Implementing Lean Manufacturing to Improve Compressed Gas and Liquid Filling Efficiency

Jun-Ing Ker[1*], Chandra Mani Shrestha[1], Yichuan Wang[2], and Hung-Yu Lee[3]

[1]Industrial Engineering, Louisiana Tech University, Ruston, Louisiana 71272, USA

[2]Department of Aviation and Supply Chain Management, Auburn University, Auburn, Alabama 36830, USA

[3]Department of Industrial and Systems Engineering, Auburn University, Auburn, Alabama 36830, USA

ABSTRACT

The main focus of this study is to apply the Lean concept and methods to help a compressed gas and liquid filling company find the root causes of slow production as well as identify where and how the gas and liquid are lost and suggest methods for improvement. A careful study of the production process was done by analyzing the setups and layout of current work stations, interviewing employees, conducting time study, drawing work flow charts, value stream mapping and measuring the input and output gas amount. Various wastes such as transportation, motion, and waiting were identified, and gas and liquid leaking stations were found. A new plant layout was provided to help the company improve the production efficiency. The results show that these lean manufacturing initiatives had led to a reduction of travel distance, production lead time and factory floor space..

1. INTRODUCTION

Improving production efficiency has been a vital goal in aspects of daily operations in manufacturing industry [1-3], particularly in compressed gas industry [4]. Companies in compressed gas industry mainly sell various gases (e.g., oxygen, argon, and nitrogen) to customers such as manufacturing companies and hospitals by transferring and distributing bulk gas to the cylinders. The compressed gas business model includes the storage of gas products from a major supplier, filling gas into cylinders, and the delivery of cylinders to customers. The proper layout improvement of facilities or work areas has the potential to increase the effective use of space, optimize the process and flow of operations, and minimize operating time and costs [5-8]. The placement of the facilities in the plant area, often referred to as facility layout problem, is known to have a significant impact upon manufacturing costs, work in process, lead times and productivity [9]. Matlock and Coulter [4] have shown that plant layout is an effective tool to help the compressed gas companies improve profitability and reduce the direct cost.

Lean manufacturing/management emphasizes cost and time reduction through identifying non-value added activities and eliminating unnecessary waste and spending from each step of production process [7]. The Lean concept and methods have been proven to be effective in help manufacturing and service industries eliminate unnecessary wastes and improve production and process efficiency [10-13]. In this study, we show how various lean tools were implemented in a compressed gas industry located in Louisiana to help improve their production efficiency and reduce production loss.

2. BACKGROUND OF CASE COMPANY AND PROBLEM STATEMENT

The case company is a distributor of industrial and medical gases and liquids in Louisiana. This company purchases their gas product wholesale in bulk liquid form, and then fill smaller liquid and gas cylinders for resale. They produce two types of gases: company-certified gas and the environmental protection agency (EPA) gas, and these gases could be reactive or non-reactive.

* Corresponding author: Tel.: (318) 257-2963; Fax: (318) 257-2562; E-mail: ker@latech.edu

After investigation of production lines, two major problems were noted. First, the company claimed that they were losing over 30% of the gases during production. Second, the company had encountered difficulty in achieving their production goals to meet the increased demand. The case company enlisted the aid of our research team to address issues within their organization. The objectives: reduce the gas and liquid filling loss and improve and streamline the production process.

The production process includes seven different workstations: (1) New/Used Cylinders; (2) Prep Area; (3) Fill Room; (4) Cylinder Await Analysis; (5) Test Area; (6) Gas Management System (GMS); and (7) Cylinder Labelling. For the production loss problems, our team focused only on their main product, oxygen gas, and implemented the findings to the rest of the products. The oxygen gas was selected because it was the best seller and also had maximum loss.

3. METHODOLOGY FOR FINDING FILLING LOSS

One important aspect of lean manufacturing is reducing raw material loss. An initial investigation of the gas and liquid filling processes revealed that the possible areas for loss were: venting during gas filling, venting during liquid filling, bulk tank leaking, and bulk tank filling. The method for examining each area of loss occurred in the gas and liquid filling processes is described in the following sections.

3.1. METHOD FOR FINDING GAS-FILLING LOSS

For the vent loss during gas filling, we started by finding the total volume of the manifold and pigtails that were vented during gas filling. To do this, we found the total length of the manifold pipe that was vented during gas filling. This was equal to 242 inches. Next, we obtained the inner diameter of the manifold pipe, which was 3/8 inches. We then found the total volume of the vented manifold pipe (v_1) to be 0.062 ft^3 as shown in equation (1).

$$v_1 = 242\pi\, r_2^2 = 242\,\pi\,(3/8)^2 = 0.062\text{ft}^3 \tag{1}$$

For the pigtail, we measured the length of one pigtail and found them to be 49.25 inches long. Next we obtained the inner diameter of the pigtail, which was ¼ inch. Afterwards, we found the total area of one pigtail, and then multiplied it 38 times because there are 38 pigtails on the oxygen manifold. The result showed that total volume vented in pigtails (v_2) was 0.112 ft^3 as shown in equation 2.

$$v_2 = 38\cdot(49.25)\cdot\pi\cdot r_1^2 = 0.112\ \text{ft}^3 \tag{2}$$

Next we added the total volume of the manifold pipe (v_1) and the total volume of the pigtails (v_2) to obtain total vented volume, which was 0.275ft^3 (v_1+ v_2). This amount is designated as V_1. Finally, we used the definition of density to find the total loss of the venting. We used this because, theoretically, the properties of the gas in the manifold and in the cylinder are the same. Therefore, rewriting the definition of density gives us a percent of the manifold volume compared to a cylinder. We can then compare the amount of gas in each to find the cubic foot vented. This is demonstrated in equations (3) and (4) where M_1 is the mass of the manifold, V_1 is the volume of the manifold, M_2 is the mass of a 251 cubic foot cylinder, and V_2 is the empty volume of a cylinder.

$$\text{Loss} = M_1/V_1 = M_2/V_2 \tag{3}$$

$$\text{Loss} = M_1/M_2 = V_1/V_2 \tag{4}$$

Since V_1 = 0.275ft^3 and V_2 = 1.602ft^3, percent of gas loss was found to be 17.136% or 43.012 ft^3. This volume loss was obtained by multiplying 17.136% by 251 ft^3, the volume of the gas cylinder.

3.2. METHOD FOR FINDING LIQUID FILLING LOSS

To find liquid filling loss, we used the Depressurization (flash) Losses Chart provided by the Chart Industries [17]. Reading the pressure gauge on the oxygen bulk tank, we found the average pressure to be 75 psi. Using the graph provided, we found that the average percent loss during liquid filling to be approximately 17%. Next we used the data for the past six months to find the average monthly liquid oxygen cylinder fills per month. Using the average monthly cubic feet usage and the average percent loss, we multiplied them together to find the average cubic feet loss due to liquid filling.

3.3. METHOD FOR FINDING IF BULK TANK IS LEAKING

To find whether or not any loss is contributed to a possible leaking of the bulk storage tanks, we used the gauge reading from the tank during non working hours. We observed the tank levels over the weekends when there was no production to see whether or not the tank levels changed. Our observations verified that the tank was not leaking.

3.4. METHOD FOR FINDING BULK TANK FILLING LOSS

To find bulk tank filling loss, we started by gathering the bills for the bulk tank filling. These bills recorded the tank levels before and after the filling as well as the amount the driver pumped into the tank. For each transaction, we compared the levels of the tank before and after the filling to find the loss. Since the tank level was measured by the depth of product in the tank and the amount pumped by the delivery truck was measured in cubic feet, we converted the change in inches in the tank to cubic feet. Then, we subtracted the amount of change (in cubic feet) in the bulk tank from the amount of the delivery to acquire the loss from filling.

3.5. FINDINGS FOR PRODUCTION LOSS

After exploring all of the possible areas of production loss, we found that the average loss during gas filling is 43 ft^3 per fill. This is about 1 cubic foot per cylinder filled. The loss for liquid oxygen filling is approximately 19-21%. Two to four percent is contributed to cylinder cool down and approximately 17% is contributed to flash losses. The monthly filling average for oxygen over the past six months was 473,917 cubic feet per month. This gives a monthly loss average of 94,783 cubic feet from liquid filling cool down and flash loss. The average loss due to flash loss alone is about 80,566 cubic feet. To help the company reduce the oxygen filling loss, we recommended that a Lo-Loss system be purchased [17]. It is an automated filling system that dramatically reduces depressurization (flash) losses during liquid cylinder filling. By maintaining an optimal pressure difference between the bulk tank and liquid cylinder, losses are kept at a minimum without increasing fill times.

4. METHODODLOGY FOR IMPROVING PRODUCTION EFFICIENCY

Another important focus of our study was to improve the production efficiency. This required a careful study of the present state to identify areas needing improvement and to establish a goal representing the future state.

4.1. PRESENT STATE

We began the study of the present state by analyzing production data of the past year. From these data, we found the product type and the sequence of operations as shown below. As a note, each number represents a production area in the plant.

1. Non-reactive gas: 1-2-3-5-6-7
2. Reactive gas: 1-2-3-4-5-6-7
3. EPA gas: 1-2-3-4-5-4-5-4-5-6-7 <<< Bottleneck

The bottleneck product, EPA gas, was selected for the analysis. This helped generate the present state layout and the spaghetti chart as illustrated in Figure 1.

Under the present method, once the order is received, the new or used empty cylinder is brought from storage and taken to the Prep Area. The used cylinders will be backed for four hours in the batch of six cylinders, and the new cylinder is coated and standardized for nine hours in the batch of six cylinders. The cylinders are transferred to the Fill Room to fill gas in the batch of six cylinders. After the fill process, the cylinders wait in the Analysis Room and then are taken to the Test Area till they pass the assay. The company-certified gas only needs one assay on the fourth day after the filling process. If it meets the certain gravimetric calculations, it is ready to be labelled and shipped out to the customer. The EPA gas must sit four days for first assay, and wait seven days for second assay. The EPA gas can be released if the two results overlap. Otherwise, it stays seven more days for the third assay and continues until the two results overlap continuously. The longest lead time for EPA gas is fourteen to twenty-one days.

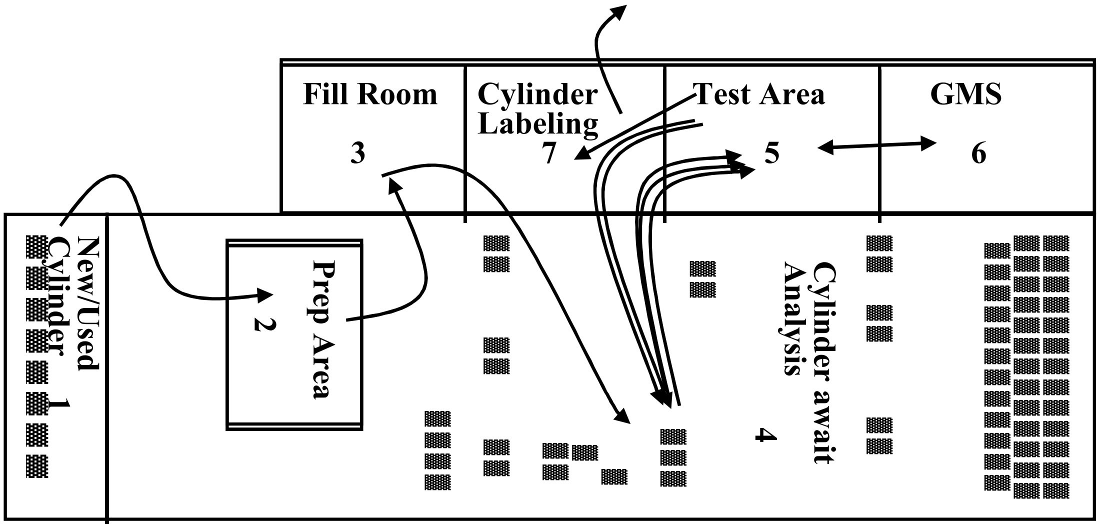

Figure 1. Present state layout with Spaghetti chart.

Value Stream Map (VSM) is a graphical tool which is created using a predefined set of standardized icons that helps the organization see and understand the flow of material and information as the product goes along different production stages [16]. In our study, we first created a VSM for the present state. We then rearranged different workstations to minimize the movement of materials or workers and generated a VSM for the future state. These tasks were carried out in conjunction with analyses of the effectiveness of each plant layout measured by the shortest overall rectilinear distance between the workstations when filling EPA gas cylinders. The VSM of the present state is shown in Figure 2 using online software from the website https://www.draw.io. In the present state, our study found that total lead time was 433.68 hours, value added time was 566 min and distance travelled by a cylinder was 433 feet.

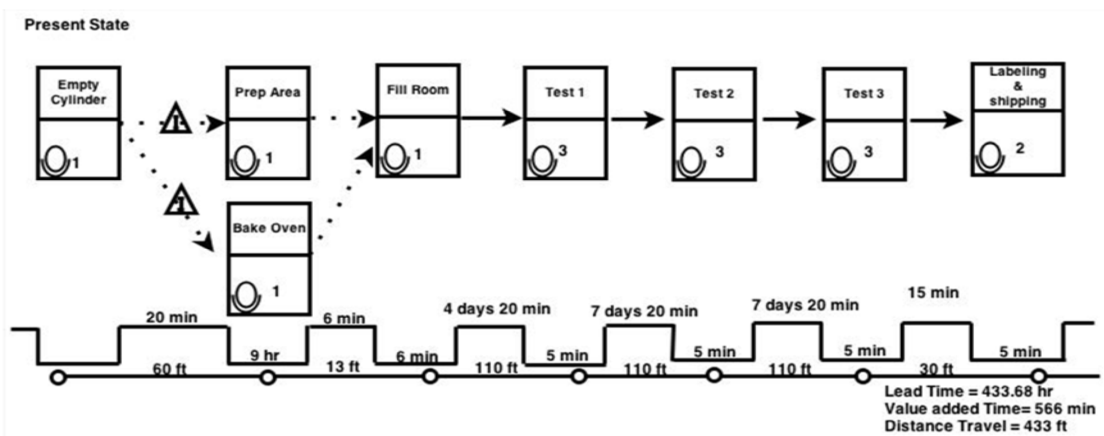

Figure 2. Present state Value Stream Map (VSM).

4.2. Present state-Layout Effectiveness Analysis

The effectiveness of the present state layout was evaluated using the approach described by Sule [18]. The area of each workstation was measured, as shown in Table 1, and a From-to-chart of the work area is presented in Table 2 according to the movements of cylinders and workers between the workstations. Note that a higher value indicates more movements were needed between two adjacent work areas. Table 3 shows the total flow of each area which is the sum of horizontal and vertical values of the From-to chart. From Table 3, a Real-value chart is obtained as shown in Table 4. Note that codes A, E, I, O, U, X represent absolutely necessary, essential, important, ordinary, unimportant and undesirable, respectively. In addition, values of 4, 3, 2, 1, 0 and -1 are assigned to these codes to signify how important two work areas need to be placed in close proximity.

Table 1. Workstation area.

Workstation	Area (Square Feet)	Workstation	Area (Square Feet)
1. New/Used cylinder	55*15=825	5. Test Area	20*10=200
2. Prep Area	25*20=500	6. GMS	15*5=75
3. Fill Room	15*10=150	7. Cylinder Labeling	10*20=200
4. Cylinder await analysis	2150		

Total Area Used: 4100 **Total Area of Facility**: 6250 **Empty Space**: 2150

Table 2. From-to-chart.

Workstation	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	-	25	-	-	-	-	-
2	25	-	25	10	-	-	-
3	-	25	-	25	10	-	5
4	10	10	25	-	40	5	5
5	-	-	10	35	-	40	25
6	-	-	-	5	40	-	-
7	5	10	-	20	25	5	-

Table 3. Total flow.

Workstation	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	-	50	-	10	-	-	5
2	-	-	50	20	-	-	10
3	-	-	-	50	20	-	5
4	-	-	-	-	75	10	25
5	-	-	-	-	-	80	50
6	-	-	-	-	-	-	5
7	-	-	-	-	-	-	-

Table 4. Real-value Chart.

Workstation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
1	-	E(3)	U(0)	O(1)	U(0)	U(0)	O(1)	5
2	-	-	E(3)	I(2)	U(0)	U(0)	O(1)	9
3	-	-	-	E(3)	I(2)	U(0)	I(2)	11
4	-	-	-	-	A(4)	O(1)	I(2)	13
5	-	-	-	-	-	A(4)	E(3)	15
6	-	-	-	-	-	-	O(1)	6
7	-	-	-	-	-	-	-	10

The total value shown in the Real-value chart of Table 4 is developed by adding the row and column values. Since the Test Area (i.e., workstation 5) has the highest total value in the chart, ideally, it should have been placed in the center of the plant, and other workstations should have been placed around it according to their importance to the Test Area and to each other. Nevertheless, the current plant layout was designed 30 years ago without studying its effectiveness. Consequently, the Test Area was placed in the corner, though it has the highest value in the Real-value chart. Figure 3 illustrates the grid presentation of the present layout. Note that one block equals 75 ft^2, which is the size of the small workstation GMS (i.e., workstation 6).

Table 5. Grid Representation of Current Layout.

1	1	1	1	1
1	1	1	1	1
4	2	2	2	1
4	2	2	2	2
4	4	4	3	3
4	4	4	4	7
4	4	4	4	7
4	4	4	4	7
4	4	4	4	5
4	4	4	4	5
4	4	4	4	6

Finally, the effectiveness of the plant was calculated using the information obtained from Table 4 and Table 5. Two numbers were assigned to the effectiveness calculation table. The first value comes from the rectilinear distance between the workstations in Table 5, and the second value came from Table 4. For example, the shortest rectilinear distance between workstations 3 and 5 is three blocks, and has two-relationship between them, giving 3*2 as the entry for row 3 and column 5 in Table 6. The sum of the multiple of the row values are calculated to the right and overall sum is the effectiveness of the layout, which is 11 for the present state.

Table 6. Effectiveness calculation.

Workstation	1	2	3	4	5	6	7	Total
1	-	0*3	1*0	0*1	5*0	7*0	2*1	2
2	-	-	0*3	0*2	4*0	5*0	1*1	1
3	-	-	-	0*3	3*2	5*0	0*2	6
4	-	-	-	-	0*4	0*1	0*2	0
5	-	-	-	-	-	0*4	0*3	0
6	-	-	-	-	-	-	2*1	2
7	-	-	-	-	-	-	-	11

4.3. FUTURE STATE

During the study of the present state, Lean wastes like transportation, motion and waiting were identified but the wait process was unavoidable due to the EPA law requirements. In developing the future state, the goals were to reduce the transportation of the cylinders, motion of the workers, and preprocessing time at workstations. These tasks were accomplished by rearranging workstations to minimize the distance between them and also the movements of the cylinder and workers. To achieve these goals, the storage area for the new/used cylinder was transferred inside to be near workstation 2, and the new and used cylinders were kept separately to reduce the time to find empty cylinders. The Fill Room was moved closer to the Prep Area so the employee can move the cylinder faster. The Test Area was moved closer to the Analysis Area because many movements existed between these two workstations. As a result, the new Sequence of Operation was: 1-2-3-4-5-6-7, as shown in Figure 3.

Compared with the previous layout, the new layout offers many advantages. A cylinder used to travel a distance of 330 feet in the previous layout for the assay until it passed in between workstations 4 and 5. In the new layout, the Test Area was moved closer to the Awaiting Area so the assay could be done without moving the cylinder. Once the cylinders come to the Awaiting Room it will stay there till it meets the EPA requirements. This change was made by the extension of the pipes from the Test Area to the awaiting cylinders. As a result, the distance travelled by a cylinder was reduced to 85 feet from 433 feet because all three tests can be done at the same place. As a consequence, the effectiveness of the new layout was calculated to be 8, significantly less than that of the previous layout. In addition, the total space required was reduced from 4100 ft^2 to 3700 ft^3, and the lead time was reduced by 1.43 hours per cylinder. The VSM of the future state is displayed in Figure 4.

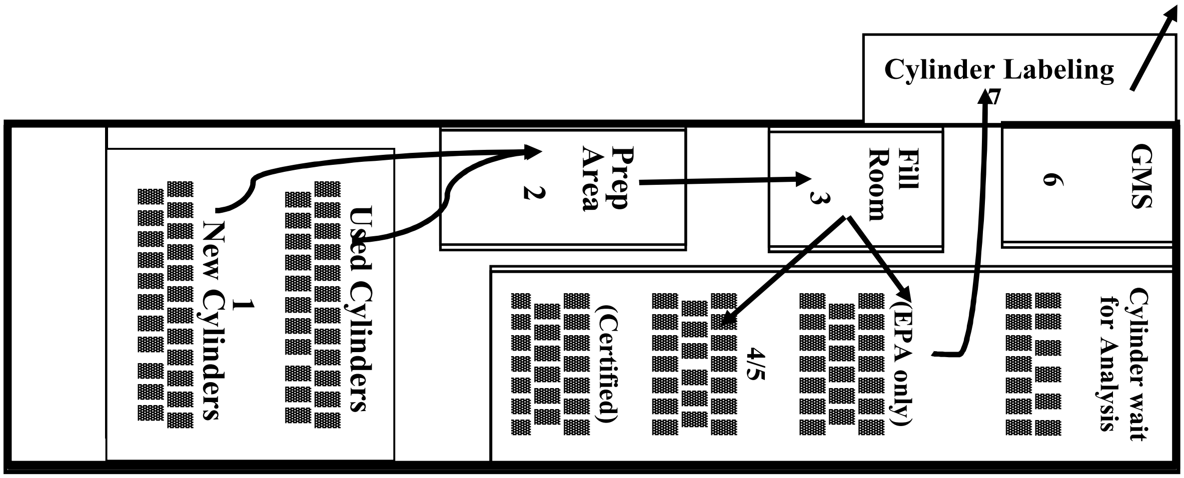

Figure 3. Future state Layout with Spaghetti chart.

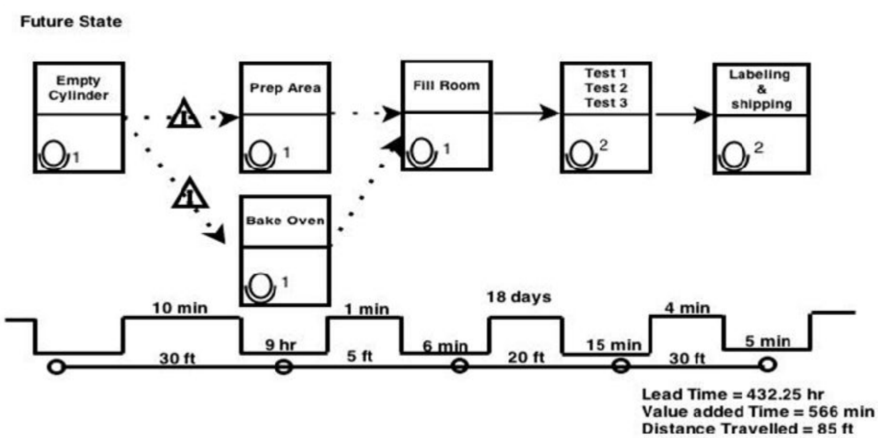

Figure 4. Future State Value Stream Map.

5. CONCLUSION

This study applied the Lean concept and methods to improve the production efficiency and reduce production loss in a compressed gas and liquid filling company. By carefully analyzing the gas and liquid filling processes, root causes of product loss were identified and methods were suggested for improvements. Various wastes such as transportation, motion, and waiting were observed and a new plant layout was generated. The results show that the new layout required less floor space, shortened cylinder travel distance and reduced process lead time.

ACKNOWLEDGEMENTS

The lead author would like to acknowledge the support of the James. E. Smith Professorship provided by Louisiana Board of Regents to realize this study.

REFERENCES

[1] E. Adam: "Alternative Quality Improvement Practices and Organization Performance", Journal of Operations Management, Vol. 12, No. 1, pp.331–347, 1994.

[2] T. R. Browning and R. D. Heath: "Reconceptualizing the Effects of Lean on Production Costs with Evidence from the F-22 Program", Journal of Operations Management, Vol. 27, pp. 23–44, 2009.

[3] R. Shah and P. Ward: "Lean Manufacturing: Context, Practice Bundles, and Performance", Journal of Operations Management, Vol. 21, pp. 129–149, 2003.

[4] P, Matlock and A, Coulter: "Lean Thinking in the Compressed Gas Industry", CryoGas International, pp.18–22, 2006.

[5] J. Cedarleaf: "Plant Layout and Flow Improvement", New York: McGraw-Hill, 1994.

[6] J. A. Tomphkins and J. A. While: "Facilities Planning", New York: Wiley, 1984.

[7] A. Rahani and M. al-Ashraf: "Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study", Engineering Procedia, Vol. 41, pp. 1727–1734, 2012.

[8] J. Ker and Y. Wang: "Applying the Principles of Lean Manufacturing to Optimize Conduit Installation Process", Lecture Notes in Electrical Engineering, Vol. 234, pp. 923–929, 2013.

[9] A. Drira, H. Pierreval, and S. Hajri-Gabouj, "Facility layout problems: A survey", Annual Reviews in Control, Vol. 31, Issue 2 , pp.255–267, 2007.

[10] E. Atmaca and S. S. Girenes: "Lean Six Sigma Methodology and Application", Quality & Quantity, Vol. 47, pp. 2107–2127, 2013.

[11] M. George: "Lean Six Sigma: Combining Six Sigma Quality with Lean Production Speed", New York: McGraw-Hill, 2002.

[12] A. G. Psychogios and L. K. Tsironis: "Towards an Integrated Framework for Lean Six Sigma Application: Lessons from the Airline Industry", Total Quality Management, Vol. 23, No. 4, pp. 397–415, 2012.

[13] F. K. Wang and K. S. Chen: "Application of Lean Six Sigma to a Panel Equipment Manufacturer", Total Quality Management, Vol. 23, No. 4, pp. 417–429, 2012.

[14] Y. Avraham: "Combining Lean, Six Sigma, and the Theory of Constraints to Achieve Breakthrough Performance" Goldratt Institute, 2009.

[15] R. B. Pojasek: "Lean, Six Sigma and the Systems Approach: Management Initiatives for Process Improvement", Environmental Quality Management, Vol. 13, pp. 85–92, 2003.

[16] S. K. P. N. Silva: "Applicability of Value Stream Mapping (vsm) in the Apparel Industry in Sri lanka", International Journal of Lean Thinking, Vol.3, No.1, pp.36–41, 2012.

[17] http://www.chartindustries.com/distribution/products/packaged-gas/lo-loss.aspx [last accessed: 01/15/14]

[18] D. Sule: "Manufacturing Facilities: Locations, Planning, and Design", Boca Raton, FL: CRC Press, 2009.