A STUDY INTO THE PRODUCTION EFFICIENCY OF CAL POLY CHOCOLATES

By

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ABSTRACT

Senior Project Title: A study into the production efficiency of Cal Poly Chocolates

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Abstract

The project objective was to: identify ways to reduce the production cost of Cal Poly Chocolates. The project was executed through the DMAIC approach, a data driven improvement cycle. Using several industrial engineering tools, 6 improvement opportunities were found. Three project deliverables were created and three process changes were recommended. The total annual savings, if recommendations are implemented, sum to $1700.

ACKNOWLEDGEMENTS

It is important to recognize the support provide by my technical advisor, Professor Karen Bangs. Karen provided great technical support and guidance, which helped approach several project issues. Lead Operator Julia Fleming and Operating Manager Molly Lear, also played a key part in this project. Both kept constant communication and helped me understand the CP Chocolates business.

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Introduction

Cal Poly chocolates is a student run business started in the year 2000 as part of Cal Poly's Food Science & Nutrition Department [1]. It is supervised by Food Science and Nutrition Department Professor Tom Neuhaus, in an effort to further follow Cal Poly's philosophy, "Learn By Doing" [8]. Through this enterprise project students, get to develop, create, package and market chocolate products [1]. All Cal Poly Chocolates are currently fair trade products. 'Fair trade products' is a term used for an ethical movement, whose goal is to help producers in developing countries get: a fair price, reduce poverty, provide for the ethical treatment of workers and farmers, and promote environmentally sustainable practices [3]. The main mission of the food production program is to, supplement the student's curriculum with hand on learning and practical experience [1]. However, even though it is a student learning program, it still aims to make profit. The business has grown to about $40,000 in annual sales [8].

Ever since production moved to a new facility on the Cal Poly Campus, not many studies have been done to improve efficiency. This is when an opportunity was found with the Operations Manager and a problem statement was created. The problem statement is:

- the operating manager is looking for ways to reduce production cost.

Current process wastes and inefficiencies will be identified. The objective will be reached through an engineering DMAIC process, centered around data. Data will be collected through time studies, work measurements, worker and product flow. Historical data such as old inventory files, and standard operating procedures will also be collected. The output of the project will be a summary of recommendations to: reduce cost, improve capacity and flow.

Background

The purpose of the background is to describe the current state of the facility. Most of this information, has been derived through observation. Currently, the Cal Poly Chocolate facility is run by 7 student operators. Chocolates are produced only three days of the week:

- Tuesdays - Chocolates are prepared melted in an oven.
- Wednesdays – Chocolates are processed into their final bar form.
- Thursday – Bars of chocolate are packaged with proper wrappers.

8 different chocolate flavors are produced, with dark chocolate and milk chocolate being the most popular. The way production is sequenced is, whichever flavor is lowest in inventory, will get produced that week. The chocolates have a 1-year shelf life and are stored in a temperature control room until they are shipped. Customers know this is a student run business and therefore do not place demand, instead they take whatever was made. Currently, the Operating Manager has been in charge for about 10 months. There was not a great transfer of information from the previous manager, so there has been a big learning curve.

The current production process starts on Tuesday with the setup of tempering machines and heating of chocolates into an oven. It is important to recognize that CP Chocolates is provided with premade chocolate bits that come in 25 pound bags. This means they do not process from the raw material – cocoa, which most chocolate corporations do. CP Chocolates simply mixes the purchased chocolate with their own ingredients. The full production process is discussed in greater detail in the Measure section of the report.

Literature Review

In order to better understand the background of this problem, research was done on common chocolate manufacturing practices. Keep in mind that CP Chocolates is not like most companies, since they do not start from raw material. Most chocolate manufacturers have 3 main steps. The first step consists of roasting the cocoa beans, in this process the outer shell of the beans is removed, and the inner cocoa bean meat is broken into small pieces called "cocoa nibs" [8]. Grinding is the second process in which cocoa nibs are grounded into "cocoa liquor" [8]. The cocoa liquor is then mixed with cocoa butter and sugar [8]. The blend is further refined to bring particle size of the added milk and sugar down, until desired finesses is reached [8]. After blending is complete, the cocoa liquor is cooled and hardened into a desired shape [8].

The research then became focused on Lean Management tools, which are at the heart of process engineering. Several Lean tools can be used to measure and analyze production processes. One tool is Value Stream Mapping, which helps to map the current state. VSM reveals obvious and hidden wastes that affects the productivity and add no value to the product [6]. These include unnecessary queue time, travel time, and waiting time. With the combination of time studies, which is used to time specific work tasks, further identification of waste can be found. Time studies specifically, can help identify set up and operating time improvements. Once time studies are performed, multiples metrics can be used to identify bottlenecks. Cycle time which is machine time plus man time, can be used to find the time for each workstation [9]. Takt time which is time available (per shift) divided by the demand (per shift) can be used to compare against cycle time [8]. If Cycle Time (for any workstation) > Takt time, then the workstation will not keep up with demand [8]. The workstation with the highest cycle time will be the biggest bottleneck. Along with time studies, motion studies can be used to identify worker motions that are uncomfortable, inefficient, or unnecessary [4]. The motions that are not needed can be eliminated, also known as non-value added activities [4].

Simulation is also another useful tool that can help improve process flow and reduce manufacturing lead time. There are multiple ways to create a simulation model, such as with SIMIO or excel software. SIMIO models are considered more dynamic models, since the software is specifically developed for simulation, whereas excel models are typically more static. As stated by a scholarly article, “Simulation proves to be an exceptional tool in such a scenario and efficiently provide an estimation of all the performance parameters” [4]. Ultimately, Lean tools and simulation models can help analyze and derive at an optimal process flow.

Design

The design process was performed with the help of the DMAIC methodology. DMAIC is “a data-driven quality strategy used to improve processes. It is an integral part of a Six Sigma initiative, but in general can be implemented as a standalone quality improvement procedure or as part of other process improvement initiatives such as lean”. In this project, DMAIC was paired primarily with Lean and less with Six Sigma tools. Each letter of the DMAIC stands for a different project stage:

- Define phase: Define the project goals and customer (internal and external) deliverables [7].
- Measure phase: Measure the process to determine current performance; quantify the problem [7].
- Analyze phase: Analyze and determine the root cause(s) of the defects [7].
- Improve phase: Improve the process by eliminating defects [7].
- Control phase: Control future process performance [7].

The define, measured, analyze, and improve phases will be covered in the Define section.

1. Define:

The define phase and project scope was identified after an interview with the plant’s operation manager, Molly Lear. The problem statement or opportunity was to, reduce production cost. With this problem statement in mind, the project scope was defined. The focus of the project should be on the production process and no other aspects of the business such as inventory control, ordering process, marketing strategy, etc.

It is also important to know who this project will impact. The main stakeholders of this project are the customers, the operation manager, and the student operators. The results of the analysis can be seen below.

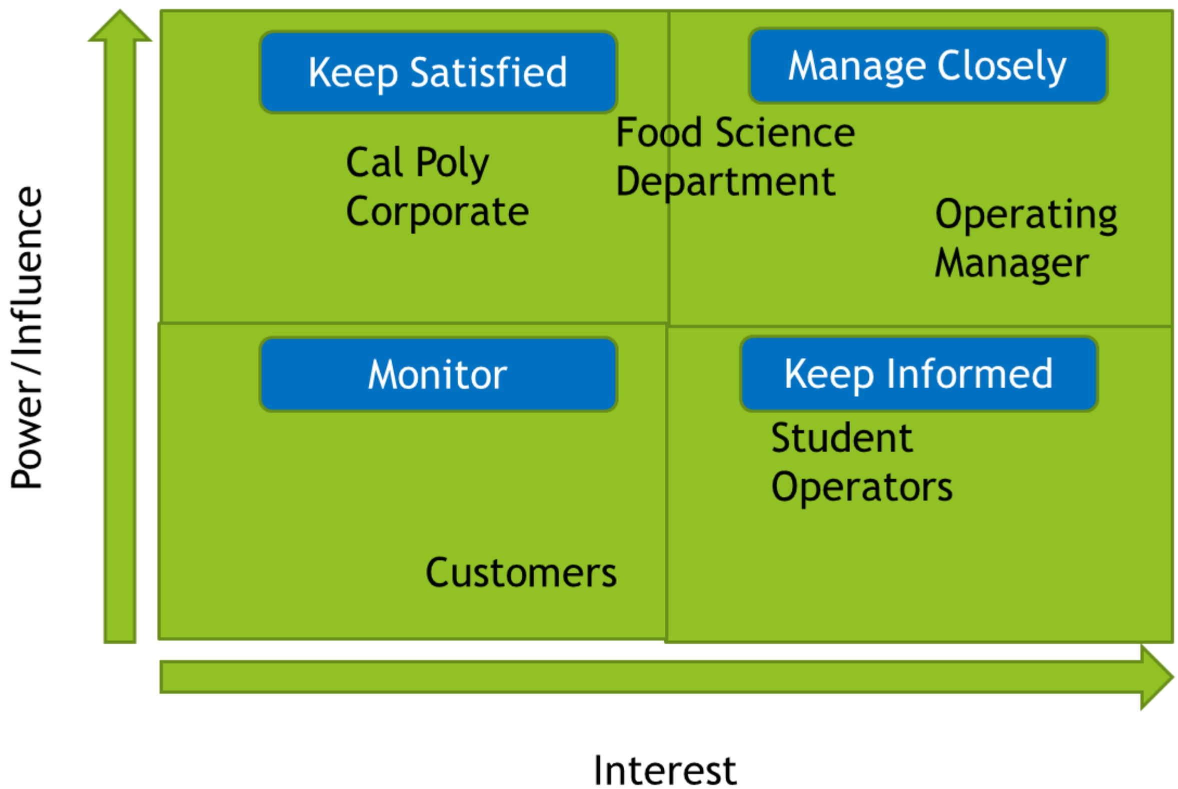
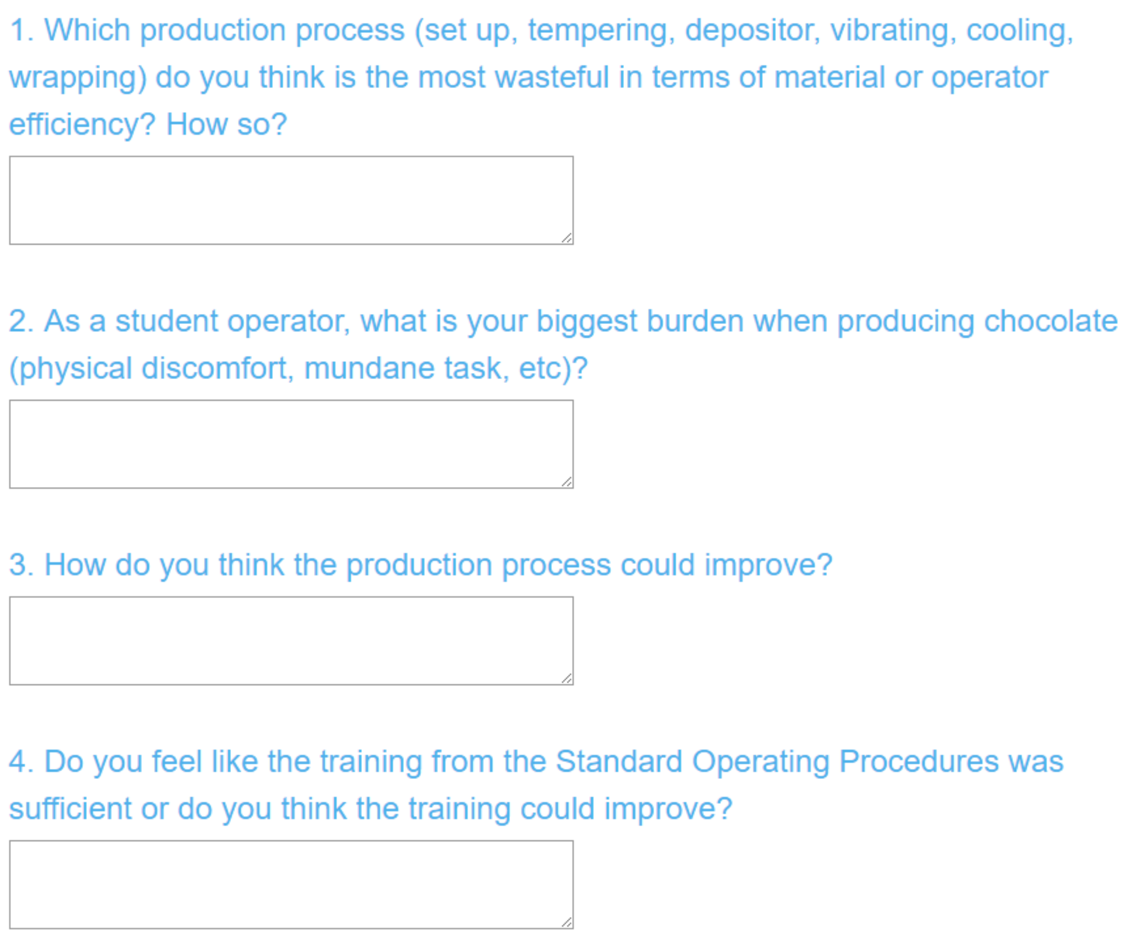


Figure 1: Stakeholder analysis chart.

The customers have low power, since they do not have the capability to make a business decision. However, customers can influence a business since they have buying capabilities. Project interest is low, since a reduction in production will not likely affect the selling price. CP Chocolates is a student enterprise business, so a reduction in selling price is less likely to occur in this type of business. If anything, a reduction in production cost increases CP Chocolate's profit, which the customer will not see. The power that the operations manager has on the business is high, she has the ability to implement suggestions. The interest of the operations manager is medium, production change is not likely to affect the way she completes her job. However, the project can directly impact the success of the business, which she is responsible for. On the other hand, student operators have low power, but have high interest from the outcome of this project. A new process change, will affect the way they do their job, whether it is changing a standard operating procedure on a machine, or the process sequence. Ultimately, student workers could leave the facility earlier due to lead time reduction. The food science department and Cal Poly corporation, also have an interest in the project. However, they do not work under the CP Chocolate business so is not as high. Their power is high so therefore we must keep them satisfied with the results of the project.

In order to closely manage the operating manager, weekly meetings were set. In these meeting questions compiled throughout the week were asked. Ultimately this helped to understand the small details of the business. Regular communication with student operators was also maintained. Each time the plant was visited, questions were asked about the process. The lead operator was open to communication outside working hours and was contacted several times. A survey was also held at the beginning of the project to gain insight into the student operator experience and where they saw potential production problems. Four questions were asked in the survey, which is found below.



1. Which production process (set up, tempering, depositor, vibrating, cooling, wrapping) do you think is the most wasteful in terms of material or operator efficiency? How so?

2. As a student operator, what is your biggest burden when producing chocolate (physical discomfort, mundane task, etc)?

3. How do you think the production process could improve?

4. Do you feel like the training from the Standard Operating Procedures was sufficient or do you think the training could improve?

Figure 2: Operator survey.

The survey was performed with the use of survey monkey, which was an easy online tool to use. With the survey responses in mind, a smoother transition into the measure phase was possible.

2. Measure:

Identifying the current process performance, was the goal of the measure phase. Time studies were performed on 2 full production runs to measure the process. In total about 18 hours were spent observing the process. 30 different work elements or processes were identified. A process flowchart of the current state was created to help visualize the flow, which can be found in the appendix section as figure 3. The figure was too large to fit in this part of the report.

The main manufacturing process are:

Day 1:

- 1 operator present
    - Mixing station Prep: 20lbs bits of hardened chocolate are taken out a 25lbs bags and placed in mixing containers. The other 5lbs get mixed the next day. Five total bags are used to fill five containers.
    - Overnight Oven Melting: The 5 containers are melted in an oven, overnight.

Day 2:

- 7 operators present
    - Mold prep: The operator wipes each row of trays with a cloth, to get out any unnecessary water spots that might be present. There are 60 molds in the whole rack.
    - Tempering machine: Chocolate must be mixed properly before being inserted to the depositor. Chocolate is heated and turns into a smooth liquid solution, with the help of a rotational wheel. Currently there are three tempering machines in the facility and 1 operator helps the mixing process simultaneously.
    - Depositor machine: Deposits various amounts of melted chocolate into a rectangular shaped mold. There is only 1 depositor machine in the facility.
    - Vibrating machine: Removes unnecessary bubbles from the bars that are currently in the molds.
    - Fridge Cooling: The molds are cooled for roughly 30-45 minutes.
    - Unmold: The chocolate bars are removed from the molds.

Day 3:

- 4 operators present
  - Flow wrap: The flow wrapping machine wraps every bar at a constant rate. Each wrapper has a design and nutritional information about the product.

Operators currently behave in a dynamic manner and move around from workstation to workstation. If there is an issue with one workstation, they will move to help troubleshoot. Once one process is finished the operators move to the workstation that is still being processed.

After time studies were completed and times of each process was identified, several metrics were calculated. A summary of the metrics can be found in figure 4, found below. In terms of efficiency 18 of the processes were non-value added, whereas 12 of them were value added. The equation used was $efficiency = \frac{value\ added\ time}{value\ added\ time\ +\ Non{-}value\ added\ time}$. The total value added time summed to 1312.4 minutes, where as non-value added was 1038.7 minutes, thus the efficiency results in 55.8%.

The takt time was another measure taken which is calculated by $takt\ time = \frac{time\ available\ in\ hrs}{Yearly\ Demand\ in\ \#\ bars}$. Takt time like mentioned earlier gives, the required rate at which one piece of unit should be produced to keep up with demand. The time available per week is about 80.25 hours. The first day, 1 worker spends 1.5 hours, the second day 7 workers spend 6.5 hours, the third day 4 workers spend 3 hours. CP Chocolates runs production about 27 weeks in a year which gives 1593 available hours / year. The 'demand' given by the number of bars they sold in the previous year is 52759. Thus, takt time after converting units to seconds comes to 108.7.

Currently it takes roughly 1620 minutes to produce 1170 bars of chocolate on 1 run. All bars are produced at the end of the run, therefore to get the proper cycle time in this scenario you divide by throughput in 1 run, $cyle\ time = \frac{Manufacturing\ Lead\ Time\ of\ 1\ run}{Throughput\ for\ 1\ run}$ gives 83.1 seconds. Since cycle time < takt time, the production is keeping up with demand. Currently every bar of chocolate produced is sold, which is why the finished good inventory comes out to 0. This means that if CP Chocolates decided to produce more often, they would earn additional revenue.

After receiving historical data from the operating manager on 14 previous runs, the average yield rate was calculated to be 93.2 %. This is considered high, an indicator that the chocolate process has good quality control. Currently the process has several quality checks where they ensure the bars and parts of the process are within specification. Quality checks include: taking weight of chocolate filled molds, taste check, and aesthetic inspection for any bloom (dusty particles). The wrapper yield rate was also calculated after observation. With the use of the flow wrapper machine, the bars are wrapped into their final form. On two runs that were observed, the yield rate was calculated to be 91.5%. A summary of all the metrics mentioned can be found in figure 4.

Metric Chart			
Efficiency	Value Added	Non-Value Added	.558
	1312.398	1038.72	
Takt Time (sec)	Time Available yearly (hrs.)	Yearly Demand (#bars)	108.7
	1593	52759	
Cycle Time (sec)	Manufacturing Lead Time (mins)	Throughput (#bars)	83.1
	1620	1170	
Finish good inventory	Made	Sold	0
	52759	52759	

Yield Rate Chocolate	93.2%		
Yield Rate Wrappers	91.5%		

Figure 4: Current state metrics

Additionally, the cycle time for each main process was identified. Like mentioned before, cycle time per process was calculated by total time spent in that work station during 1 run, divided by throughput for 1 run. Keep in mind some processes are machine based, whereas the others are human related. The main processes are chocolate prep, oven processing, tempering, mold prep, depositor prep, vibrating table, fridge cooling, unmolding, flow wrapper.

- Human processes: chocolate prep, mold prep, depositor prep, and unmolding.
- Machine processes: overnight oven, tempering, ingredient mix (with tempering machine), depositor, fridge cooling, and flow wrapping.

It is important to note, that currently the tempering and ingredient mixing is affected by human labor. The tempering machines allow for operators to help the process by mixing, which the operators currently do. For this reason, the tempering and ingredient mixing processes are limited by the machine capability, but can be affected by operator efforts. The cycle times of each workstation or process was calculated and graphed in figure 5.

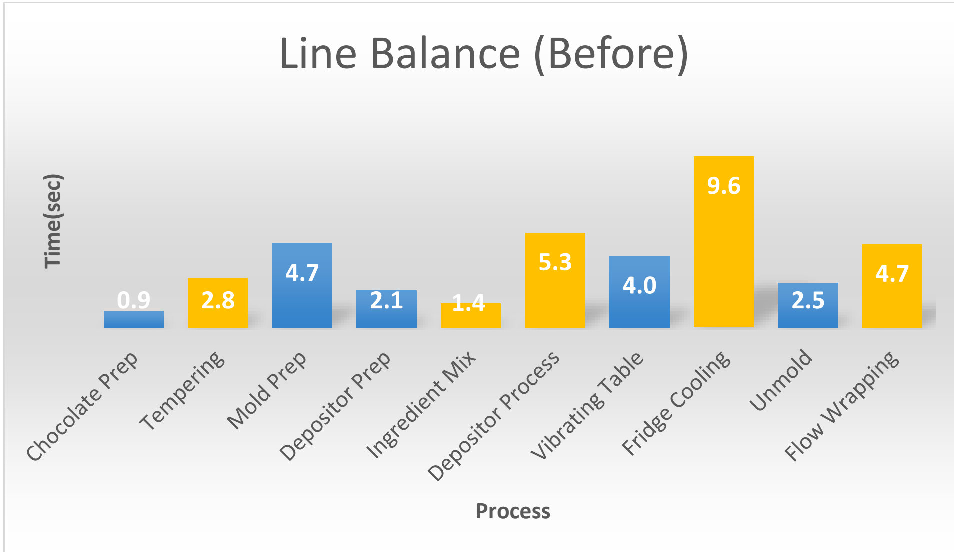


Figure 5: Current state line balance

The cycle time for overnight oven process was omitted from the graph in figure 5, since it's value of 61.5 seconds, would not fit on the graph. From the graph, it can be observed that the current line balance is very uneven which means, several bottlenecks are present. Bottlenecks will be analyzed in the next section.

A cost model was also performed to analyze the success of the business, in financial terms. Dark chocolate was chosen as the template for material cost. Costs were calculated using non-recurring, recurring direct, and recurring indirect costs. However, since CP Chocolates is financed by Cal Poly corporation some costs were excluded. Namely, depositor, tempering, and flow wrapper purchased costs were omitted. As well as the manager salary cost, who Cal Poly corporation also covers. Knowing that the current selling price for Dark chocolate is $2 dollars apiece, it was calculated that the profit per unit is $.63. However, after Including the omissions from the previous calculation, the cost per unit rises to $8.34/unit from $1.37/unit. Thus, the profit per unit is a loss of -$6.34 in profit, for every bar sold. A summary of the findings can be found in the charts below, figure 6. It can be concluded that CP Chocolates would not be running without the financial aid from Cal Poly corporation.

With Support

Top Level Financials	
Qty Needed (based on demand)	4397
Cost	$ 6,732.88
Cost Per Unit	$ 1.37
Current sold price per unit	$ 2.00
Profit per unit	$ 0.63
Ideal Price Per Unit	$ 1.65

Manufacturing Metrics	
Throughput (Unit/Mo)	4907
Capacity	5260
Yield	93%
Qty Needed to Build	4713
Duration to Build (Mo)	1

Without Support

Top Level Financials	
Qty Needed (based on demand)	4397
Cost	$ 40,918.85
Cost Per Unit	$ 8.34
Current sold price per unit	$ 2.00
Profit per unit	$ (6.34)
Ideal Price Per Unit	$ 10.01

Manufacturing Metrics	
Throughput (Unit/Mo)	4907
Capacity	5260
Yield	93%
Qty Needed to Build	4713
Duration to Build (Mo)	1

Figure 6: Cost model for support vs. no support.

3. Analyze:

Several wastes were identified through process observation. After looking at process times and flowchart, 5 wastes were identified. The first three wastes were related to temperature. Ideally, chocolate should be produced in room temperature or 69-degree Fahrenheit. However, the Cal Poly facility does not have temperature control and is often below 69 degrees. After observing a very cold day, where the temperature was 49 degrees Fahrenheit, the process lead time increased by 1 hour. This was also verified by the operators who said, "on the coldest day an extra hour is added to the whole process". The three work elements affected are the tempering process, depositor set-up, and depositor process 1 (Refer to figure 3 - process flowchart for the full list of work elements). The tempering process is affected since the chocolate needs to be mixed at a warm temperature. Roughly 10 minutes are added to the process on the coldest day. The depositor machine must be at the right temperature to work, including the fixtures and jigs. Roughly 25 minutes are added to the depositor set-up on the coldest day. ‘Depositor process 1’, also takes an extra 25 minutes to process. Thus, the following rates were calculated using the worst day as a baseline:

- $Rate = \frac{abs(temperature\ difference\ from\ 69°\ Fahrenheit)}{Extra\ time\ added\ to\ work\ element}$ in time/degree
    - Tempering: 0.5 minutes/degree
    - Depositor set-up: 1.25 minutes/degree
    - Depositor process 1: 1.25 minutes/degree

On an average morning in San Luis Obispo between 8-10 am, which is when these 3 processes occur, the temperature is about 59° Fahrenheit. Thus, the average deviation from ideal room temperature is 10°. On a given production run: 10 minutes is added to the tempering process, 12.5 minutes is added to the depositor set-up, and 12.5 minutes to ‘depositor process 1’.

The next waste observed, was the overnight storing of chocolates, which occurs on day 1. Currently the operator stores 5 batches of chocolate in 3 ovens, for 20 hours overnight. When asked however, only 10 hours is required to melt chocolate properly. Even though this is a value-added step, only 10 of those hours is value added, the rest is over processing. The reason for this situation is because, the operator likes to come in at a convenient time, which is in the morning. This creates energy waste which ends up being payed by Cal Poly corporation.

The last two wastages identified occur with the flow wrapper on day 3. The first waste occurs after machine set-up, called flow wrap realignment as labeled on figure 3. The machine often goes through multiple trial runs, until the bars are wrapped according to standard. After the unsuccessful trials occur, multiple wrappers are thrown away. This waste is a big material cost increase. Currently 14.1 minutes are spent in this step. This work element is completely non-value added and could be prevented with a better set up procedure. The other wastage associated with the flow wrapper, occurs when it begins to process. Once the bars are being packaged, the machine breakdowns on average 3 times. Each time breakdown occurs, the machine is down 7 minutes for a total of 21 minutes. This step also wastes more wrappers.

To help identify the root causes to these wastes, an FMEA was performed. The higher the RPN score received, the more critical the failure is. The equation used is $RPN = (Severity) * (Likelihood\ of\ occuring) * (Ease\ of\ detection)$. The full chart can be seen in the appendix section under figure 7.

- Flow wrapper realignment RPN = 135
    - Root cause: There is not an effective set-up procedure for the flow wrapper. This is caused by each operators setting up the machine in a different way, a human error. There is currently an SOP for setup, but it is not being followed.
    - Recommended Solution: Have a checklist sheet with the SOP's, which requires each operator to complete the procedure in the same order.
- Inventory control for wrappers RPN = 120
    - Root cause: There is not a standard procedure for measuring wrapper yield rate. Currently the operator marks an average of 100 wrappers scrapped per run, regardless of how many were thrown away.
    - Recommended Solution: Have the operators throw the useless wrappers into a container, that can be weighed after. The weight of the container will then be subtracted and the remaining weight will be divided by the weight of 1 single wrapper. This will give you an accurate estimate of how many wrappers were scrapped.
- Flow wrapping breakdown RPN = 64

- Root cause: The machine breaks down due to several different machine related issues. Once a breakdown occurs, the likelihood of it happening again is very high. The operators currently lack the troubleshooting skills to solve breakdown in an efficient manner. They often forget to reset the machine to home setting when a breakdown occurs.
- Recommended Solution: Have a poster in front of the workstation that helps to troubleshoot the most common problems. A large sized visual poster with the process for troubleshooting is recommended.

- Bloom on chocolate (unwanted dusty particles that cause scrap) RPN = 48
  - Root cause: With the help of the lead operator, it was discovered that bloom occurs in the tempering process. When the 5lbs of hardened chocolate, is not inserted immediately into the 20lbs of melted chocolate, bloom occurs. This is also a human error, since the operators forget to follow standard procedure.
  - Recommended solution: Place a vivid poster in front of the workstation, to remind operators they must insert the 5lbs, immediately after the batch is taken out of the oven.

The other two failures, associated with tempering and depositors were caused by undesired room temperature, like mentioned earlier. A solution was developed but found to be impractical, since those work elements are not bottleneck stations in the current state.

Analyzing the bottleneck graph, it was observed that mold prepping was an avoidable bottleneck. The tempering, mold prep, and depositor prep occur simultaneously and depositing cannot begin until all 3 are finished.

- Bottleneck Solution: by increasing the resource allocation (# of operators) from the tempering and depositor stations to mold prep, the bottleneck can be prevented.
  - 3 operators who currently help mix tempering station should go to mold prepping.
  - 1 operator from the depositor set-up station should go to mold prepping.

Fridge cooling and depositor the bottleneck that could not be prevented, as both are currently running at full capacity.

4. Improve:

With the help of FMEA root causes were identified, and solutions were created. Three of the solutions required a deliverable, which were developed with the help of the lead operator and manager.

- Flow wrapper realignment: In order to decrease human errors during setup, a checklist sheet was created to accompany operators during set up. The checklist sheet called figure 8, can be found in the appendix section of the report. The sheet consists of every step needed to complete flow wrapper set up. Descriptions of each step are listed in the next column, which were taken directly from the Standard Operating Procedure (SOP) sheet of the machine. Operators read over the procedure once during worker training, but they often forget them and do not follow each step in the recommended sequence. A picture is placed on the next column, to remind workers where to complete each step. The last column is a checklist box, that requires workers to check off the step once completed.
  - Impact: With the help of subject matter experts (SME's), estimates of improvements were calculated. Currently the realignment process which is unnecessary takes 15 minutes, with the checklist it is estimated to reduce to 7 minutes.
- Flow wrapping breakdown: The machine often breaks down and the operators are left spending much time troubleshooting. When a breakdown occurs, the likelihood it occurs again increases,

because operators forget to reset the machine to home position at 11 cm. The process flowchart is a step by step tool, that covers the most common reasons for machine breakdown. The flowchart lists the most likelihood failure first. The flow chart follows a question and action structure. The question follows a yes or no path, that leads to an action to solve that issue or continue to troubleshoot for other issues. The first question is, 'is the machine in home position, at 11 cm?'. If no then an action follows, 'Reset machine to home position at 11 cm'. If yes the troubleshooting proceeds to the second highest failure occurrence, 'Is the film located 1 5/8" from the side'. The process continues onto other actions and questions. If no solution was found after all those steps, contacting the operating manager is suggested. The full troubleshooting process chart can be found in the appendix section as figure 9.

    - Impact: With the help of SME's, it was estimated that the occurrence of machine breakdown would go from 3 times per run, to only 2 times. Since each breakdown consumes 7 minutes, the total time down would reduce to 14 minutes.

- Bloom prevention: At the beginning of the tempering process, operators occasionally forget to immediately pour the 5lb of solid chocolate into the 20lbs off the oven. This human error results in scrapping the whole batch. The temperature of the batch lowers to an unacceptable temperature, where the 5lb does not mix well. Thus, the bars when hardened will have dust particles, resulting from improper crystallized chocolate. Crystallization deals with the inner molecules of chocolate, the concept is beyond this paper. Thus, a poster has been created with a reminder, 'Mix in the remaining 5 lbs. of chocolate IMMEDIATELY after the 20 lb. batch is taken out of oven!'. The poster is titled 'bloom prevention' and a picture of the task being done is also included. Find the poster in the appendix section as figure 10.

- Impact: With the SME insight, it was estimated that the bloom would reduce about half of the time. Currently it occurs 2 out of 14 runs on average, this means it would only occur 1 out of 14 runs in the future state.

Methods

In order to test our improvements, a current state model in excel was created. Originally a SIMIO simulation was going to be developed, but because of the practicality of excel and time constraint, SIMIO was not pursued. The excel model works very similar to how a project management sheet works. Every process in production is listed, and the preceding processes are identified. Some processes do not have any preceding tasks, others have multiple. Each preceding task was identified, with the help of the process chart developed in figure 3. The times were then listed next to each step, and the total production lead time was outputted. The improvements as discovered from the previous section were inserted into the 'future state' model and a new production lead time resulted. Each of the 3 days resulted in a reduction in production. New cycle times for each station was calculated, as result of the excel model.

Results

The model allowed us to approach the bottleneck problem from the second day, by reducing process times through resource allocation. In the current state, each operator contributes to half of the depositor setup time, about 10 each. Removing 1 operator from the depositor, adds the process time to 32.87 minutes. Similarly, in the tempering process, the operators contribute to reducing the mixing process by about 5 minutes. This was explained through operator interviews. Since there are 3 tempering machines, those 3 operators, instead of speeding that process up, would go to the mold prep station. Thus, the new tempering process time for the first three batches goes from 23.08 to 28.08

minutes. The mold prep station with added resources, since it's a human task, reduces process time from 81.9 to 60.25 minutes. Average number of operators in the workstation increased from 3.2 to 4.35, since the workers are dynamic. Looking at the future state line balancing chart, found as figure 11 in the appendix section, the cycle times have leveled out. The bottleneck reduction with mold prep, reduces production time on the second day by 21.7 minutes. Since 7 workers are present and the minimum wage is 10.5 dollars, 26.5 dollars are saved for 1 run.

On the first day by having the worker place the chocolate in the oven just 10 hours, reduces the process time by 10 hours. The energy savings were then calculated: number of ovens used is 3, Kilowatt used for a standard oven is 2.4, hours spent per run is 10, dollars per Kilowatt hour is .125. Therefore, the dollars saved computing the dot product, comes to 9$ per run or 252$ per year. On the third day, the flow wrapping improvements with the checklist, and troubleshooting poster comes to a reduction of 14 minutes saved. With 4 workers on that day and 10.5 minimum wage, gives $9.8 saved.

Compiling the yearly amount saved in labor cost from day 2 and 3, comes to $1017.4. With new cycles times from all the improvements listed above, the balance of the line becomes far more even and no preventable bottlenecks are present. The exceptions are the fridge storing and depositor processing steps, that are currently running at full capacity. A more even line, is a more efficient production process. The new manufacturing lead time is now 996.8 as opposed to 1632.5 minutes, 600 of those minutes were shaved from the overnight oven time. With a typical throughput of 1170 per run, the new cycle time reduces from 83.7 to 51.1 seconds.

With the reduction of bloom with the poster, the yield rate improves from 93.2% to 93.7%. Although this metric does not signify huge improvements, additional revenue does. With the additional estimated 154 bars saved at a $2 selling price, results in $308 additional revenue. This means capacity increases from 52759 bars to 52913 bars. The improvements from the checklist and troubleshooting poster results in a wrapper yield rate of 96.2%, a significant increase from 91.5%. Before 108 wrappers were wasted on average per run, now it is estimated 59 would be wasted per run. With a cost of $.09 per wrapper, results in a yearly savings of $123.5. Additionally, by placing scrapped wrappers into a bin and then weighing them, allows an inventory accuracy of 100%. This is an improvement from 92.6%, since currently the operators throw away the wrappers and the operating manager estimates, 100 are scrapped every run.

A summary of the 'Current vs future' state can be found as figure 12, in the appendix section. As concluded all recommendations can be implemented at 0 cost. The three deliverables, flow wrapper checklist, troubleshooting poster, and bloom poster have been produced. These deliverables can be printed and used by the operating manager. The other recommendations, require the operating manager to change standard procedures. The first change of process would be to have the chocolate placed in the oven for only 10 hours. The second is to throw away the wrappers into a bin and then have 1 person weight them. The third will be to tell the operators to prioritize mold prep. 1 operator should only set up the depositor and the 3 operators at the tempering station should not help the mixing process, once the wheel is functioning. An operator can occasional check on tempering to track progress.

The observation on this process occurred over two runs so the current state is believed to have been captured accurately. Therefore, all other recommendations are predicted to improve the future state, with high confidence. This is given that the subject matter experts, who predicted the future improvements of the posters and checklist, gave an accurate estimation. The ovens savings by having the operator come at a later time, is very accurate. The only recommendation possibly not as valid, could be the mold prepping prioritization. The calculations on how much time the operators reduce the tempering process, was an estimate given from operator observations. The depositor time estimate, about having 1 operator contributing to half the time of the setup, is also an estimate from the project team. Ultimately, the operating manager is highly encouraged to implement the recommendations made above.

Conclusion

CP Chocolates is a student run business that produces a variety of chocolates. After an operating manager interview, the opportunity found was, the business is looking for ways to reduce production cost. The approach of the project was to follow a DMAIC engineering methodology, centered around data. The scope of the project was solely on chocolate production and no other parts of the business such as: inventory control, marketing, supplier management, etc. Thus, many LEAN and six sigma tools were used. Data collection occurred over 2 production runs, where process times were collected. The data was then analyzed using LEAN and six sigma tools and recommendations were made. Three of the recommendations were process changes and three were supporting tools to improve production. The 3 recommendations were:

- Student operator should only place the chocolate batches in the oven for 10 hours on day 1 to save energy.
- 1 operator from the depositor setup and 3 operators who help the tempering process, should join the mold prep station to reduce bottleneck.
- Operators should throw away wrappers to the trash and then weigh them to improve inventory accuracy.

Three tools were created to reduce human error:

- A bloom reduction poster that reminds employees to insert the 5lbs of chocolates into the 20lbs out of the oven, immediately. This increases chocolate yield rate.

- A checklist sheet that reminds operators what the flow wrapping setup process is, and ensures each operator executes the setup in the same sequence. This reduce the time it takes to realign the machine and prevent machine breakdown.
- A troubleshooting poster for the flow wrapper that supports operators how to troubleshooting machine breakdown. This would reduce the chance of breakdown occurring again.

After developing an excel model of the current process, quantifying the improvements was possible. In which the total savings for all improvements, resulted in $1700 worth of savings. The original objective was to find ways to reduce production cost, which was accomplished.

If the project were to be done again, a SIMIO model could have been used to simulate the process. SIMIO would have provided, a more dynamic way to run what if scenarios on the process. Based on my findings I recommend the operating manager to implement all 6 recommendations. Overall, the project allowed for the use of many Industrial Engineering tools that are commonly used in process improvement. As a result, both the main stakeholders and the project member, benefitted from the project.

Appendix Section

Figure 1: Stakeholder analysis chart.

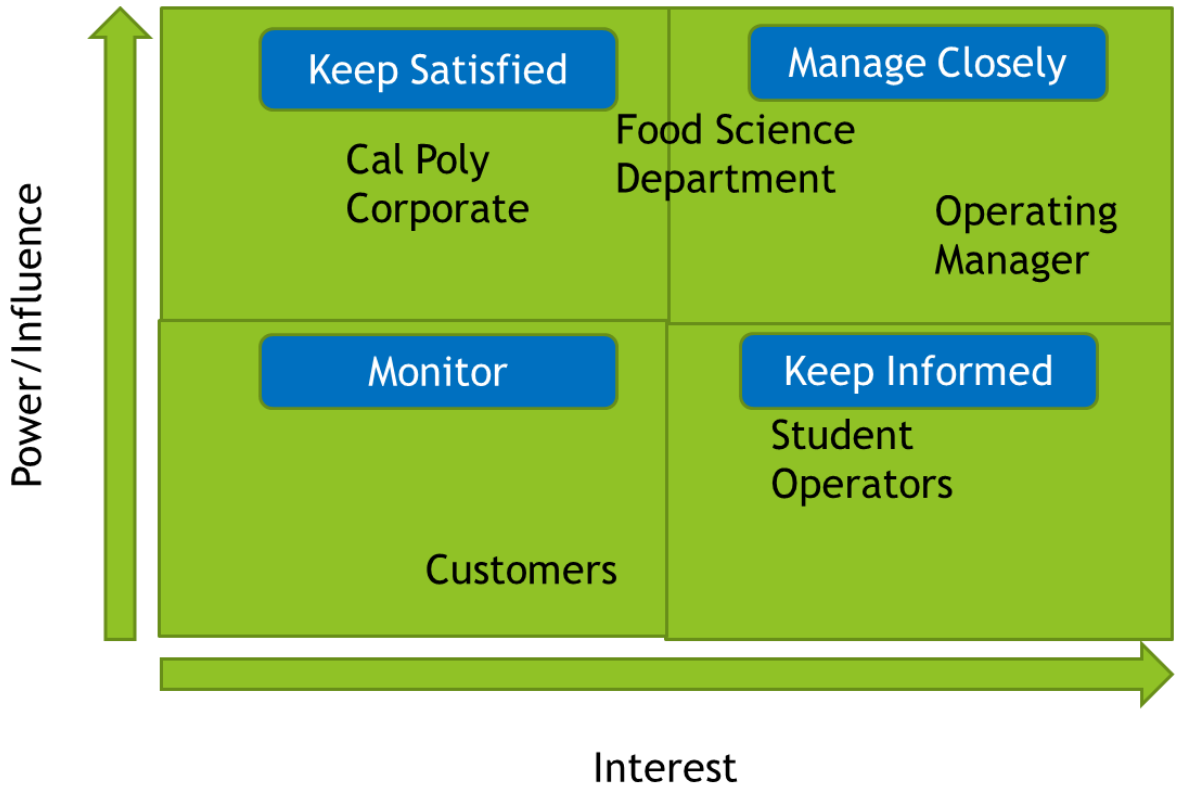
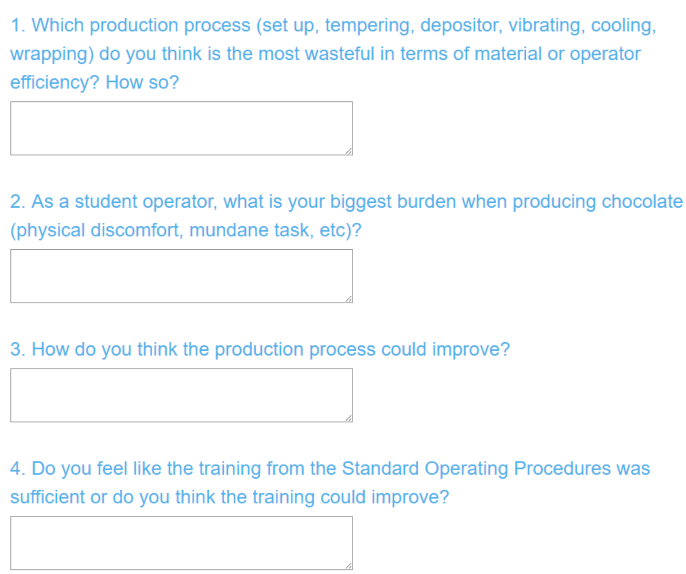


Figure 2: Operator survey.



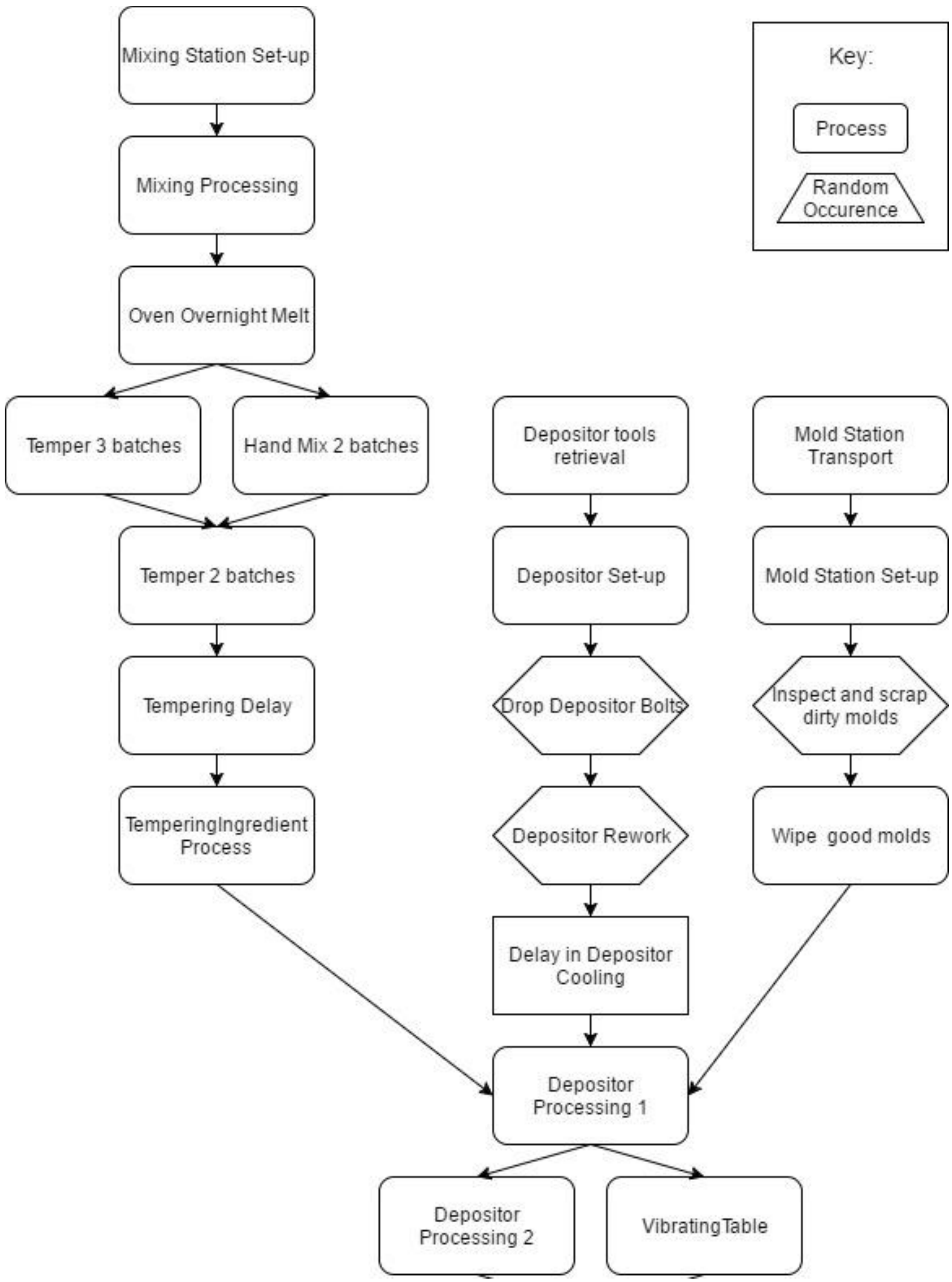
1. Which production process (set up, tempering, depositor, vibrating, cooling, wrapping) do you think is the most wasteful in terms of material or operator efficiency? How so?

2. As a student operator, what is your biggest burden when producing chocolate (physical discomfort, mundane task, etc)?

3. How do you think the production process could improve?

4. Do you feel like the training from the Standard Operating Procedures was sufficient or do you think the training could improve?

Figure 3: Current state process flowchart.



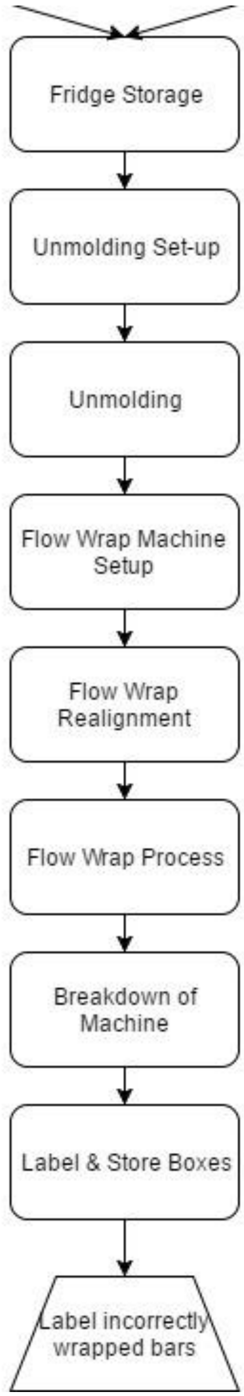

Fridge Storage
Unmolding Set-up
Unmolding
Flow Wrap Machine Setup
Flow Wrap Realignment
Flow Wrap Process
Breakdown of Machine
Label & Store Boxes
Label incorrectly wrapped bars

Figure 4: Current state metrics

Metric Chart			
Efficiency	Value Added	Non-Value Added	.558
	1312.398	1038.72	
Takt Time (sec)	Time Available yearly (hrs.)	Yearly Demand (#bars)	108.7
	1593	52759	
Cycle Time (sec)	Manufacturing Lead Time (mins)	Throughput (#bars)	83.1
	1620	1170	
Finish good inventory	Made	Sold	0
	52759	52759	
Yield Rate Chocolate	93.2%		
Yield Rate Wrappers	91.5%		

Figure 5: Current state line balance

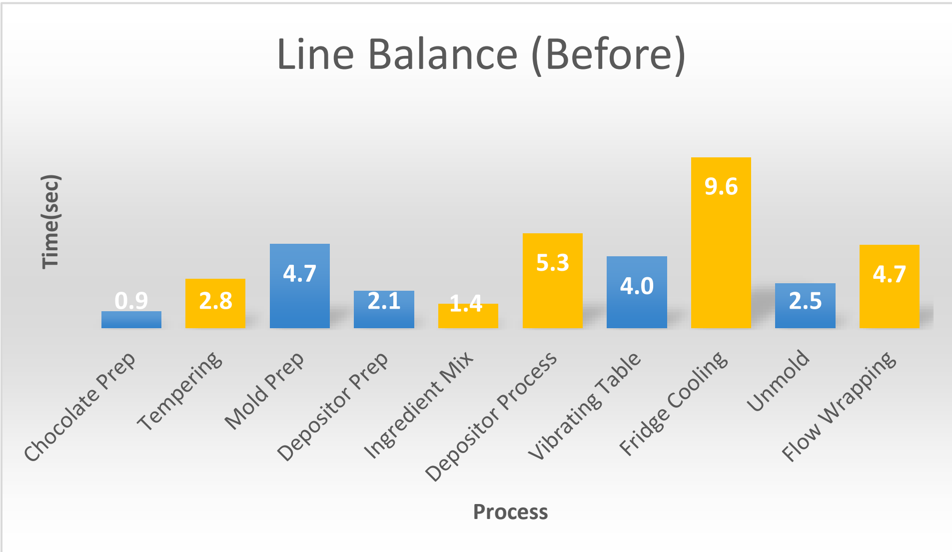


Figure 6: Cost model for support vs. no support.

With Support

Top Level Financials	
Qty Needed (based on demand)	4397
Cost	$ 6,732.88
Cost Per Unit	$ 1.37
Current sold price per unit	$ 2.00
Profit per unit	$ 0.63
Ideal Price Per Unit	$ 1.65

Manufacturing Metrics	
Throughput (Unit/Mo)	4907
Capacity	5260
Yield	93%
Qty Needed to Build	4713
Duration to Build (Mo)	1

Without Support

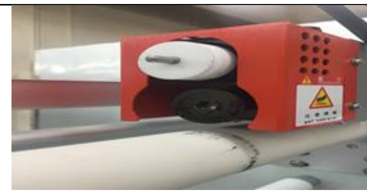
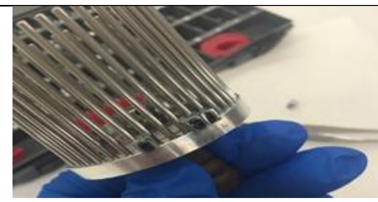
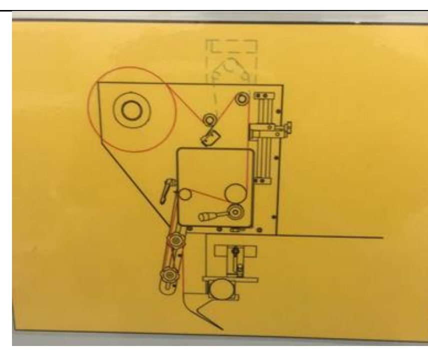
Top Level Financials	
Qty Needed (based on demand)	4397
Cost	$ 40,918.85
Cost Per Unit	$ 8.34
Current sold price per unit	$ 2.00
Profit per unit	$ (6.34)
Ideal Price Per Unit	$ 10.01

Manufacturing Metrics	
Throughput (Unit/Mo)	4907
Capacity	5260
Yield	93%
Qty Needed to Build	4713
Duration to Build (Mo)	1

Figure 7: FMEA of production.

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	RPN	Recommended Action(s)
Melt the chocolate in tempering machine	The chocolate takes very long to melt	The production line is delayed until it actually melts	2	The room is too cold	4	Visual	2	16	Have 1 operator come in 0.5 hours earlier so the machines can rise up to temperature
Depositor spits out chocolate bits into molds	It is too cold to let the depositor spit chocolate out	The production line is delayed	3	The room is too cold	5	Visual	2	30	Have 1 operator come in 0.5 hours earlier so the depositor can rise up to temperature
Final chocolate bar aesthetic	Has bloom on surface	whole batch needs to be scrapped	8	Operator waits too long before melting 5lbs of chocolate	3	Visual Inspection	2	48	Visual Management instruction with must do's at what time
Flow wrapping realignment	The alignment of the machine and wrapper is not correct	There needs to be a realignment of the machine	5	Not an effective set up procedure for alignment of wrapper	9	Wait for a run of wrapping to go through and check	3	135	Have a checklist that requires systematic steps to do process
Flow wrapping processing	The machine breaksdown due to chocolate getting cut	1 chocolate is scrappped, multiple bar wrappers scrapped, delay in production	8	The flow wrap machine is not adjusting speed to size of wrapper decrease in radius	8	Machine detects error and stops the machine	1	64	Visual SOP for problem solving
Cleaning of molds	Chocolate stains are left on mold	Molds can not be used for production	2	Molds are not being cleaned fast enough after use or effectively	4	Visual	5	40	Have molds damp in water filled detergent immediately after use
Inventory of wrappers	There is no current way to keep track of wrappers wasted	There is not a proper way to measure wrapping yield rate	3		10	Estimate of 100 each time	4	120	Instead of throwing in trash, throw them in bin that will be weighed after production

Figure 8: Flow Wrapping Setup Checklist.

Step	Procedure	Picture	Done?
1	Remove lot code wheel from holder on top left area of the flow wrapper, encased in the orange box		
2a	Change numbers on the lot code wheel using the gray box of numbers. Lot code should always begin with the 2 numbers representing the year followed by the 3 digit Julian date, i.e. '16001' for Jan 1st, 2016. All numbers must be added backwards to appear correctly on the flow wrap film.		
2b	Finished lot code wheel should look like the picture below after the numbers have been added. Be sure that the red stopper is tightly in place so numbers do not shift during packaging. When wheel is ready, place back in orange casing, lining up the holes.		
3	Load flow wrap film according to diagram. Ensure that the brown signal strip marker on the film goes through the metal film guide where the eyelet reads the brown marker. All rotating levers will need to be switched to "open" to load the film, there is one under the eyelet reader, and two at the bottom where the fin seal is applied.		

4	Continue running the film through the Flow wrapper according to the diagram. When it is fully looped through the bottom, wrap the film around the metal feeder located just on top of the metal plate where the fin seal is applied. Run the film through the slit so that it is centered on the runner. Do this by checking underneath the metal plate to see that the film is the same length on each side. Continue running film through the slit in the heated plate until it reaches the end so the jaws at the far right side of the machine will catch the film and it will continuously run through. **Caution: the plate will begin to heat as soon as the machine is turned on**	 	
5	Switch all levers to “Closed” position. Turn machine on by rotating the red knob clockwise to “On” position. Make sure E-Stop is not engaged		
6	Check settings for Flow Wrapper ‘Fin Seal’ and ‘End Seal’ Temperatures. Temperatures should always read 172 and 110, respectively		

7	After Accucheck test has been performed (Accucheck Tests addressed in next section) press start button to ensure that the machine was set up properly and is fully functional. Make adjustments as necessary. Bag length on display next to temperatures should always read 140. If it fluctuates between 138-142, that is OK.		
8	Once quality check is complete, load bars and press start. If a bar snaps or they stack on top of each other, immediately stop the machine (ESTOP), take out all bars, cut film just before feeding area at the bottom, and reload it through the slit in the heated metal plate. Test again for proper function.		
9	In the event that the machine needs to be immediately stopped, press in the E-Stop button shown below. The machine will have to be completely turned off and the E-Stop will need to be released in order to reset the machine.		

Figure 9: Flow wrapper troubleshooting process chart.

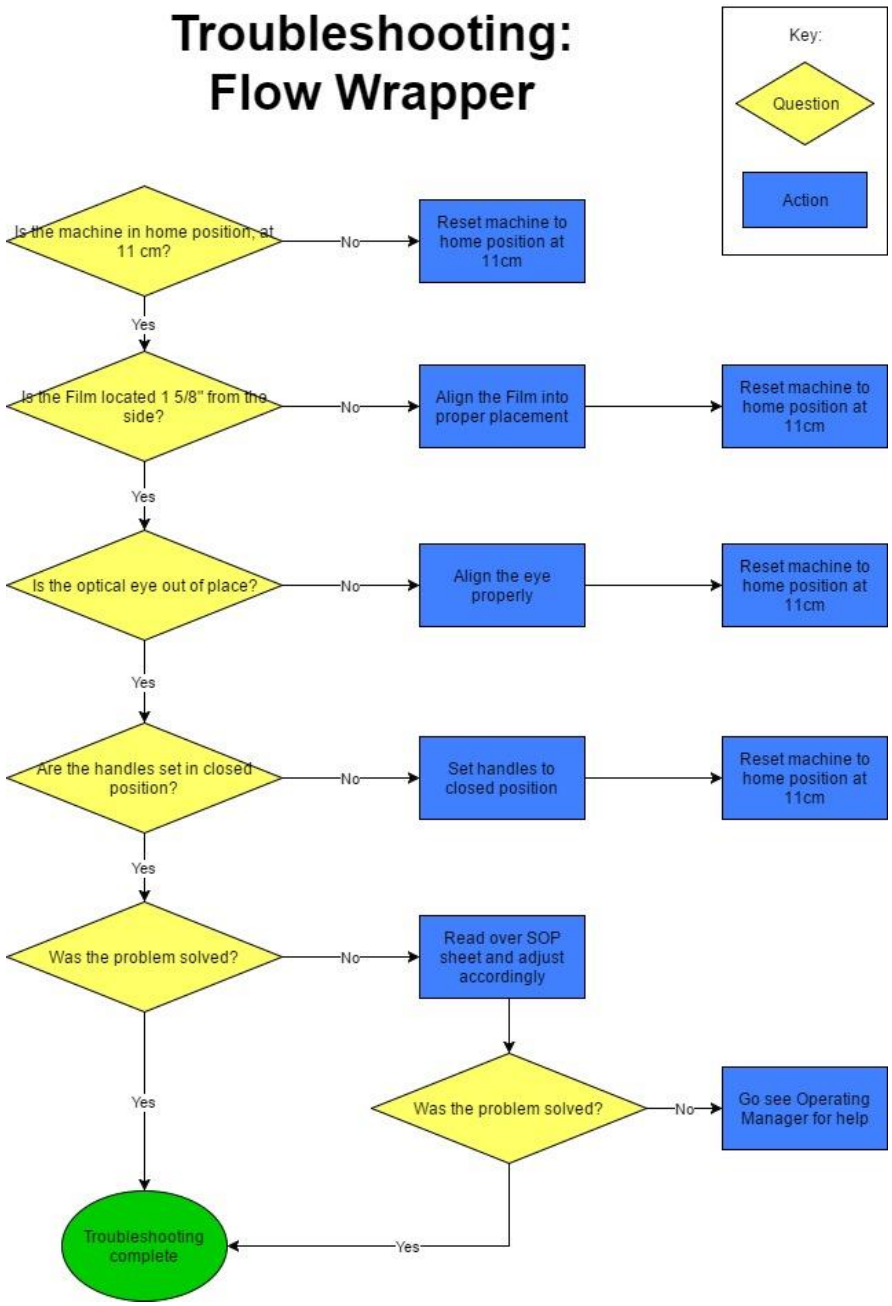


Figure 10: Bloom prevention poster.

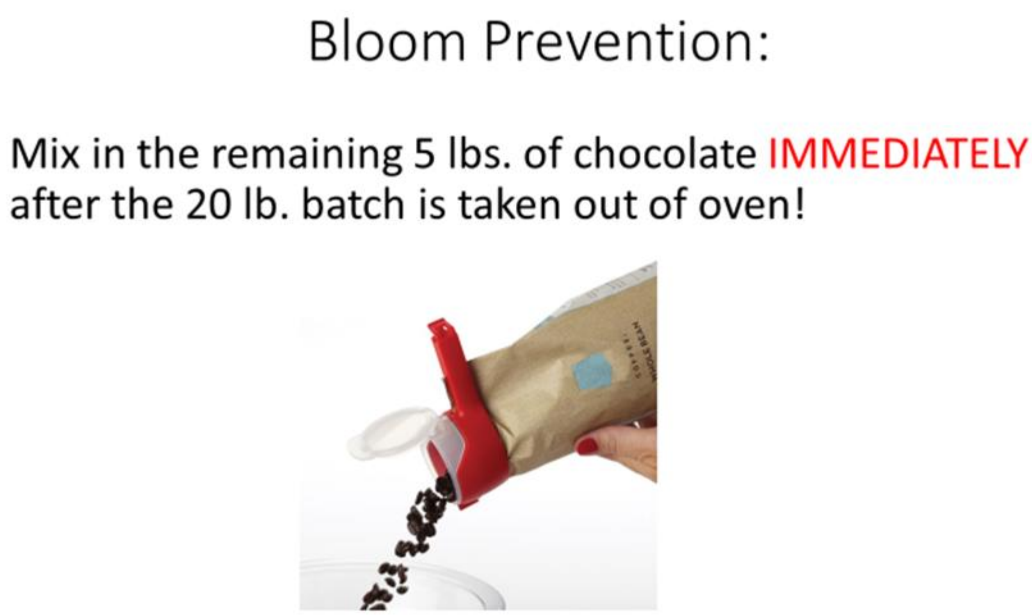


Figure 11: Future state line balance.

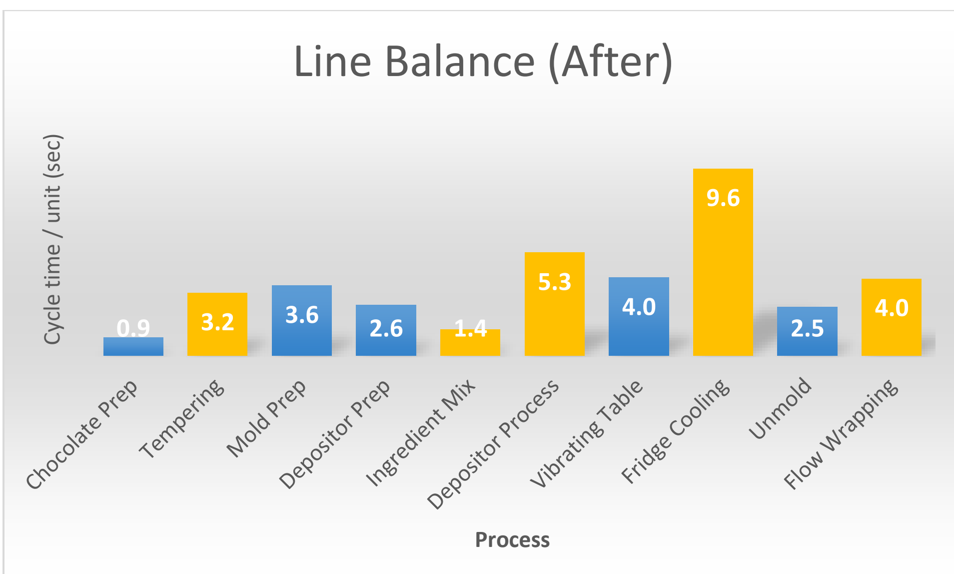


Figure 12: Current vs Future state metrics and savings

	Value Added (min)	Non-Value Added (min)	Efficiency
Before	1312.40	1038.72	0.54
Before(without oven time)	1312.40	438.72	0.75
After	1335.40	424.67	0.76
Oven process			
Energy savings/run	$9.00		
Energy savings/yr	$252.00		
	Total Time Available yearly (hr)	**Yearly Bar Demand (#bars)**	**Takt time (secs)**
Takt Time	1593.0	52759.0	108.7
Yield Rate			
Before (Chocolate)	93.2%		
Before (Wrappers)	91.5%		
After (Chocolate)	93.7%		
After (Wrappers)	96.2%		
Inventory Accuracy (wrappers)	Actual	Estimated	Accuracy
	216	200	92.59%
	216	216	100.00%
Wrappers			
Material Savings / run	$4.41		
Material savings / yr	$123.48		
	Manufacturing Lead time (min)	**Rate (sec)**	
Before	1632.45	83.72	
After	996.76	51.12	
Labor Cost			
Day 2 savings	$26.52		
Day 3 savings	$9.81		
saved per run	$36.34		
saved per year	$1,017.38		
Capacity			
# bars	52759		
# bars	52913		
Additional bars / yr	308		

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