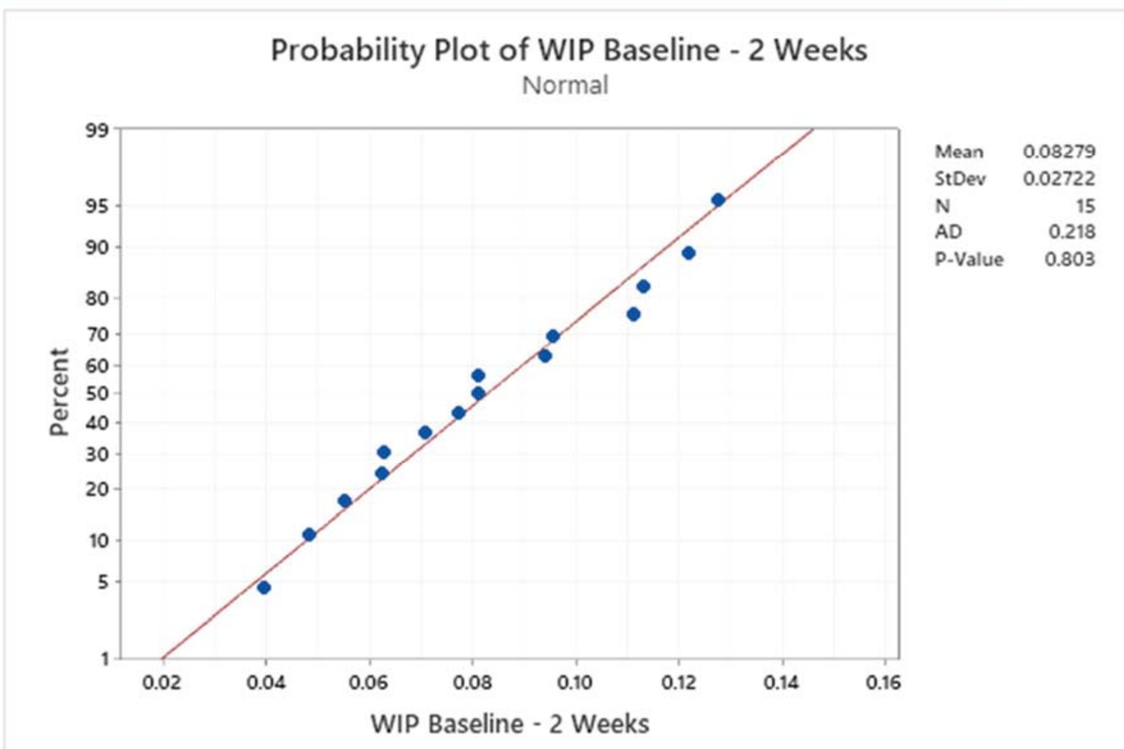
Variable	N	Mean	StDev	Min	Max	G	P
WIP Baseline - Immediate	21	0.07945	0.02006	0.05190	0.12730	2.39	0.217

* NOTE * No outlier at the 5% level of significance



Appendix F — WIP Process Closures, 2 Week Hold





Outlier Test: WIP Baseline - 2 Weeks

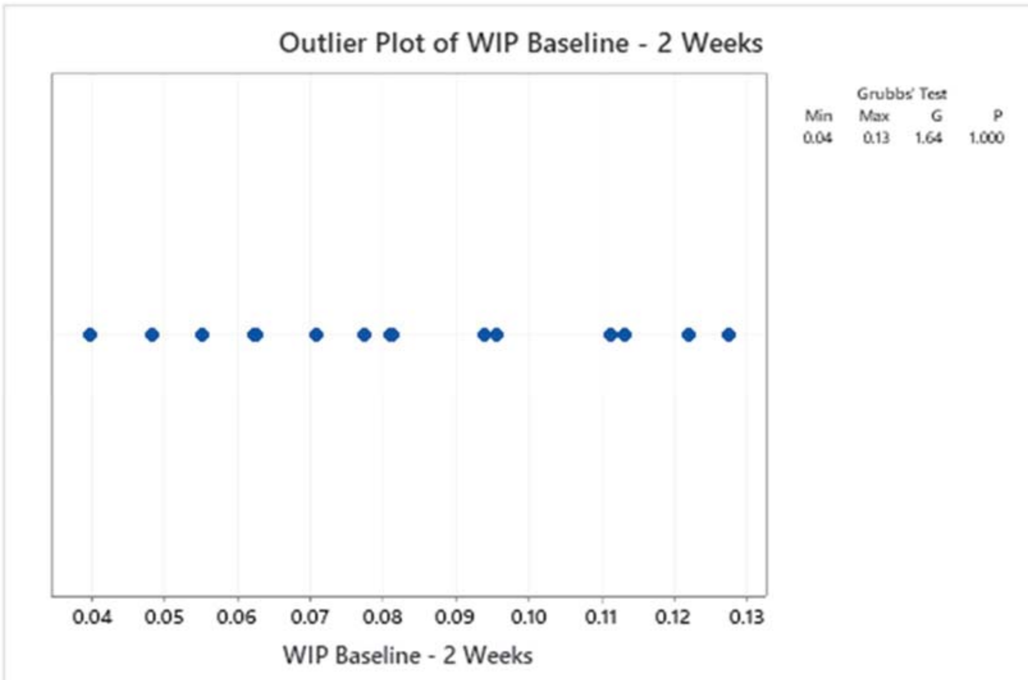
Method

Null hypothesis	All data values come from the same normal population
Alternative hypothesis	Smallest or largest data value is an outlier
Significance level	α = 0.05

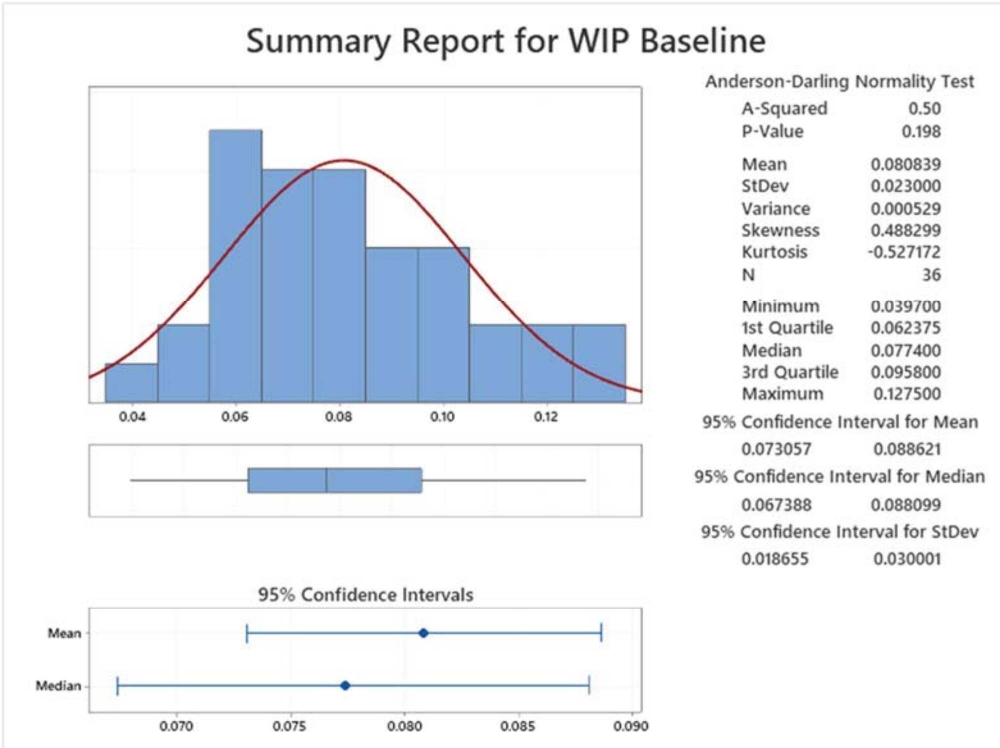
Grubbs' Test

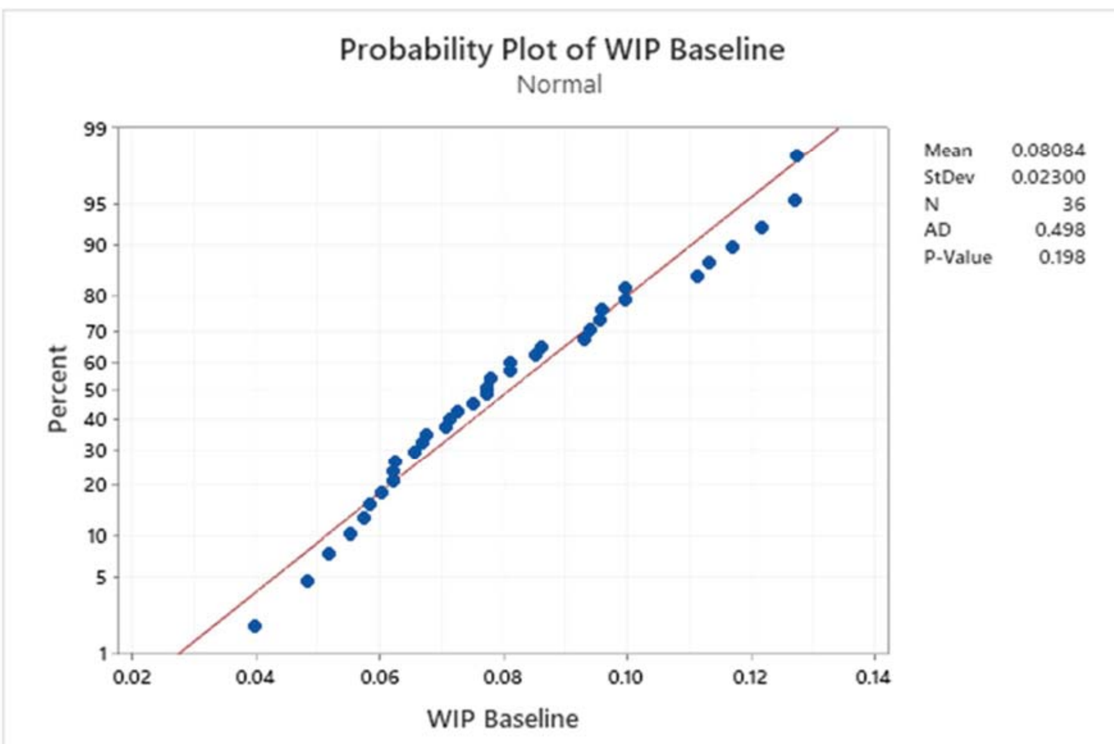
Variable	N	Mean	StDev	Min	Max	G	P
WIP Baseline - 2 Weeks	15	0.08279	0.02722	0.03970	0.12750	1.64	1.000

* NOTE * No outlier at the 5% level of significance



Appendix G — WIP Process Closures, Combined





Outlier Test: WIP Baseline

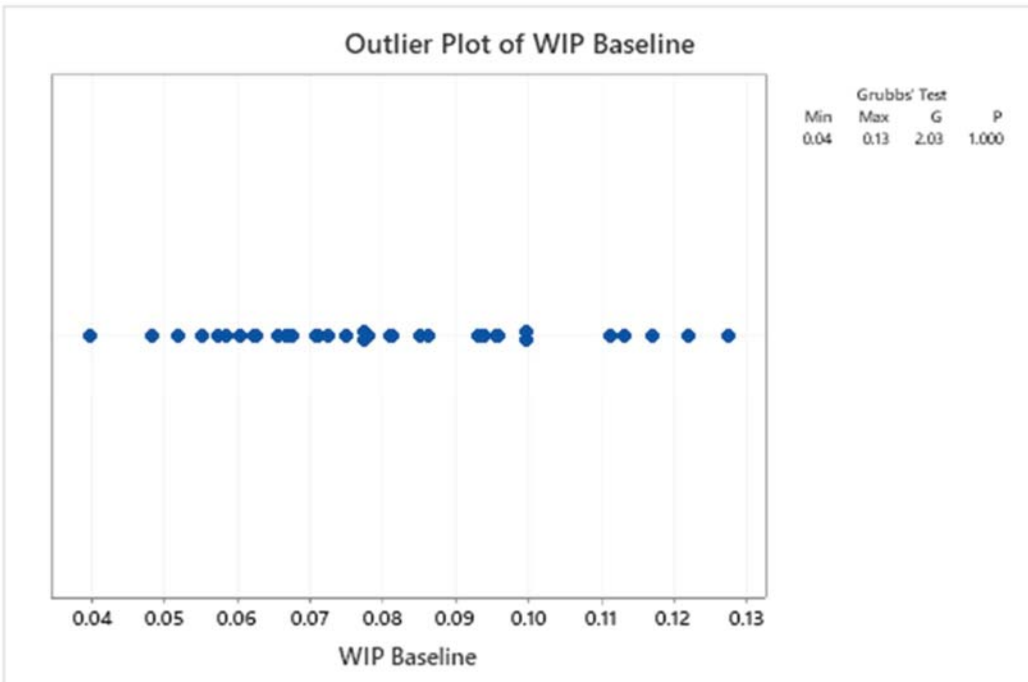
Method

Null hypothesis	All data values come from the same normal population
Alternative hypothesis	Smallest or largest data value is an outlier
Significance level	α = 0.05

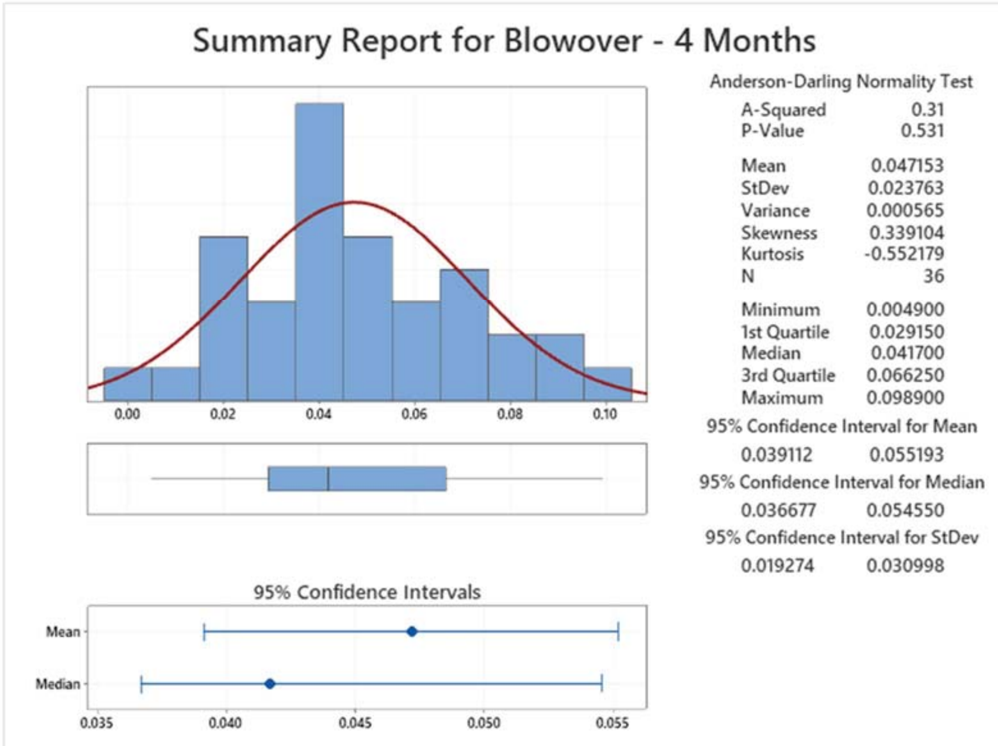
Grubbs' Test

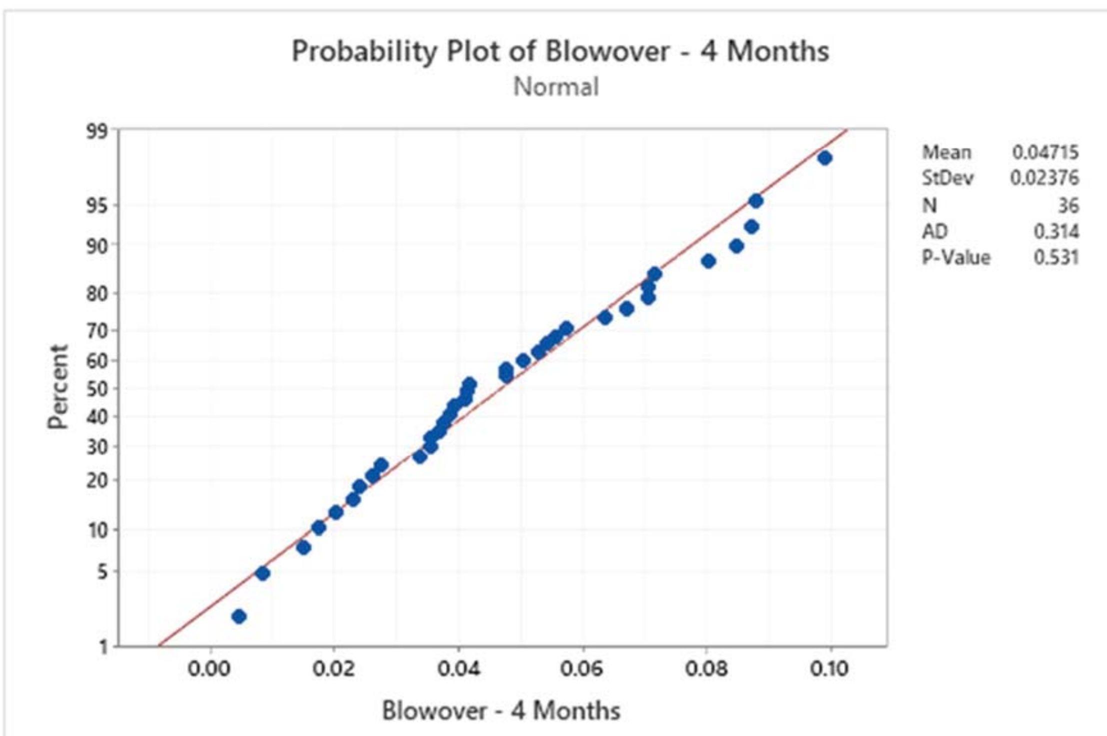
Variable	N	Mean	StDev	Min	Max	G	P
WIP Baseline	36	0.08084	0.02300	0.03970	0.12750	2.03	1.000

* NOTE * No outlier at the 5% level of significance



Appendix H — Airveyor Process Closures, 4 Month Hold





Outlier Test: Blowover - 4 Months

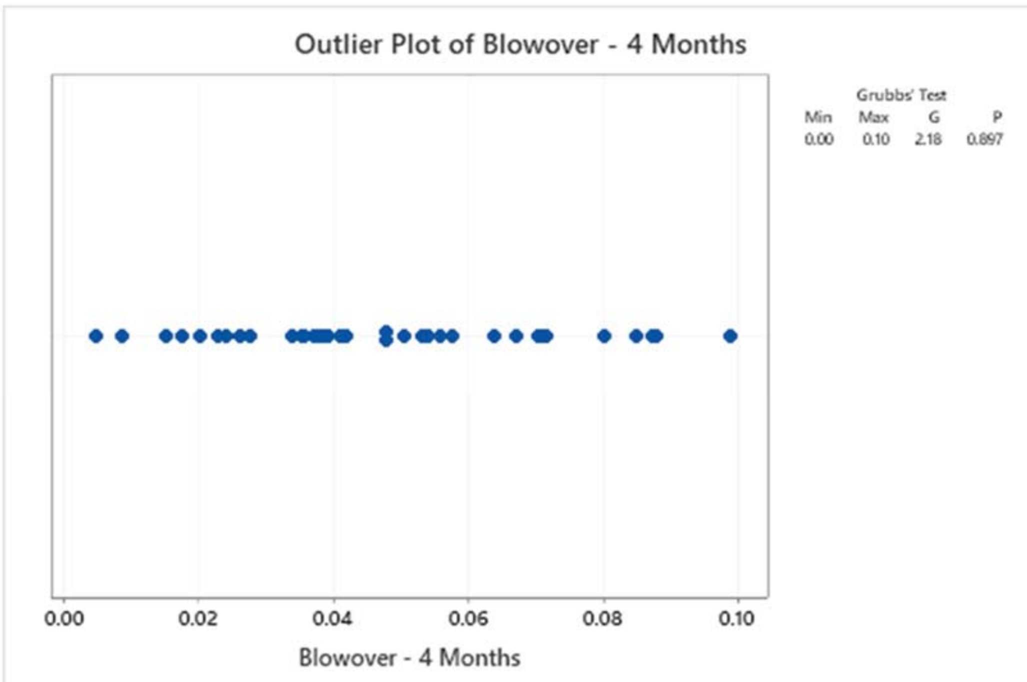
Method

Null hypothesis	All data values come from the same normal population
Alternative hypothesis	Smallest or largest data value is an outlier
Significance level	α = 0.05

Grubbs' Test

Variable	N	Mean	StDev	Min	Max	G	P
Blowover - 4 Months	36	0.04715	0.02376	0.00490	0.09890	2.18	0.897

* NOTE * No outlier at the 5% level of significance



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