Manufacturing Process Optimization for a Small Scale Craft Brewery

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Abstract *— This research empirically examines the process of craft beer manufacturing in a newly established Microbrewery. Craft beer is the fastest growing segment, with an increase in sales of 151% from 2011 to 2012. This popularity increase is due, along with other factors, to the shift in the taste of the consumers towards a more complex preference. The nature of this small business makes it imperative for the budget to be carefully managed. In order to maximize the use of capital investment, the logistics of the process need to be defined from the beginning. Lean manufacturing tools are used to analyze and improve the brewing system. The methods employed require the implementation of a descriptive phase, evaluative phase and assessment phase. The production process is optimized, resulting in a reduction of about 25 percent in production time and an increase of 50 percent in manufacturing volume.*

Key Terms *— Craft beer, Lean Manufacturing, Microbrewery, Process improvement.*

INTRODUCTION

Over the last few years the beer market has experienced a dramatic change. This is due, mainly, to a shift in the consumer's taste towards a more complex preference. The result is an increment in the offer of imported craft produced beer. According to statistics, sales in this sector have increased in 46.7% during the last year.

The market of craft beer is almost completely dominated by foreign beers. Domestic beer production is still targeted, mainly, to consumers that seek a simpler and lighter alcoholic beverage, with a bland taste that contrasts from the fullness that characterize craft beers. Producing this specialized beverage requires direct attention to process variables and the use of high quality ingredients and in order to deliver the required flavor complexity and maintain competitiveness.

Research Description

The brewery is a small new company, dedicated to the production of artisan beer. The nature of the business makes it imperative that the budget be carefully managed. The logistics of the process need to be defined from the beginning in order to maximize the use of capital investment.

Research Objectives

The main objective of this project is to increase the company's competitiveness by optimizing the production process. All the tasks involved will be standardized and contained in a company process Standard Operation Procedures (SOP) Book. The goal is to reduce processing time while increasing production volume.

Research Contributions

The quality of the product will be assured with the standardization of the process and the creation of an SOP manual. Processing steps synchronization will result in a reduction on the batch production time of about 20 to 30 percent and an increase in production volume of 50%.

LITERATURE REVIEW

The process of producing beer is known as brewing. It involves steeping a starch source in water (which is called mashing) in order to extract sugars and then fermenting the resulting liquid with yeast. The mainly used sugar source is malted barley, which are grains that have been germinated and then heated.[1] The process of fermentation converts sugars into alcohol and carbon dioxide, in a biochemical reaction that takes place at the cellular level. Hops, which are the female flowers of the Humulus lupulus plant, are then added to infuse aroma and bitterness [2] to contrast with the sweetness of the malt. This ingredient also serves as a stabilizing agent because of its antibacterial characteristics.

History

Brewing has been traced back to the Sumerians at around 2000 BC., when embedded a hymn to Ninkasi, the goddess of beer. This hymn is in fact a recipe for beer.[3] It continued with the Egyptians and was then brought to Europe. During the medieval times, beer was the only known safe way to consume water, since rivers and other sources were too polluted. Monasteries were among the firsts groups to produce beer from a commercial point of view.

Beer production at a larger scale had its beginnings in America. Throughout the early 1800s, newly arrived families started up breweries like the ones they new back in Europe.[4] Much later, industrial revolution made it possible for beer production to be increased to the scales we know now. It wasn't until the 1960s and 70s when micro brewing started to resurge, with home brewing movements. This resulted in the current craft beer offer we have today.

Market Analysis

The statistics for Production, Bottling and Import of Alcoholic Beverages from the Department of Treasury of Puerto Rico (PR) show that the general beer market has been either stable or increasing in the last couple of years.[5] While importation of beer has decreased as a whole, the local production has done the opposite, showing a certain tendency for people to choose native over foreign products. Local production experienced an average increase of 11.8% per year, from 2004 to 2009 while importation has decreased 3.0% on average each year during the same time period. However, the mentioned reduction on importation cannot be used as a trend for the particular case of specialized beer, which has experimented an exponential increase on popularity and sales.

According to Symphony IRI, the firm that compiles market statistics, the Craft beer segment in PR represents about 1% of the total beer sales and is expected to grow up to 7% in the near future. Their data shows that during the period that ended on July 2012, 652,064 liters of craft beer were sold, which represents about $6 million. This makes it the fastest growing category, with a growth of 150.8% when compared to the 259,967 liters sold the previous year.[6]

Ingeniero Microbrewery's process will consist of mashing, initial fermentation, secondary fermentation, keg transferring and lagering or cold conditioning. Production Operations will start on the summer of 2013.

METHODOLOGY

To accomplish the research objectives an analytic system was used. The system was divided into three phases, which sought to define operational details and to identify and assess opportunities for improvements. An interview with the head brewer was performed in order to obtain the compiled information.

Descriptive Phase

This section provided details regarding the process employed for producing beer at Ingeniero Microbrewery. It presented an overview of the materials and equipment required as well as the timed processing steps, from a chronological perspective.

- **Equipment and Raw Materials:** The purpose of this segment was to familiarize with the current structure of the brewery. A detailed description of both, equipment and raw material, employed in the manufacturing process was performed at this stage.
- **Process Description:** An important task for this research was the description of the manufacturing process. This was performed to have a better understanding of the current brewing practices, in order to analyze it and identify opportunities in this area.

Evaluative Phase

The information obtained about the equipment and the process was compiled and classified using charts, in order to simplify evaluation. Evaluation consisted on pointing out the specific areas of opportunity, focusing on the interrelation between the equipment and the process aspects. This, in turn, facilitated the assessment phase, which is described next.

Assessment Phase

Lean Manufacturing was used as a strategy for the process improvement. The core idea behind lean manufacturing is maximizing customer value while minimizing waste, thereby achieving manufacturing excellence through the creation of more value with fewer resources.

Waste is defined as an activity that does not add any value to the end product. With the elimination of waste along the entire manufacturing process companies are able to create processes that need less human effort, less space, less capital and less time to produce high quality, lower cost products compared with traditional business systems.

Lean Manufacturing gives priority to simple, small, and continuous improvement such as changing the placement of a tool, or putting two workstations closer together. As these small improvements are added together, they can lead to a higher level of efficiency throughout the whole system.

To implement lean principles in a company, the workforce involved in the manufacturing process must chase a lean thinking to complete the transformation from the old way of thinking. To help guide companies through a lean transformation, Womack and Jones developed a five-step thought process detailed in their book, Lean Thinking (Free Press, 2003).[7]

As shown in Figure 1, the five steps represent a continuous cycle of improvement, and act as the foundation for the successful implementation of lean in a facility.

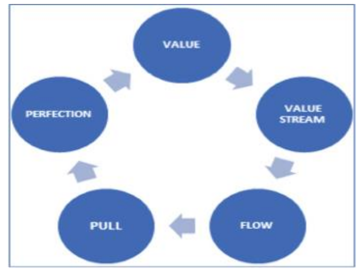

Figure 1
Guiding Principles of Lean

To evaluate the improvement opportunities found in the evaluative phase, the following lean manufacturing tools [8] were used:

- **Value Stream Mapping (VSM):** A tool used to visually map the flow of production. It shows the current and future state of processes in a way that highlights opportunities for improvement. A key component of VSM is differentiating value-adding activities from non-value adding activities. Reducing or eliminating non-value adding activities is of paramount importance and a principle goal of Lean Manufacturing.
- **PDCA (Plan, Do, Check, Act):** It is an iterative methodology for implementing improvements. The first step is to establish a plan and expected results. Next the plan is implemented and the expected results achieved are verified. Then a review is conducted and the process is assessed to determine the corresponding corrective actions.
- **Visual Management or 5S:** Method used as a cleanup activity at the workplace to enhance a higher productivity probability and a safer place to work. The 5S refers to the five areas this method is addressed to: Sort- eliminate that which is not needed; Set In Order- organize remaining items; Shine- clean and inspect work area; Standardize- write standards for above and Sustain- regularly apply the standards.
- **Takt Time:** Is the pace of production that aligns production with customer demand. Calculated as Planned Production Time/ Customer Demand. Provides a simple, consistent and intuitive method of pacing

production. Is easily extended to provide an efficiency goal for the plant floor.

- **Standardized Work:** Documented procedures for manufacturing that capture best practices (including the time to complete each task). Must be "living" documentation that is easy to change. It eliminates waste by consistently applying best practices. Forms a baseline for future improvement activities.

RESULTS AND DISCUSSION

The results obtained after implementing the principles of lean manufacturing are displayed below. The detailed information presented was evaluated using the tools described in the previous section. The optimized process was tested and is displayed in a Gantt chart.

Description

The company initially has 3 stoves and kettles, 6 primary fermenters, 19 secondary fermenters and 40 kegs (see Figure 2). The primary fermenters are 6.5 gallon buckets made of food grade plastic. Secondary fermenters are bottle shaped, polyethylene terephthalate (PET) containers, which are transparent and have a capacity for 6 gallons. The kegs are made of pressure resistant stainless steel and have a net volumetric capacity of 5.26 gallons.

Figure 2
Primary Fermenter, Secondary Fermenter and Keg

The basic 4 ingredients of beer are water, barley, hops and yeast (see Figure 3). Most used raw material is water, which is obtained from PR Aqueducts and Sewers Authority. This water is filtered at the brewery using a carbon membrane. The main ingredient used to produce beer is malted barley. Here, it is used in the form of extract and has the consistency of a high-density syrup. Malted barley grains are also employed to improve the color and the flavor of the product. The last materials are the hops and the yeast. Hops are used in the form of pellets, which come wrapped in 1-ounce packages and the yeast comes as a dry powder inside vacuum-sealed packets.

Figure 3
Water, Malted Barley, Hop Cones and Brewer's Yeast

The first stage of the operational process is cooking. It involves heating malt extracts in water along with malted barley grains and hop pellets. The ingredients are heated at medium-low flame to avoid sticking of material to the kettle. This takes about four hours per batch and results in the production of what is called wort. The total cooking time to produce six kegs in 2 cycles is 8 hours. The wort is cooled by submerging the kettles in an ice bath. Cooling the wort inside the primary fermenters in an ice bath does not work well since plastic does not transmit heat as well as the steel from the kettles does.

The wort is then transferred into a fermenter, where the second stage takes place. Transferring takes about 10 minutes. The wort is contained in an air-locked six-gallon vessel and yeast is added. This part is known as the primary fermentation and takes about 5 days. Primary fermentation is where the majority of the sugars are converted into alcohol and carbon dioxide.

The liquid is moved into a bottle shaped vessel and it takes 15 minutes to do so. This second fermentation occurs for 13 days, with the purpose of clarifying the beer. The transfer between vessels results in the removal of precipitated solids, which are left at the bottom of the primary vessel. The flat beer obtained after this process is packaged into five-gallon kegs and carbonated.

Packaging and carbonating take around an hour. The product is then cold conditioned for 5 days in refrigerators before they is ready to be shipped. Weekly production is 6 kegs per week but the demand is projected to be 8 kegs per week as more potential clients are willing to establish distribution agreements with the company.

Evaluation

After analyzing the manufacturing process of the brewery, it was found that there were flaws in the way the schedule was designed, mainly because time was being wasted between the startups of the batches (see Figure 4). This represented an opportunity to reduce production time. A reduction in time, in term, led to a chance of increasing production volume. This was the other potential discovered and can be partially categorized as a result of the first improvement.

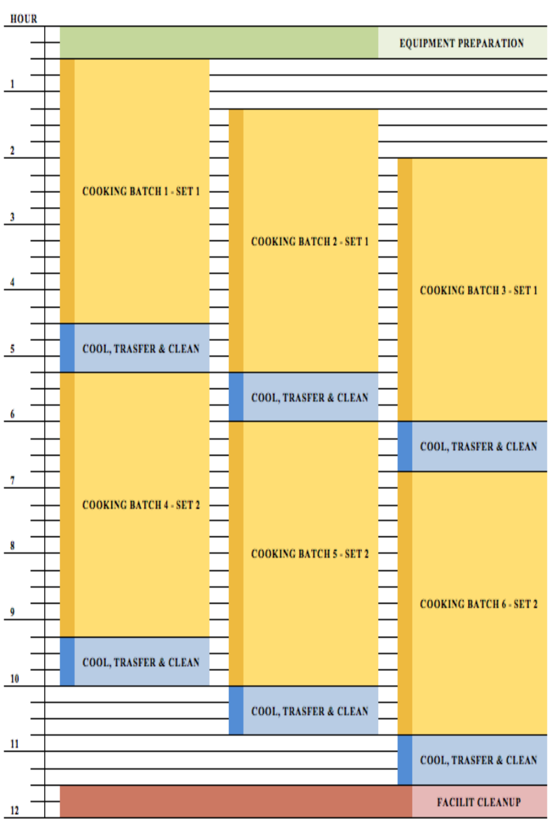

Figure 4
Initial Manufacturing Process Schedule

Assessment

The flow of production was charted using a VSM. A current state value stream map was adjusted to comply with projected demand and to create flow by eliminating waste. Non-value adding activities were identified and removed from the flow. The map is shown in Figure 5 and includes only the value adding components.

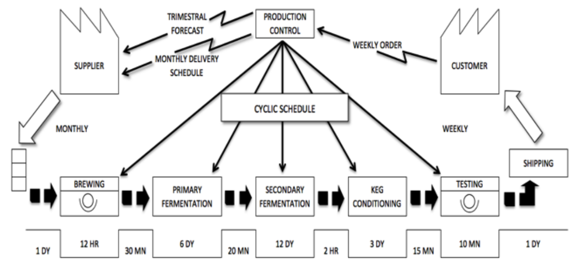

Figure 5
Future State Value Stream Map

After performing an updated market analysis, it was determined that the projected demand would be 8 kegs per week, instead of the 6 previously calculated. This meant that the demand would not be covered with the initial production strategy. To set the pace of the manufacturing activity, the Takt time was calculated. Since production size is conveyed in sets, keg demand and production had to be converted first into this measure, Equations (1) and (3). The Takt time for the initial production plan is shown in Equation (2). The variables were then adjusted to compensate for projected demand and Takt time was re-determined, see Equation (4).

Production time = 12 hours per week
Initial keg demand = 6 kegs per week
Set size = 3 kegs per set

$$Initial\ set\ demand = \frac{initial\ keg\ demand}{set\ size} \tag{1}$$

$$= \frac{6\ {}^{kegs}/_{week}}{3\ {}^{kegs}/_{set}} = 2\ {}^{sets}/_{week}$$

$$Initial\ Takt\ time = \frac{production\ time}{initial\ set\ demand} \tag{2}$$

$$= \frac{12\ ^{hr}/_{wk}}{2\ ^{set}/_{wk}} = 6\ ^{hr}/_{set}$$

Production time = 12 hours per week
Projected keg demand = 8 kegs per week
Set size = 3 kegs per set

$$Projected\ set\ demand = \frac{projected\ keg\ demand}{set\ size} \quad (3)$$

$$= \frac{8\ ^{kegs}/_{week}}{3\ ^{kegs}/_{set}} = 2.66\ ^{sets}/_{week}$$

$$\approx 3\ ^{sets}/_{week}$$

$$Takt\ time = \frac{production\ time}{projected\ set\ demand} \quad (4)$$

$$= \frac{12\ ^{hr}/_{week}}{3\ ^{set}/_{week}} = 4\ ^{hr}/_{set}$$

The process was optimized, leading to a reduction in manufacturing time, for a set of three kegs, from 6 to 4 hours; that is, more is manufactured in less time. This allowed for production volume to be augmented from 6 to 9 kegs per week, leaving the total number of operation hours unchanged.

The projected demand of 8 kegs per week will be covered, with the increment in manufacturing volume mentioned before. The extra keg manufactured is not considered as overproduction since it will be used as the tasting marketing tool to attract new customers. The equation presented will serve as a tool to calculate requirements on future changes in demand.

The Takt time determination conducted to changes in the brewing schedule. In order to satisfy the new pace requirements, wort sterilization time was reduced. This was achieved by increasing the cooking temperature and including stirring of the material. The offsets between the beginnings of the brewing stages were adjusted in order to make better use of the time. This led to a more efficient process, with the cooling and transferring steps of one batch occurring without delaying other batches. The details of the adjusted process are shown in the Gantt chart below (Figure 6).

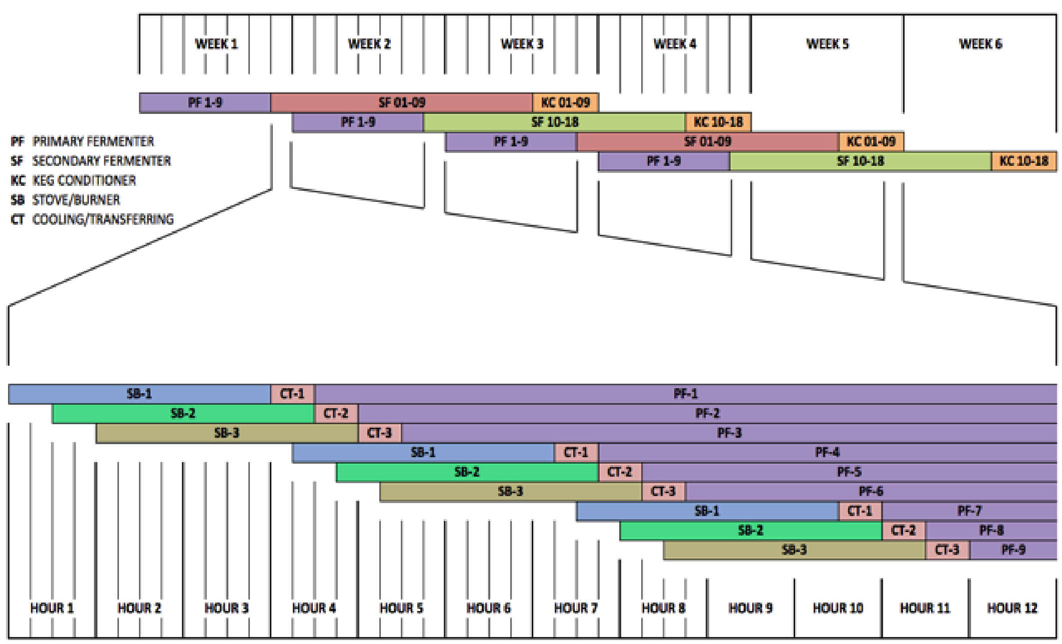

Figure 6
Optimized Manufacturing Process Schedule

After determination and detailing, the improved production plan was implemented in order to verify specification compliance capabilities. Three brewing stage runs were performed and the steps were timed. The entire task list could be completed within the time limits established in the plan.

A walkthrough was conducted at the brewery to study the organization of the workplace. With the guidance of production personnel, the sections were inspected and all of the equipment and tools were examined for their characteristics and function. The inspection revealed that there were many unnecessary tools and some equipment was out of place. The equipment was rearranged in a way that it allows for the process to be more fluent (see Figure 7). The components of fabrication will start at one point of the production area and will continue their way to the end in an uninterrupted line.

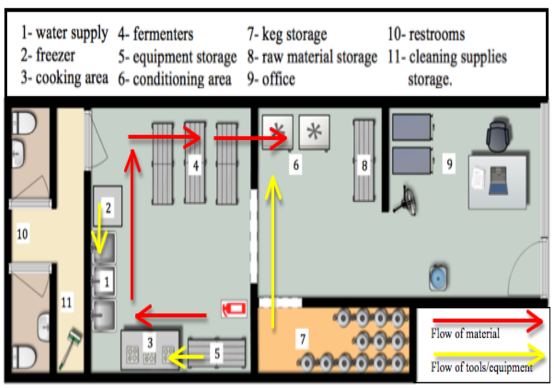

Figure 7
Facility Layout

Materials and tools were classified and placed adjacent to the areas in which they were to be needed. Personnel will now have access to these materials, as they need them to perform a function, without wasting time moving around. Storage requirements were determined for raw materials and small equipment. They were organized by room temperature needs, taking accessibility into account. Finally, labels were implemented to indicate placement of tools and materials (see Figures 8 and 9).

Figure 8
Manufacturing Area Before 5S

Figure 9
Manufacturing Area After 5S

The whole production process was redacted, with the brewer, into a manual. Task were classified by order of sequence and then divided into subtasks. Each of the steps that constitute each subtask was specified to the most minimum detail, including pictures of the materials, tools and equipment involved.

To facilitate movement, a map of the site was incorporated. The map consisted of a facility layout with a grid, with letters on the vertical side and numbers on the horizontal axe to pinpoint location. It also includes an alphabetical list of items with their respective coordinates. These coordinates are also indicated within the task and steps list.

This system was tested in order to evaluate its effectiveness. Testing consisted on providing a completely inexperienced individual with this production manual and measuring the time of the tasks performed. The individual was instructed to follow the each of the steps in an exact manner and without rushing. Emphasis was put on the importance of precision over timing in order to reduce the chance of jeopardizing the integrity of the process. The experiment resulted in a well-executed brewing process, which only exceeded the established Takt time by 7 percent on the overall.

CONCLUSIONS

Small companies with limited budget can considerably increase production, without reducing business feasibility, by using the correct lean manufacturing tools. Well-implemented lean manufacturing tools translate into process optimization, which can allow for product demand increments to be covered.

When applied to a small brewery, VSM reduces waste and provides an overall view of a process in terms of logistics. It facilitates supervision and timing overview. Takt time serves to set the manufacturing goals needed in order to redefine operations to meet the increasing customer demand for craft beer.

Perhaps seeming simple, the 5S method provides an amount of small improvements that, when put together, result in an overall increase in brewing efficiency. Finally, good standardization guarantees the timing and integrity of a brewing process. It provides guidance to such detail that even inexperience personnel can produce beer and comply with the standards of a small craft brewery.

REFERENCES

[1] Unknown, "Quality Factors for Malting, Brewing and other End-uses", Oregon State University, Retrieved on March 23rd 2013, http://www.oregonstate.edu

[2] University of Minnesota Library, “Hops-'Humulus lupulus'”, University of Minnesota, Retrieved on March 21st 2013, https://www.lib.umn.edu/botanical/plant.php.

[3] Roces, R, “The Development of Beer Through History”, Sourcebooks Project, Fordham University, 2010.

[4] History Channel, “History of beer in America”, A&E Television Networks LLC, 2009.

[5] Oficina de Estadísticas, “Estadisticas de Producción, Envasado e Importación de Bebidas Alcohólicas”, Departamento de Hacienda de Puerto Rico, 2012.

[6] Matínez, A, “Crece Como la Espuma la Cerveza Artesanal en la Isla”, El Nuevo Día, Sección de Negocios, 2012.

[7] Womack, J, P, et al., “Lean Thinking: Banish Waste and Create Wealth in your Corporation,” Revised and updated, Free Press Simon & Schuster, 2003.

[8] Juran, J, M, et al., “Juran’s Quality Handbook”, 5th ed., McGraw-Hill, 1999.