Application of Lean Line Concepts to Improve Efficiency of PE Pump Assembly Lines

Dr. Mohan Babu. G. N.
Professor, Dept. of Industrial Engineering and Management
M.S. Ramaiah Institute of Technology
Bangalore, India.

Mr. Varun Yadav. D
Graduate Student (M .Tech in Industrial Engineering)
Dept. of Industrial Engineering and Management
M.S. Ramaiah Institute of Technology
Bangalore, India.

Abstract: **This paper is concerned with implementation of lean line concepts in multi-cylinder fuel injection pump assembly lines in a multinational company[1]. Presently, the plant has 8 assembly lines that run for 3 shifts a day, wherein a total of 264 operators assemble 5 types of pumps (2/3/4/5/6 cylinders). The company has employed batch production that has resulted in very long lead times for products. Assembly of each type of pump involves 26 operations. All pumps require a similar sequence of operations, but more the number of cylinders in the pump being assembled larger would be the assembly time due to increased work content. Due to frequent changes in the customer demand and reduction in the number of operations - thanks to Kaizen, the lines need to be frequently rebalanced vis-à-vis changes *takt* times. Our analysis showed that the variation in monthly demand for pumps over the past 39 periods is normally distributed. A target production capacity to meet the monthly demand for at least 90% of the times was set. This monthly production requirement was converted into daily demand requirements and the corresponding *takt* times and Planned Cycle Times (PCTs) for various types of pump assembly were calculated. In our lean approach we divided each U-shaped assembly line into cells each with a set of tasks allocated to an operator and performed in a loop. The sum of task times in a loop is closely matched with the PCT of the pump type being assembled. When the assembly lines were balanced with this new PCTs, the number of operators drastically required. A production schedule combining both dedicated and mixed model production is proposed to produce every product every day in small batches as per its daily demand. The improved production schedule prepared required only 202 assembly operators as compared to 264 of the present practice. In other words, 62 operators are available for reallocation to other jobs which represented a huge saving of 23.5% workforce.**

Keywords: Lean line concepts, multi-cylinder fuel injection pumps, assembly line balancing, mixed model production schedule.

I. INTRODUCTION

Multi-cylinder fuel injection pumps are at the heart of diesel engines used in earthmovers, heavy vehicles, gensets, and marine vehicles. They help in controlling the fuel injection into engine. The multinational company where the study was carried out has a plant with 8 dedicated assembly lines that run 3 shifts a day. The lines assemble 5 types of multi-cylinder fuel injection pumps namely, 2-cylinder, 3-cylinder, 4 cylinder, 5-cylinder and 6-cylinder pumps. All types of pumps require a similar sequence of assembly operations. The assembly process that had earlier involved 28 tasks/operations now has only 26 due to the company's Kaizen drive. The different types of pumps require different amount of time to assemble them. In other words, a pump having more number of cylinders in it calls for greater assembly time, as some tasks in it take longer times relative to smaller pumps. The sequence of assembly tasks and the associated task times for various types of pump models are given in the Table I. Wherever the task involved both man and machine elements, the time taken by each of them is indicated separately.

Demand data over the past several years indicates that the monthly customer demand has varied widely for all types of pumps. In essence, it translates into significantly varying daily demand. Hence, *takt* time also undergoes frequent revision demanding frequent rebalancing of lines. The related literature is reviewed to explore ways of efficiently addressing this situation.

II. LITERATURE REVIEW

Significant amount of research work on assembly lines has focused on Assembly Line Balancing (ALB). Assembly line balancing is the allocation of tasks among the assembling stations such that precedence relations are not violated and the station time is less than the *takt* time [1].

Takt time is the desired time between two successive units of output from a production line. It sets pace of production. It determines the throughput to be achieved to meet the average customer demand in a certain current period [2]. Production planning department computes *takt* time using demand forecast data and the effective time available to produce in a certain period. The latter is affected by overall equipment effectiveness (OEE) of equipment in the assembly line. *Takt* time is calculated as follows.

[1] The name of the company is not indicated for the sake of maintaining confidentiality

$$\text{Takt time} = \frac{\text{Total Avaialable Production Time}}{\text{Total Production Requirements}} \quad \ldots(1)$$

TABLE 1: Time required for assembling pumps with different number of cylinders.

Si No.	Manual Time in (s)					Machine Time in (s)
	2 Cylinder Pump	3 Cylinder Pump	4 Cylinder Pump	5 Cylinder Pump	6 Cylinder Pump	
1	12	12	12	12	12	
2	32	35	37	40	43	
3	21	28	36	48	54	
4	27	44	65	86	103	
5	13	19	22	27	32	18
6	75	75	75	75	75	
7	56	59	69	75	78	
8	59	71	78	87	90	
9	96	96	96	96	96	
10	5	5	5	5	5	22
11	30	30	30	30	30	
12	-	-	-	37	37	
13	68	68	68	68	68	
14	48	48	48	48	48	
15	41	41	41	41	41	
16	5	5	5	5	5	25
17	7	7	7	7	7	
18	26	29	31	33	35	
19	26	26	26	26	26	
20	29	34	41	46	51	
21	29	29	29	29	29	12
22	71	71	71	71	71	
23	33	33	33	33	33	
24	54	54	54	54	54	
25	10	16	20	24	28	
26	16	24	32	40	48	
Total Manual Task Time (in s)	889	959	1031	1143	1199	
Total Machine Operation Time (in s)	77	77	77	77	77	
Total Assembly Time (in s)	966	1036	1108	1220	1276	

Variations in production output is common, which may be due to quality problems, untrained operator on the job, substandard material, power fluctuations and so on. To guard against these problems, one could think of maintaining buffer inventory. But inventory is viewed as a waste as it adds only cost to the product. Therefore instead of carrying inventory one could balance the line such that throughput time is slightly lesser than the *takt* time. This time is called planned cycle time (PCT) [3].

Assembly line balancing problems can be solved using exact methods, heuristics and meta-heuristics [4]. Operations research approaches like integer programming and dynamic programming provide optimal solutions to the assembly line balancing problems. These exact methods involve a lot of computational effort. With the increase in precedence constraints and the number of tasks, formulation of ALB problem becomes very difficult and practically impossible to solve manually. Heuristic approaches help in solving ALB problems with lesser manual effort. However, heuristic approaches don't guarantee optimal solutions to the problem and provide only feasible (sometimes near optimal) solutions. Heuristics are usually problem-specific and difficult limited in their generic applications. They produce unique solution to a problem. But an ALB problem may have more than one acceptable solution which may go ignored by a heuristic approach. To overcome these disadvantages meta-heuristics have been proposed for solving the assembly line balancing problems [5]. A meta-heuristic gives solutions which are near optimal but may have been ignored by a heuristic. There are two types of meta-heuristic approaches: (i) Local search methods and (ii) Evolutionary methods. Local search method searches its neighborhood for new solutions based on the current solution. Some examples of this method are simulated annealing, tabu search, greedy randomized adaptive search procedure (GRASP). Evolutionary method generates many solutions at every iteration. Some examples of this method are genetic algorithm and ant colony optimization technique.

There are two lean manufacturing approaches used for the ALB problems: (i) Rabbit chasing approach and (ii) Dividing the assembly line in cells [6]. In Rabbit chasing approach, an operator is introduced into the assembly cell just after the first operator. He may be approximately a task behind the first operator. In the similar way we can introduce any number of operators. The cycle time of Rabbit chasing approach is calculated by dividing the total assembly time for the product by number of operators. The cycle time thus derived is valid until it is greater than the cycle time of the slowest work station in the assembly line. Otherwise, the cycle time would be the slowest station time in the assembly cell.

Another alternative lean approach to Rabbit chasing approach is dividing the U shaped assembly line into cells. Each cell is assigned a set of tasks such that the sum of tasks in the cell is less than or equal to the PCT, and is called one operator loop. Also the cells are designed in such a way that the operator paths within the assembly line do not cross each other. The cycle time of the assembly line will be the longest operator loop i.e. the cell in which the sum of tasks is greater than other cells. A comparison of Rabbit chasing approach vis-à-vis Dividing the assembly line into cells is shown in figure 1.

One can use above mentioned approaches to balance the assembly line. The efficiency of the balanced line is calculated as follows.

$$\text{Balancing Efficiency} = \frac{\text{Sum of all task times}}{\text{Number of loops} * \text{longest loop}} \quad \dots(2)$$

Once the assembly line is balanced the production schedule can be prepared. The schedule is nothing but a time table to indicate what must be produced and when.

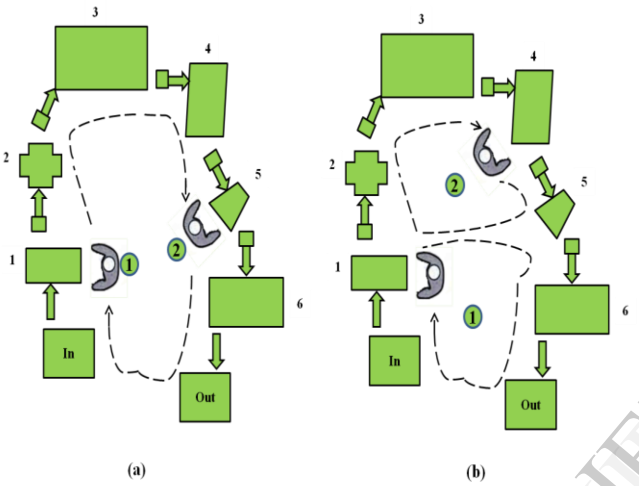

Figure 1: (a) Rabbit chasing approach and (b) Dividing the U-shaped assembly line into cells approach.

Scheduling production to meet varying daily-demands results in either the workers (and machines) working overtime or left idle. Excess demand strains the production system and lean demand underutilizes the resources. This can be prevented by maintaining leveled production every day, which is called as Heijunka by Japanese. Heijunka aims to level the workload of all work centers by producing roughly the same mix of products every day. The same sequence is repeated throughout a leveling period. This has an effect of reducing inventory [7]. Assembling of all product types in appropriate batch sizes in a mixed fashion on a single line every day is referred to as mixed- model assembly [8]. However, when the production is made in large batches to minimize the number of setups, one needs to maintain a large amount of inventory of raw materials and finished goods which is undesirable. Producing in small batches reduces inventory levels and also lead times of the products.

III. PROBLEM STATEMENT

The company is currently assembling pumps with 2, 3, 4, 5, and 6 cylinders on its 8 U-shaped assembly lines. The present study, after examining demand data for more than past 36 months, observed that the demand for pumps ranged from 30,000 to 80,000 per month. The changing monthly demand requires the calculation of new *takt* time every month, and rebalancing the assembly line accordingly.

The plant currently runs batch assembly schedule which has very long lead times for certain products being assembled. When the assembly is scheduled in the order 2, 3, 4, 5 and 6 cylinder pumps in a month, a customer who has ordered 6 cylinder pumps must wait till the end of the month to receive the product.

The company's assembly plant has 8 assembly lines and all of them operate 3 shifts a day. As there are 11 dedicated assembly operators in every assembly line, the plant in all has 264 operators (11 x 8 x 3) working in a day. More the number of cylinders in a pump, more the time it takes for the assembly as shown in the Table I. This means a pump with lesser number of cylinders will require lesser number of operators for assembly when compared to a pump with more number of cylinders. The assembly lines have been balanced for the most time consuming model, i.e., 6 cylinder pump. The loops are defined for this model and the same are used for assembling other models too. This has resulted in underutilization of the resources and a lot of inefficiency.

The present study aimed to balance existing U-shaped assembly lines by dividing each assembly line into cells as necessary, and then propose a method to assemble every pump every day (EPED) in appropriate batch sizes by employing either dedicated assembly or mixed model assembly concepts. The objective set out for the study was to improve the assembly efficiency, reduce the inventory, cut down the lead time for fulfilling the customer order.

IV. METHODOLOGY

Conventional line balancing heuristics such as Shortest task first, Longest task first, Ranked positional weight are not used for balancing U-shaped assembly lines because these heuristic rules do not consider the way the assembly line is laid out i.e., line configuration. The following is the generalized procedure for balancing U-shaped assembly line.

1. Determine *takt* time and PCT.
2. Start with a single operator, and the first task.
3. Load the operator with first task, and next immediate neighboring task in the U-line, then next neighboring task (all tasks that are immediately around him as shown in figure 2) and so on till the sum of task time is less than PCT.
4. Once the operator is loaded with tasks up to the PCT, or else leftover time with the operator is less than the next neighboring task, then allocate a new operator to the line and start allocating the task to the new operator.
5. Make sure that during the allocation of tasks, paths of operators in the U-line do not cross each other.

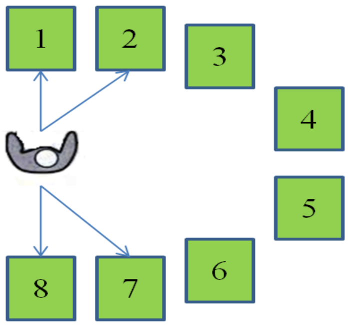

Figure 2: Neighboring tasks for an operator.

6. Continue with the above steps till all the tasks in the assembly line are allocated to operators.
7. Determine the number of operator loops, cycle time (slowest operator time or maximum loop time) and calculate the efficiency.
8. Identify any improvements in the assembly line and implement them.
9. Rebalance the line after implementing the improvements.

After balancing the assembly line the assembly schedule can be prepared.

This study proposed an approach that combines the concepts of dedicated assembly and mixed model assembly in the assembly plant in order to produce every pump type every day in appropriate quantities thus reducing the lead times and inventory carried. The proposed ALB and scheduling algorithm is as follows.

1. Determine the daily requirements of various pump types based on their monthly demand. Compute *takt* time and PCT taking into account effective assembly time available on a line per day.
2. Select the pump type with the highest demand relative to others.
3. Assign the task of assembling this type of pumps to a dedicated assembly line.
4. If the assembly line capacity is not adequate to assemble these pumps in the quantity required for a day, dedicate one more assembly line. Keep adding more and more dedicated lines till the daily requirement of that pump type is met. If no more pump types need to be assembled, go to step 6.
5. If some time is left over in the last dedicated line, try to accommodate the pump type with next highest daily demand for the remaining capacity available. Go to step 4.
6. Assign the number of operators to a line based on the pump type that requires the largest time of assembly on that line.
7. Any excess line capacity leftover after allocation of all pump types can be kept as buffer capacity to accommodate any variations in the assembly process.
8. If the leftover capacity is as large as a shift, then we can shut down the line for that shift.

V. Data Collection and Analysis

The literature review reflected on several heuristics such as longest task first, shortest task first and ranked positional weight approaches being used for ALB. Further, the company has adopted its own procedure of balancing the line. We have proposed an approach based on lean concepts in the previous section. It is interesting to analyze the performances (ALB efficiency) of all these approaches against a common data set. Hence, data on the standard time required to complete each assembly task on various types of pumps were collected (Refer Table 1.) Further, data relating to the monthly demand for various types of pumps over the past 39 months was collected (See Table 2). Notwithstanding the collection of a larger data set, the study first tested the various approaches on a sample data, i.e., on the demand for the latest month for both 2-cylinder and 6-cylinder pumps that represented the extremes of total assembly times required. This was enough to contrast their line balancing performances and the results are exhibited in Table II.

Table II: Comparison of assembly line balancing methods for 6 cylinder pumps.

	Assembly Line Balancing Methods used on 6 Cylinder Pumps				
	Current Method	Longest Task First Heuristic	Shortest Task First Heuristic	Ranked Positional Weight Heuristic	Lean Method
Cycle Time in s	158	165	165	165	158
No. of Operators	11	10	10	9	9
Efficiency	69.98 %	72.66%	72.66%	80.74%	84.31 %

From Table II we can infer that the current method adopted by the company to allocate operators is less efficient. Although heuristic approaches resulted in better balancing efficiency they were not suitable for a U-shaped assembly lines as they resulted in operator loops that crossed each other. Our lean approach of dividing the assembly line into cells improved the line efficiency to 84.31%. The resulting solution was also effective as operator paths did not cross each other. Similarly, the evaluation process was repeated for assembly of 2 cylinder pumps and the results are shown in Table III.

Table III: Comparison of assembly line balancing methods for 2 cylinder pumps.

	Assembly Line Balancing Methods used on 2 Cylinder Pumps				
	Current Method	Longest Task First Heuristic	Shortest Task First Heuristic	Ranked Positional Weight Heuristic	Lean Method
Cycle Time in s	158	160	158	163	160
No. of Operators	11	7	7	7	6
Efficiency	51.15 %	79.37%	80.37%	77.91%	92.60 %

The Tables II and III show that the proposed procedure based on lean concept works better than other approaches on a U-shaped assembly line.

Having found evidence for the better performance of the proposed lean approach, the study later used complete demand data (for all 39 months from January 2011 to March 2014) to determine PCT, operator loops for different pump types, allocation of operators, and prepare assembly schedule on all assembly lines for meeting daily requirement of each type of pump in appropriate batch sizes. Examination of the data revealed that the variation in monthly demand for multi-cylinder pumps over the abovementioned period could be well approximated by Normal distribution with a mean of 64,612 pumps and a standard deviation of 9304 as shown in Figure 3.

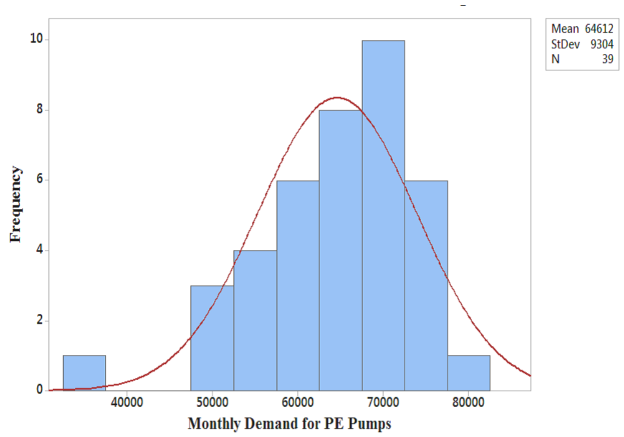

Figure 3: Normal distribution showing the demand for pumps.

After discussing with the company executives, it was decided that the assembly plant should be able to meet the customers' demand for at least 90% of the times. Setting the system capacity to meet the demand for at least 90% of the times implies that $P(X \leq x) = 0.90$ where x is the system capacity. With respect to a standard normal curve, this is equivalent to $P(Z \leq z) = 0.90$, and the corresponding value of $z = 1.285$. Substituting $\mu = 64{,}612$ and $\sigma = 9{,}304$ and $z = 1.285$ in the equation $x = \mu + z\,\sigma$, we get x = 76,568 pumps per month. That is, monthly 76,568 pumps have to be assembled to meet the demand 90% of the times. This 90% is a pragmatic upper limit because there has been only one data point among 39 that has exceeded this limit. Hence, balancing the lines to meet the customer demand 100% of the times will result in gross underutilization of line capacities.

Given a planned capacity of 76,568 pumps per month and a typical 26-working -day month, the daily requirement would be 2944.92 pumps from all 8 lines together, or 368.11 pumps rounded to 369 pumps per line. Similarly, in a 3-shifts day with 435 working minutes in each shift, the total available production time (in seconds) per line in a day is 3*435*60 = 78,300 s. Thus using equation 1, we can compute the *takt* time as follows.

Takt time = 78,300 / 369 = 212.19 s per pump

Considering the company-specified Overall Equipment Effectiveness (OEE) as 65%, the computed planned cycle time would become 212.19 * 0.65 = 137.92 s per pump. Keeping this planned cycle time 137.92 s per pump the lines were balanced for assembling all types of pumps. The efficiency of the balanced line, cycle time, and number of operator loops for all the types of pumps are summarized in the Table IV.

Table IV: Cycle time in s, number of operators required and the efficiency of the balanced line.

Pump Type	2 Cylinder Pumps	3 Cylinder Pumps	4 Cylinder Pumps	5 Cylinder Pumps	6 Cylinder Pumps
Total Task Time (in s)	889	959	1031	1143	1199
Cycle Time (in s)	134	134	131	134	136
No. of Operators	7	8	9	10	10
Efficiency	94.78	89.46	87.45	85.30	88.16

Once the lines are balanced and number of operators required for the assembly is determined for every pump type, the production schedule for all the lines can be prepared.

As said earlier the current practice in the company is to produce pumps in batches. The plant ships products by the end of third shift every day. The lead times for the sample data i.e. the current month demand using batch productions is shown in Table V.

Table V: Shortest and longest lead times in days for the sample demand data.

Pump Type	Shortest Lead Time in days	Longest Lead Time in days
2 cylinder pumps	1	2
3 cylinder pumps	2	18
4 cylinder pumps	18	23
5 cylinder pumps	23	23
6 cylinder pumps	23	26

It can be seen in Table V that for a customer who has ordered 2 cylinder pumps can get his order delivered on 1st day or 2nd day. A customer who has ordered for a 3 cylinder pump can expect his delivery anytime between 2nd day and 18th day. Similarly for the 4 cylinder pump the order delivery is anytime between 18th day and 23rd day. The demand for 5 cylinder pumps is very less, therefore any order for 5 cylinder pumps is planned to be delivered on 23rd day. A customer who has ordered a 6 cylinder pump must wait almost till the end of the month, and can get the delivery anytime between 23rd day and 26th day. One can observe long lead times associated with various types of pumps. Hence, the present study recommends mixed model assembly producing every pump type every day in appropriate batch sizes.

The demand data for each type of pump over the past 39 months is seen to be normally distributed. The number of that type of pumps to be produced monthly to meet the customer demand for at least 90% of the times is computed as earlier using standard normal tables. This monthly figure is translated into daily requirement. The monthly and daily requirement of various types of pumps (2/3/4/5/6 cylinder pumps) and their cycle time in s are shown in Table VI. The daily schedule to assemble them in the required number is prepared as shown in Table VII.

Table VI: Daily production requirement for individual pump types

Pump Type	Monthly Demand	Daily Demand	Cycle Time in s
2 cylinder pumps	3826	148	134
3 cylinder pumps	49091	1889	134
4 cylinder pumps	16763	645	131
5 cylinder pumps	60	3	134
6 cylinder pumps	6833	263	136
Total Demand	76573	2948	

Each shift of plant operation has 435 working minutes or 26,100 s. Considering the stipulated OEE of 65% the effective available time is only 283 minutes or 16,965 s. Once the cycle time of a given pump and the effective available time/shift are known, the number of that type of pumps that can be assembled in a shift can be computed.

As 3-cylinder pump has the highest daily demand we considered it on priority for scheduling. Given that only 378 such pumps can be assembled in all the 3 shifts on a line per day, but 1889 are required, 5 assembly lines are to be assigned to this task. Then we considered 4-cylinder pump that has next highest daily demand and continued in the same way assigning its assembly task to the 6th and 7th assembly lines. The remaining capacity on the 7th line is used to accommodate the pump type with next highest daily demand. The scheduling of the remaining types of pumps namely, 2-cylinder, 6-cylinder and 5-cylinder pumps in that order, is also done on the same principle. Table 6 shows the daily schedule to be followed in a month to cater to the demand of customers for at least 90% of the times. For the 8th assembly line, we see that both 2-cylinder and 6-cylinder pumps are produced in the same shift (i.e., shift 1). In such cases, the number of operators required in the shift is determined by that pump type with greater cycle time. This is done to avoid any bottlenecks in the production.

Table VII: Daily production schedule to meet the demand for various types of pumps.

Assembly Line and Operators Required	Shift 1		Shift 2		Shift 3	
	Pump Type	Qty	Pump Type	Qty	Pump Type	Qty
Line 1	3 cylinder	126	3 cylinder	126	3 cylinder	126
Operators Required	8		8		8	
line 2	3 cylinder	126	3 cylinder	126	3 cylinder	126
Operators Required	8		8		8	
Line 3	3 cylinder	126	3 cylinder	126	3 cylinder	126
Operators Required	8		8		8	
Line 4	3 cylinder	126	3 cylinder	126	3 cylinder	126
Operators Required	8		8		8	
Line 5	3 cylinder	126	3 cylinder	126	3 cylinder	125
Operators Required	8		8		8	
Line 6	4 cylinder	129	4 cylinder	129	4 cylinder	129
Operators Required	9		9		9	
Line 7	4 cylinder	129	4 cylinder	129	2 cylinder	126
Operators Required	9		9		7	
Line 8	2 cylinder	22	6 cylinder	124	6 cylinder	41
	6 cylinder	98			5 cylinder	3
Operators Required	10		10		10	
Total Pump Qty Produced					2948	
Total No. of Operators Required per Day					202	

This ALB approach with: (i) cells formed in U-shaped assembly line, (ii) assembly of each type of pump every day in certain quantities, and (iii) a schedule to meet the customers orders at least 90% of the times, ensured the following.

(i) Customers need not wait for long for fulfillment of their order,
(ii) A drastic reduction in the inventory carried,
(iii) A significant improvement in the line balancing efficiency and
(iv) Considerable amount of slack capacity is still available to meet contingencies, as the lines are balanced keeping in view the 90% of the ***peak*** demand.

Table VII shows that the number of operators required by our lean approach to assembly line balancing is only 202, while the previous practice in the company has been to use 264 operators. In other words, 62 operators are available for reallocation to other jobs which represented a huge saving of 23.5% workforce. Similar exercises for the implementation of lean concepts in other manufacturing and assembly lines in the plants can save significant amount of labour and in turn cost to the company. This is apart from the other benefits mentioned above.

VI. CONCLUSIONS

Assembly line balancing problems are dynamic in nature. With Kaizen and changing customer demand there is always a need to frequently rebalance the assembly line. The problem becomes complex when more than one type of product is assembled on the line. Presently, in the multi-national company where the study was carried out a variety of fuel injection pumps - namely 2/3/4/5/6 cylinder pumps - are being assembled. More the number of cylinders in a pump, greater would be its assembly time. The assembly process has 26 tasks and is being done by 11 dedicated operators in a line. 8 such lines operating 3 shifts a day have employed a total of 264 operators. In the batch assembly operations followed previously, neither the balancing efficiency was high nor the responsiveness to customers' orders was good.

Literature indicated that the problem of assembly line balancing has been addressed in many ways. However, for U-shaped assembly lines under examination, it was found that they did not perform well. Hence, the study planned a lean approach to balance the lines. The U-shaped assembly lines were divided into cells. Each cell was a set of tasks in the assembly line, such that the total task time is less than or equal to the planned cycle time (PCT). Historical monthly demand data for the period January 2011 to March 2014 was analyzed and quantity to meet the daily demand at least 90% of the times was determined for individual pump variety. The *takt* time and planned cycle time (PCT) to meet this was determined, and the lines were balanced to this PCT. The number of operators required was also determined. Based on this, a production plan to produce every pump type every day was prepared. The production plan showed that the total number of operators required to meet 90% of the peak daily demand is 202. However, previously the company employed as many as 264 dedicated assembly operators. Hence, the lean approach resulted in a saving of 62 operators and they are available for reallocation to other jobs. Also the proposed production schedule to produce every pump type every day produced all products in appropriate batch sizes which not only reduced the customer order fulfillment times, but also inventory carried. Further, as the lines are balanced keeping in view 90% of the peak daily demand, there would be sufficient slack time available (at all other lower demands) to meet any contingency. Studies similar to this could be undertaken in other manufacturing assembly areas too to effect reduction in cost and improve service to customers.

REFERENCES

[1] C. Ortiz, *Kaizen assembly*, 1st ed. Boca Raton, Florida: CRC Taylor & Francis, 2006.

[2] T. Luyster and D. Tapping, *Creating your lean future state*, 1st ed. New York: Productivity Press, 2006.

[3] K.J. Duggan, *Creating mixed model value streams*, 1st ed. Boca Raton, Florida: CRC Press, 2013.

[4] P. Mahapatra, *Operations management*, 1st ed. New Delhi: PHI Learning, 2010.

[5] B. Jarboui, P. Siarry and J. Teghem, *Metaheuristics for production scheduling*, 1st ed. London: ISTE, 2013.

[6] J.M. Nicholas and A. Soni, *The portal to lean production*, 1st ed. Boca Raton, Florida: Taylor & Francis, 2006.

[7] P. Haghirian, *Understanding Japanese management practices*, 1st ed. New York: Business Expert Press, 2010.

[8] J. M Nicholas, *Competitive Manufacturing Management*, 1st ed. India: Tata McGraw-Hill Education, 2001.