Lean Manufacturing Applied to In-Process Protein Concentration Determination Changing the Standard UV-Spectrometer for the Solo Variable Pathlength Extinction

Heriberto Flores Jiménez
Master in Manufacturing Competitiveness
Jose Alberto Morales, PhD
Industrial Engineering
Polytechnic University of Puerto Rico

Abstract *— The protein concentration test is a complicated test, which requires a lot of time and materials. Currently the test is being performed using an old equipment of UV-Spectrometer Visible. In this project, the researcher tried the implementation of a new methodology that can reduce both. The main objectives are to reduce wasting time and cost. A relocation where the testing is performed was also looked, to reduce the amount of time it takes to start processing the sample. By comparing the same sample in both equipment, the laboratory analyst calculates the average of materials and costs needed for each test can be calculated. The time it takes to deliver the sample to another lab versus performing the test in the same room was also measured. By implementing the use of the new equipment of SOLO VPE the time and amount of resources needed to perform the tests can be reduced.*

Key Terms *— 5S, Solo VPE, Spectrometer, Waste.*

PROBLEM STATEMENT

After many years of performing an analytical testing for the in-process protein concentration using an Ultraviolet Spectrometer, the laboratory analysts noticed that the procedure and equipment were really time and material consuming. The downtime since the product is collected in the manufacturing area, delivered to the laboratory, the test is performed, the results are calculated and then sent back to the manufacturing area, is hours long. Most of the time the personnel from the manufacturing area has everything set up and there are not many tasks they can perform while they wait for the results. On the other hand, the laboratory must perform a serious of critical steps to process the drug to get the desired results. Since it has many steps, there is a great chance to commit a mistake, which can lead to a re-test and more downtime hours and use of materials. The equipment of UV spectrometer is outdated, has a complicated methodology and uses a lot of materials. One of the things that needs to be prepared with anticipation is the buffer for each specific drug, which is prepared in high volumes to have stock for the week. One of the materials is a 1mm quartz cuvette that needs to be cleaned after each measurement and this process is time consuming. Any minimum alteration, like a scratch or residue, can change the value causing the test to fail. This has a high chance of human error since there must be at least a minimum of three measurements per solution used. Human error can be minimized using more advance systems. The pharmaceutical and manufacturing organizations must encourage the use of a lean methodology to help improve the overall process. Most of the time people resents change, but new equipment and processes can bring good opportunities to any department of the organization.

Research Description

During the manufacturing process, there is enough waste already when filling syringes due to the spills, broken glass, uncovered syringes, and ones that do not pass inspection. There is a part of them that are also separated for different testings to ensure the quality of the product, which as an overall has an impact on the monetary aspect. The protein concentration UV Spectrometry requires a small amount of drug product. The challenge is to perform the testing following the methodology and with no failures. There is a new equipment which focusses on some of the aspects mentioned before which use less material, disposables equipment and

does not use a buffer solution for the sample measures. All of these represent a significative change in company current procedure. The name of the equipment is Solo Variable Pathlength Extinction. This equipment is so easy to use that manufacturing personnel can be trained to perform the test inside their respective areas, while lowering the downtime of the production process.

Research Objectives

The main goal is to identify and recognize the areas in which the manufacturing process, of protein concentration, have the most waste and eliminates it using Six Sigma Methodology and Lean Manufacturing practices. By applying and using these methods, the company can reduce the amount needed to sample, test cost and the time needed to perform the test in the Analytical Laboratory. After performing the desired changes and methodology, the company must use the gathered data and information to analyze the process before and after, comparing time, quantity, resources, and profits. With the results and evidence at hand, supervisors must arrange and organize the information collected to create diagrams and tables to appraise and compare the gathered data as well as understand and apply Lean Manufacturing and Six Sigma concepts to every area of work.

Research Contributions

It is important to constantly review and update the company's processes to have them synchronized with the current market procedures. By implementing a new testing methodology, while complying with FDA standards and the company's Standard Operating Procedures, it will reduce the waste of the manufactured drug, reduce downtime, and increase profits. Since the company has many branches, another goal is to implement this in every one of them, increasing even more their revenues without compromising the product integrity. This can also help to meet the quarterly quotas faster, making even more space to produce extra product lots. This project can also help employees get certifications in yellow, green, and black belt. It will have a direct impact in the Operation and Excellence Department. Performing the Lean Manufacturing Practices will motivate others to do the same things and apply them into their respective areas.

LITERATURE REVIEW

Background

Henry Ford was the first one to start revolutionizing how to improve an automobile assembly line but was limited to a specific model. Then Taiichi Ohno and Kiichiro Toyoda improved his way of thinking to improve the flow and variety. Lean methodology was born. It can be defined as the ability to eliminate waste to make a process achieve a continuous flow [1]. Inside lean manufacturing, there are techniques like 5s and Six Sigma where the flow can be observed and measured. To make organizations more efficient they must eliminate non-value-added (NVA) activities to reduce waste and costs, and achieved their goal by applying Sig Sigma [2], Operational Excellence and Kaizen techniques, which helps them standardize the work. Some ways to eliminate waste can be lowering the number of defective units, over-processing, motion, overproduction, waiting time, transportation, and inventory space. With different metrics, before and after, the amount of time and money that can be saved and used for other tasks can be measured quantitively.

Business also use the product lifecycle management approach, which helps to reduce costs, improve quality, and innovate products. It is important to identify which activities are the ones that add value to create a value stream map. This helps maintain a constant flow of work and reduce waiting times [3]. Visual aid in the processes helps the employees have a better understanding of what should be done, how should be done, and how fast. To achieve a lean process, many tools can be used, including the steps from DMAIC, which are define, measure, analyze, improve, and control.

There are many types of UV-Spectrometer; one is the 60-beam OMEGA laser system, which is used for inertial confinement fusion studies. It has 60 different configurations that consist in a main infrared beam of pathlength of 1053nm that passes, and amplifies, through a Potassium Dihydride Phosphite crystal and produces a UV light of 351nm [4]. The Omega UV is a complicated equipment which uses multiples crystals to change the bandwidths, when applying the spectral dispersion. Is a technique to produce a more uniform and time integrated illumination profile at the target. There are many variables which can affect the measure of the beam; one is a change in the intensity in a rapid variation in time. It is a complicated equipment compared to the UV-Spectrometer.

Every equipment requires instrumental calibration and verification to get the desired results, but they are subject to errors. Any laboratory that performs tests, and provides to the United States (US), is ruled by stipulated standards. In the US it is under the cGMP's regulations. The US Pharmacopeia General Chapter on Analytical Instrument Qualification became effective in August 2008 [5]. It stipulates that all instruments need to be calibrated, have established written directions, schedules, limits of acceptance criteria, and steps to perform if there is an out of limit result. The definition of calibration is the set of operations which established the relationship between values indicated by a measuring instrument and the known values of a reference standard. The absorbance is verified by using a Certified Reference Material with a known concentration. A mean value is calculated and compared with the one of the Certificate of analysis.

There is a new equipment for protein concentration which requires less materials and takes less time: The Solo Variable Pathlength Extinction (Solo VPE) [6]. Slope Spectroscopy leverages the power and flexibility of variable pathlength technology to create a rapid, robust, and repeatable concentration measurement method for biologics, small molecules, or any sample typically analyzed with UV-Vis methods. Unlike the single value dependence of legacy UV-Vis methods, the data dense slope method characterizes samples by collecting multiple absorbance data points at several pathlengths to create a section curve (Absorbance vs. Pathlength plot) [7]. Even though the Solo VPE equipment can acquire data from the traditional UV-Vis method, the main methodology uses different pathlengths, which are dynamically controlled. The sample using the Solo VPE was Myoglobin, were different pathlengths were measured and with the Beer-Lamber Law, the analyst can demonstrate that the pathlength is directly proportional to the absorbance. With a specific wavelength, the laboratory analyst can measure both values and generate a graph, which he can calculate with a linear regression [8]. The range which the analyst uses the Spectrometer is in the ultraviolet, visible, and near-infrared regions. In comparison, there is another method used for more complicated solutions or materials, because it gathers reflected light. It is called diffuse reflectance spectroscopy (DRS) and provides direct information about chemical nature and is quantitative. It has an advantage; it can be used were the material is and there is no need to get it to a laboratory [9].

EXPERIMENT

Introduction

Maintaining the workplace operating as optimal as possible, the analyst must have, and apply, the lean manufacturing methodology. In this experiment, the researcher is looking for ways to maximize the analysis of a specific sample test, protein concentration. By taking the time since the sample is taken and analyzed, the analyst can calculate an average amount of the total time it takes to perform it. By eliminating the routes, the sample needs to go through, the investigator expects a reduction in time. It is also important to stay up to date with the current technology, which is why the current UV-Spectrometer used for the

test with a new equipment, the SOLO VPE was compared. The amount and price of materials used per equipment will also be compared to justify the use of the new equipment but staying within the established parameters of the tests.

Objectives

The main objective of this project is to reduce the amount of time it takes for the sample to arrive at the desired place as well as the time it takes to perform the test. This reduction in time will result in an elimination of a type of waste that affects the overall process. With the validation of the SOLO VPE equipment, a decrease in the cost of the analysis and a reduction in the time of the testing will be anticipated. In summary, the main objective is to change equipment to make the process faster and more cost effective. Once the approval of the new equipment arrives, the area in which the test is performed must change and training the manufacturing employees to do the test can start.

METHODOLOGY

To continue the project, the first step is to find the procedures and parameters approved by the FDA and the USP. After that research is done, first employees need to perform the usual test with each of the steps, starting from the time the sample is collected from the manufacturing tank. The next step is to start measuring the time it takes to get to the laboratory. An analysis on the amount of materials used to perform the test, the amount of money they cost and the amount of time from start to finish of the analysis must be performed. This will give the analyst an accurate idea on what the total cost and time is. The validation team expert needs to validate the Solo VPE equipment to analyze the current protein sample he needs. After that, he repeats the same analysis of cost of materials and the time of the testing, and the time it takes to get where it is performed. The validation expert can proceed to the next step, which is the comparison between both results of each equipment. The Solo VPE will be installed in the same manufacturing area which the drug is collected. The personnel will require training.

After the validation professional performs and compares the performance of each equipment, the manufacturing area could average the production lots made per week, monthly or yearly. This can show the amount of time and money saved on a yearly basis. The data should be presented in tables and graphs for a clear representation of the result. This can be the first milestone.

The next phase should include the specific steps on what it is supposed to be the implementation of the equipment inside the area, implement the new methodology and change the SOP's. The analyst must first validate the new methodology that will comply with the parameters and the results should be the same of with the other equipment. The test will be done and evaluate like before to evaluate the integrity of the testing. The new parameters, once verified and checked, can be implemented to the SOP's using a validation process. This can take at least two or three months, since is a change that can impact a lot of the manufacturing and quality process. He has achieved another important milestone in this part.

The organization must identify the areas of improvements to apply the lean manufacturing mentality and eliminate waste. In this project, the researcher target is to change the equipment used to test the protein sample and move it from the analytical laboratory to the manufacturing area. The first part of the project needs to justify the change of equipment from one area to another. To achieve this, the analyst needs to collect numerical data and statistics of time. He proceeds to do a weekly monitoring of the time the sample is collected until it arrives at the laboratory and presents this to both areas to have access to the workflow of them. With a calibrated stopwatch, he proceeds to enter the manufacturing area before the sample collection; this is time 0. When the manufacturing employee connects the required equipment to collect it, is when the analyst starts to time it. The analyst follows the operator through all the stages he goes through to get to the laboratory. The analyst also

writes down the number of steps as another measure of comparison. The stopwatch is never stopped, because at this point it is necessary to document the stages the sample goes through. The first data collection since the sample is collected is when is set on a material exit airlock. After this, it is necessary to stay with the operator the amount of time the sample is on that airlock; is the amount of time it takes the operator to get undress and out of that area. This time is also annotated. Once he picks it up again, it needs to be transported to another airlock, so the time and steps are written down. Again, the amount of time of the sample spent on that airlock is the amount of time it takes the operator to change clothes again and picks up the sample. The number of steps is recorded and the time also. The sample is picked up and transported to the laboratory where it is documented as delivered and placed in a refrigerator. The analyst can perform a calculation to change the number of steps into distance of feet using the equivalence that 1 step is 2.5 feet. These two measurements were performed only one time since the route to be taken is always the same. After this, the manufacturing personnel can designate an area where the sample is collected, for the use of the protein concentration equipment. The analyst proceeds to evaluate using the same criteria, time, and distance. After he collects the data from both, he can proceed to compare both criteria to evaluate if there is a difference in time or distance.

The next part, the manufacturing area, needs to achieve the justification of the use for the new equipment to process the sample. The manager needs to do a comparison of the use of materials of the UV-Spectrometer for a sample and the same for the SOLO VPE. The laboratory analyst proceeds to perform the protein concentration test on the UV equipment. The validation expert determines to test 3 samples to calculate an average of material used per sample. The analyst estimated and overall value of all the materials used per equipment. The analyst made a list of each of the individual material that needed to be used to complete the test following the procedures. The sampling was performed on different days because the analysis takes a lot of time. On the first day, the researcher calculated an average of the materials used for that sample, from beginning to end. This step was repeated 2 more times, for a total of 3 samples. For the SOLO VPE 3 samples on 3 different days were analyzed, writing down each of the materials used to calculate an average cost per sample. On this stage, every single material used is documented and assigned an individual value. The analyst and validation expert need a minimum of 2 weeks to do this. The total cost of each of the equipment is compared and analyzed to have an overall idea of the difference in cost. To be more specific, the investigator calculated the individual cost of each sample and calculated and average for each equipment (Figure 1 and 2). Another data that is gathered during this process is the amount of time it takes to perform the test since the delivery of the sample to the designated area. Here, the researcher calculated the time since the analyst took the sample and the ending time when the results are sent to the specific area. Only one sample of each equipment was evaluated and then compared. Once he has all the data collected, then proceeds to tabulate them and make a comparison between equipment. The results can be presented to the specific managers or a board to justify the purchase of the new equipment.

The last part of the process is the validation of the new equipment in the new area and it is the hardest. A new methodology needs to be created and proved that it will work for the desired protein. This is performed by validations experts. There are many steps that need to be evaluated and pass to accept the new method. The first criteria is the specificity, the capacity to clearly measure the analyte in the presence of another component, such as the plastic cuvette. The slope of each blank matrix sample is analyzed with the plastic cuvettes. The slope is measured in the difference in absorbance values divided by the change in pathlength, the value must be less or equal to 0.01AU. The next criteria are the linearity, how linear are the results directly proportional to the concentration. The laboratory analyst must have a

protein sample, and it will be measured 3 consecutive times, for different concentrations, for 3 days. He calculates and average of each sample concentration. Then, each value is used to calculate the % of difference with the Certificate of Analysis of the sample. He also needs to calculate the standard deviation of each sample and divide it by the average, and the result is multiplied by 100 to get the percent relative standard deviation. This value should be within 5%. The next criteria are accuracy, how close is the result to the true value. The results from the last explanation are used to calculate this; is the difference of the measured concentrations and the nominal concentration cannot be ± 5% the stipulated concentration. The precision of the equipment is measured by analyzing 6 aliquots of a reference sample material in the plastic cuvette, with a given COA value. Since the analyst knows the specific value, he can calculate the percentage of relative standard deviation for all 6 samples and must also fall in the range of ± 5%. The samples should be reproducible so to prove that they are the same sample to be analyzed by three different analysts. Since the value is known, the percentage of difference between analysts should be within the ± 5% limit. Each analyst evaluates the sample in triplicate. The analyst must also evaluate the range at which the analyte results are still in parameters for the specificity, linearity, and precision (accuracy). He needs to analyze the amount of which the sample remains genuine by doing deliberate and small variations in the procedure. In this stage, the validation expert knowingly recommended to measure 3 samples but with quartz cuvettes and compare them to the values of the ones with the plastic ones. The results should be within 5% of the results of the plastic ones.

The process to use the SOLO VPE requires a few steps. Before using, the platform must be cleaned with a dry cloth with low particulate. Place a new fibrette in the quick set coupler, slowly pushing upwards until it stops with the delivery fiber. Push the quick set coupler up until it stops, and let it go. It will automatically adjust the space. When the equipment is on, the user is logged in and the analyst proceeds to open the software of SOLO VPE. The first icon he presses quick check and then coupler check. For the sample stage, remove the delivery fiber of the platform and connect it to the transmission tool on the vessel holder. Align the opening with the delivery fiber with the transmission tool opening. Press ok and write coupler check and sign it. The result will be showed on the display. Remove the delivery fiber from the sample vessel holder and disconnect the delivery fiber from the transmission tool. Insert again the delivery fiber in its place, above the soloVPE and reconnect it to the FC connector. Press the quick check with nothing on the sample vessel holder. Place the fibrette gently, close the door and press ok. The final lecture should be more or equal to 75%, as the acceptance criteria. Save the data and print it, discard the fibrette after. Evaluate all the materials, considering that they are up to date and not broken. Select the desired method, open it, and open the quick slope data acquisition window. In the right, he pressed the button with three dots to add the additional sample method information.

The last stage is to teach the employees on how to use the equipment, perform troubleshooting and learn the steps to perform a retest if something is out of the parameters. Using Lean Six Sigma, the researcher can start defining and applying the different methods he used to achieve company goals. The researcher will use the DMAIC methodology; define, measure, analyze, improve, and control. After successfully implementing the new procedure, the investigator must evaluate the results. If the new equipment works within the specific needs, the investigator can present the total of savings the company will have. He will also produce the same tables and graphs used in phase one. By using averages on each one, the managers should be able to appreciate a reduction of time and material that is being used for the testing and at the same time, an increase in the amount of production per week. Traducing that value into monetary amounts, the superiors can appreciate a comparison in the quantity that can be saved per year by

changing the equipment with a new and better technology. By doing this, the company should expect other departments, or other sites from the same company, even other companies, to implement specific methodologies to achieve a similar goal.

Data Reduction

By changing to the new SOLO VPE equipment there is a significant amount of data that is not required to be documented on paper. The analyst eliminates the time to do manual calculation and reduce the human error. There is a reduction of the material needed to perform the test, consequently, there is less use inventory space. There is a reduction of time wasted by the manufacturing employee waiting for the test, because now he will be able to perform it in the same area (Figure 4 and 5). The other analytical employee can now spend that time performing different testing, that can accelerate the release of the lots. The system can generate audit trails which can be printed when needed for the FDA. The reduction in materials result in a reduction in cost; this has a positive impact because saving money for the company is always a good thing. This money can be used to buy new equipment and perform changes like the ones the organization is doing.

Analysis of Techniques

One of the techniques used to analyze the gathered information was the t-test and Hypothesis test. The researcher assumed a level of specificity of 0.05 and assumed a normal distribution. These two things are needed to be defined to maintain controls on the analysis. The two statements to be analyzed and compared are the following: Null Hypothesis (H0): When using the SOLO VPE system, the total cost of the sample testing will be equal as the total sample cost of when using the UV-Spectrometer. $\mu1 = \mu2 = \$600.00$. Alternate Hypothesis (H1): When using the SOLO VPE system, the total cost of the sample testing will be less than the total sample cost of when using the UV-Spectrometer. $\mu1 < \mu2$; $\mu1 < \$600.00$.

RESULTS

The first part is the time evaluation it takes to perform the sample test in the laboratory using the UV-spectrometer and compare it to the time it takes to perform the test inside the area where the sample is collected. The measuring of time starts since the sample is collected in the manufacturing area (See Table 1). The sample must go through different airlocks to get them out of the area, and it also includes a change of clothes from the operator. After it arrives on the laboratory, the analyst must perform a serious of steps prior the start of the testing to analyze it. The amount of time it takes to analyze the sample since the time of collection is about 270 minutes, in comparison with 120 minutes (Table 2). This measurement does not include the time it takes if the sample fails the test and it has to be repeated if the test was performed with the new equipment inside the area where it is collected. When analyzing and applying the lean manufacturing mentality and techniques, the employees can see that there is a waste of time of 150 minutes. This is more than 2 hours that any employee can use to perform other tasks.

The next part of the evaluation is the cost. If the upper management compares the total costs from both equipment (Table 6), even the first investment from using the UV-spectrometer is higher than the SOLO VPE. From a clear view, the supervisors can see that the SOLO VPE uses less materials, which involves also less inventory space. Since the managers needed a more specific comparison, 3 samples of each equipment were tested and measured. Each sample per equipment was prepared in the same way, according to the methodology. After a series of calculations, an average cost per sample for each test is achieved. In this part, the researcher performed a hypothesis test to help prove that the use of the new equipment, SOLO VPE, would have a lower cost per test than the old equipment, UV-VIS Spectrometer. The results of the test are in Table 7.

After the approval of the new equipment, there are a series of tests that needs to be done prior to its

use. It requires a validation process for the new methodology. The results must be specific and there should be no interference from the new materials and mechanisms with the determination of the protein. This can be done by taking measures with empty plastic cuvettes and fall inside the parameters. The results must be linear, directly proportional to the concentration of the sample. It can be by measuring multiple samples of different concentrations. The validation expert needs to perform a test to see how accurate the sample is to the expected value. The equipment precision can be evaluated by measuring different samples from the same analyst to see the repeatability, or from different analysts to see the reproducibility. A system suitability test is also performed before the samples and after the samples to ensure that the equipment is working as expected. The value given should be within parameters of the reference material with a given COA.

Table 1

Average Time it Takes from Sample Collection to Sample Test with UV-Spectrometer

Stage of sample	Amount of total time (mins)
Time since collection to time of delivery to the laboratory	20
Preparation of materials	40
Print Data SOP, methods, and forms	30
UV sample runs	120
Data documentation, calculation, and verification	60
Total	270

Table 2

Average Time it Takes from Sample Collection to Sample Test with Solo VPE

Stage of sample	Amount of total time (mins)
Time since collection to time of delivery to the laboratory	0
Preparation of materials	25
Print Data SOP, methods, and forms	15
UV sample runs	60
Data documentation, calculation, and verification	20
Total	120

Table 3

Number of Steps Taken when Transporting the Sample from Manufacturing Area to the Laboratory Area

Stage of the sample	Number of steps
From collection to 1st airlock	25
From 1st airlock to pick up from the outside	75
From 1st airlock to 2nd airlock	95
From 2nd airlock to pick up from the outside	100
From 2nd airlock to analytical lab.	30
Total	325

Table 4

Number of Steps taken if the Equipment was in the Same Area it is Collected

Stage of the sample	Number of steps
Collection to equipment	10

Table 5

Detailed Material Cost Comparison

SOLO VPE Materials	UV-Spectrometer Materials
Fibrettes P50 Unit price: $420.00	Phosphate Buffered Saline Tablets Package Price (50 tablets): $73.20
Plastic Sample Vessels Unit price: $260.00	HPCL grade water Unit price: $349.00
Lens Paper 4x6 50SH PK12BK Package Price: $7.08	5mL Polypropylene tubes: Package price (1000): $325.52
Pipette Transfer GR 500 PK Package Price: $17.37	14mL Polypropylene tubes: Package price (1000): $385.66
Albumin 10x1mL AMPS Unit Price: $65.99	50mL Polypropylene tubes: Package price (100): $112.00
Ampule Snapper 1-2mL CS144 Unit Price: $18.75	250 µL Disposable pipette tips Package a rack (96 tips): $ 29.99
Centrifuge Tube 15mL Unit Price: $77.58	1000 µL Disposable pipette tips Package a rack (96 tips, 8 racks): $55.00
SOLO VPE equipment Price: $1,920.75	5000 µL Disposable pipette tips Package a rack (50 tips, 10 racks): $ 139.99
Reference Material Price 1mL: $352.70	Polyethylene Transfer Pipettes Price (500): $94.50
Polyethylene Transfer Pipettes Price (500): $94.50	Quartz Reduced Volume Cuvette Agilent Price: $475.00
	Agilent / HP 8453 UV-Visible Spectrophotometer Price: $2,950.00
	Reference Material Price 1mL: $352.70
	Lens Paper 4x6 50SH PK12BK Package Price: $7.08
	Methanol 4L: $159.00
	100 µL Disposable pipette tips Package a rack (100 tips): $ 48.00
	50 µL Disposable pipette tips Package a rack (100 tips): $ 51.60
	Rainin Micropipette L1000 Price: $286.00
	Rainin Micropipette L5000 Price: $268.20
	Rainin Micropipette L100 Price: $250.20
	Rainin Micropipette L200 Price: $250.20
	Rainin Micropipette L2000 Price: $250.20
	Rainin Positive Displacement MR-250 Price: $214.20
	Gilson Microman M-50 Price: $243.00
	Gilson Microman M-100 Price: $214.20
	Magnetic Stir Plate Price: $626.00
	Ph Meter Price: $150.00
Initial Total: $ 3, 228.72	**Initial Total: $8,342.44**

Table 6
Total Average Cost Comparison Between UV-Spectrometer and Solo VPE

Sample	Total Average Cost using UV-Spectrometer	Total Average Cost using Solo VPE
1	$ 936.25	$ 467.27
2	$ 942.36	$ 669.35
3	$ 1,309.19	$ 465.85

Table 7
Results from Hypothesis Test

N=3	**S^2= 13708.43**	**S= 117.08**	**μ=600**	**X barra= 534.16**	
Solo VPE	Sample	Solo VPE total	xi-media	(xi-media) ^2	Varianza
	1	467.27	-66.88	4473.82	13708.43
	2	669.35	135.19	18277.23	
	3	465.85	-68.30	4665.80	Std. Dev
	media	534.156		27416.86	117.08
N=3	**S^2= 45614.3**	**S= 213.56**	**μ=600**	**X barra= 1062.6**	
UV-Spec.	Sample	UV-Spect total			
	1	936.25	-126.35	15964.3225	Varianza
	2	942.36	-120.24	14457.6576	45614.3041
	3	1309.19	246.59	60806.6281	Std. Dev
	Media	1062.6		91228.6082	213.575055

Table 8
T-test of Two Sample Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances

	SOLO VPE total	*UV-SPECT total*
Mean	534.1566667	1062.6
Variance	13708.43213	45614.3041
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-3.757928074	
P(T<=t) one-tail	0.016468382	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.032936765	
t Critical two-tail	3.182446305	

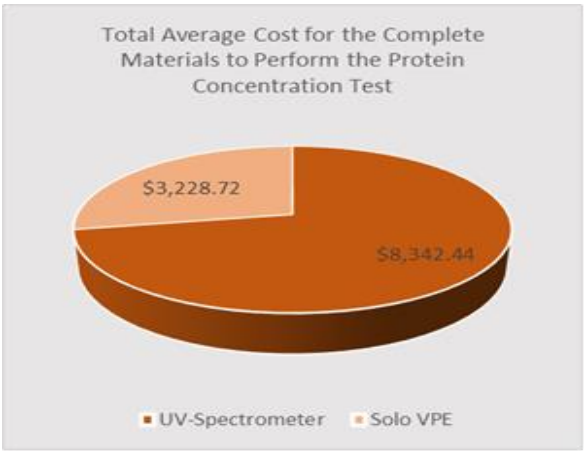

Figure 1
Visual Total Cost Comparison

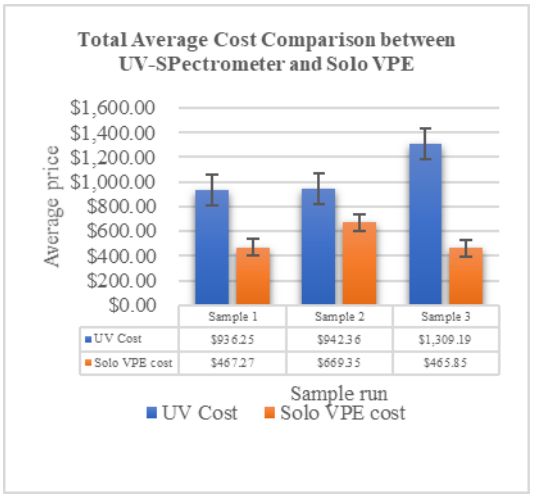

Figure 2
Total Average Cost Comparison Between UV-Spectrometer and Solo VPE

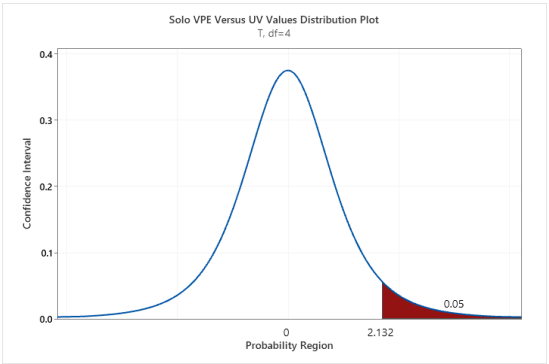

Figure 3
T-test of Two Sample Assuming Unequal Variances

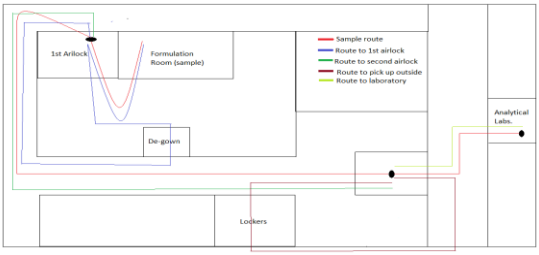

Figure 4
Spaghetti Diagram of Route of Sample and Operator Before the Equipment Implementation

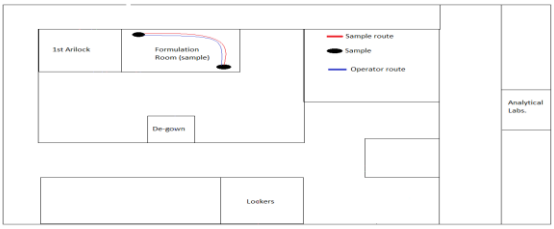

Figure 5
Spaghetti Diagram of Route of Sample and Operator After the Equipment Implementation

CONCLUSION

After applying the Lean Manufacturing techniques to the whole process of the analysis of protein concentration, there were a lot of areas of opportunities which were improved. By analyzing the workflow and steps that the test had to undergo, using the UV-Spectrometer, the investigator gathered a great amount of information that helped to make changes. The overall amount of time saved by changing the test from one area to the same area which it is collected was substantial. By eliminating the different pathways which the sample had to go through, the investigator has increased the speed which the test is started and performed, and there is more time for the analytical analyst to perform other tests. By training the manufacturing employees to perform the test in the same area, the supervisors avoided having downtime of waiting on the sample results.

Although a lot of time is saved by moving the equipment from the laboratory to the sampling area, the organization can also see a time and cost reduction by implementing a new equipment to perform the test. The use of SOLO VPE significantly reduced the cost of the test and reduced the overall testing time. By comparing the material cost of each equipment, its components, and amounts of raw material needed per sample, upper management can see the average saved using the new equipment. The UV-Spectrometer requires a lot of maintenance, a great amount of materials, and has a higher chance of error; this is because the use of the new equipment it eliminates the need to prepare, and use, a buffer solution to get the readings. The SOLO VPE does not need the preparation of a buffer solution, and the sample can be dispensed directly. After many years of performing an analytical

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