Optimization and Simulation of Layout of Engine Cylinder Block Line for Improving Productivity

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Abstract

In manufacturing systems, facility layout design has an importance as it helps to improve the productivity of layout, influences manufacturing costs, WIP and lead times. The current work aims to enhance the productivity of engine cylinder block line and achieving the increased demand by design of mixed product production line. Two production line has been considered for present work. After the detailed analysis of every activity at each workstation, merging of both production line has been done and new workstation sequence and proposed cycle time for each workstation has been evaluated. The Yamazumi chart is used to compare the average proposed cycle time at each workstation and the new takt time for balancing the line. New layout established the possibility of reducing the manpower and number of workstations for new demand. New layout is analyzed by using Witness simulation software which helped to determine the operators and workstations idle and busy time. Simulation results of new layout brought about reduction in manpower and reduction in idle time of operator. The proposed new layout demonstrates an increase in yield and productivity compared to the current layout.

Keywords
Layout design, Productivity, Mixed-product, Yamazumi chart and witness software.

1. Introduction
Industries are always in search of various strategies in order to gain a competitive advantage and have to conceive and implement new strategies which give them the advantages such as flexibility, quick response, low cost, efficiency, quality, reliability and service. Enterprises must constantly enhance the underlying business and production process to be competitive. Production layout plays an important role in manufacturing industry. The performance of a production line is strongly affected by different layout configurations. A good layout design can help you make better use of resources including equipment, materials, space, and labor, as well as reduce inventory and setup time. Changing a layout design is an expensive and long-term endeavor. Any change or rearrangement of an existing layout incurs a significant cost in terms of both relocation and processing time. As a result, modifying the layout design cannot be done directly.

This study involved design of new mixed product production layout by combining the two lines at automobile industry. The goal of this study is to identify the current state of both line by doing detailed study of every operation and collecting all the necessary data useful for designing new improved proposed layout for not only improving the productivity but also optimizing the layout.

2. Literature Review
To get the maximum benefits companies always try to increase their productivity. Work study can be used for manufacturing unit to enhance productivity (Bargi and Raushan 2014). Work study consist of method study in which we can find most effective method of performing job and work measurement helps to determine the time required by operator for doing an operation on job at defined level of performance (Biswas et. al. 2016). There are other many

techniques as well to increase the productivity where we can use lean tools value stream mapping (VSM) model and technique for analyzing the non-value added activities (NVA) and valueadded activities VA doing the work standardization to get the productivity improvement, better quality, and waste elimination [S. Vijay and Prabha 2021]. Non-value-added activities are a major concern in any manufacturing system as they are the major waste. These are the operations that do not add any value to the product, i.e., the activities that the business must pay for even when the client is not paying the business for them. Companies can save resources by identifying these types of activity and removing them(Sharma and Meeta 2018). In order to improve plant space utilization, we can utilize systematic layout planning theory to reduce material handling and eliminate material flow backtracking, which will ultimately result in fewer work in progress (WIP) (Nyati et. al. 2017).

Line balancing is important tool in production which involves the balancing operator and machine time to match the production rate to the takt time. Before line balancing time study and analyzing process flow to find processes which are above the takt time and various line balancing methods are used (Harikrishnan et. al. 2020). Nithish Kumar et. al. (2014) presented the effectiveness of line balancing technique on the existing line which increase the line efficiency and reduced the number of workstations. Three-line balancing models were used such as kilbridge and wester column, rank positional weight and largest candidate rule out of which Rank positional weight method found to be more effective.

One extremely helpful tool that manufacturing organizations utilize to find the best solutions to their manufacturing problems and get higher returns from the process is simulation software. Numerous studies have looked into the advantages of using simulations to help with production layout design. To assist with decisions about plant capacity requirements, buffer size requirements, and the implications of changes in plant design on throughput time Eloranta and Raisanen (1987) suggested a simulation-based planning tool. With the help of simulation, we can create multiple what-if scenarios without affecting the ongoing process and can select the best possible outcome for the process (Poleshettiwar et.al.2016). Machine utilization and operator productivity can be visualized by simulation software which help to do optimization and improve the productivity (Raut et. al. 2016). Bhadekar et. al. (2017) presented the integration of simulation using WITNESS software with technique for order performance by similarity to ideal solution (TOPSIS) a Multiple Criteria Decision Making (MCDM) methodology to identify the best optimize layout which provide the better reliable results. Also, we can use longest processing time (LPT) concept to ensure the maximum utilization of all machines and the can also verify that by doing simulation by using simulation software (Deokar et. al. 2016).

From literature it is found that many tools and line balancing technique were employed in order to improve the productivity of layout. Also, it has been discovered that simulation is an important tool for modeling manufacturing systems in order to identify bottlenecks in the process and to suggest various alternatives to help select the best alternative by comparing different layouts. Simulation also helps to do analysis without actually implementing the solution and disrupting the actual production process. However limited attempts were made to improve the productivity and doing the simulation of mix product layout model using simulation software. Hence an attempt is made in this to design mixed product line and doing simulation of proposed layout using Witness software.

3. Problem Definition

This case study work has been done at automobile industry that manufacture engines for marine, gensets etc. applications. This research work has been done at engine cylinder block manufacturing division where three different models of engine cylinder blocks were manufactured. All the operations are carried out manually in this unit so the cycle time for each operation is more and this leads to operator anxiety and discomfort. Due to this, company is facing difficulty in achieving the increase in the total demand from 15 to 20 engine cylinder blocks per day as it will require more manpower and more space.

4. Methodology

The whole process of study work can be shortly explained by the following Figure 1. Multiple steps are required in the design of a proposed line to obtain an efficient layout arrangement of various resources, including machinery, equipment, raw materials, and labor. Three different models of engine cylinder block which are manufactured by company are Part A, Part B and Part C. Part A and Part Bis same only the difference is its volume capacity. Part Ais a 12-cylinder engine block whereas Part B is 16-cylinder engine block. Part Cisalso 16-cylinder block but different from Part A and Part B. Current process flow has been studied in detail and all the data is collected and using this

data new layout has been designed (Figure 2). To validate the theoretical results, Witness software has been used to analysis proposed line and finally the current and proposed layout were compared.
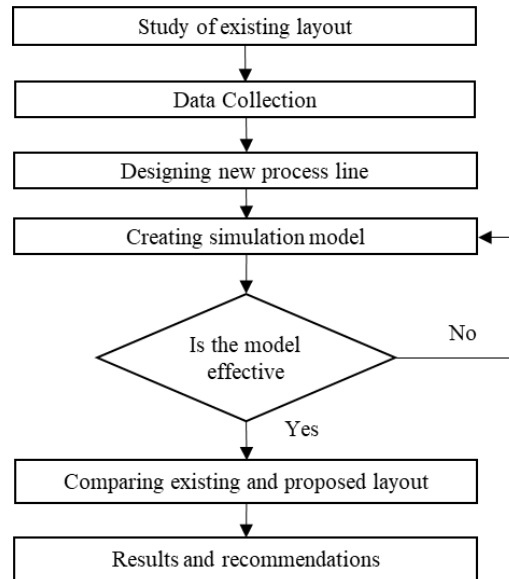

Figure 1. Steps in methodology

4.1 Current Layout
Current layout of engine cylinder block unit is shown below.
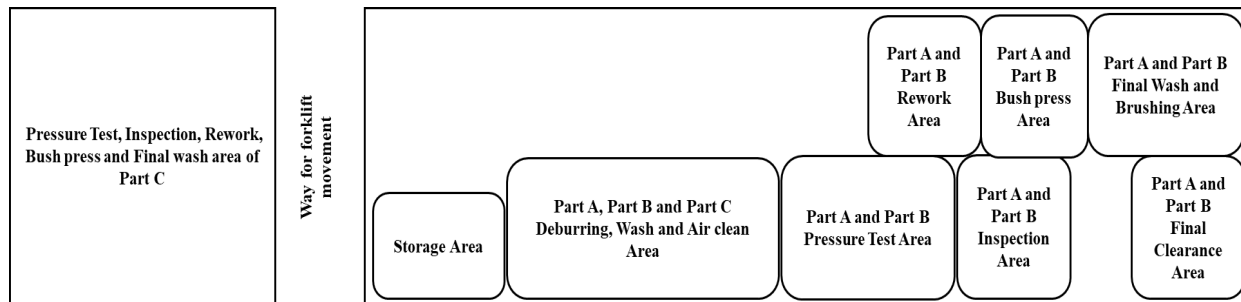

Figure 2. Current layout

Company follows a particular process to manufacture all the three models of engine cylinder block. Current layout consists of two production line, one is for Part A and Part B and another production line is for Part C.The existing line flow is carefully analyzed before layout design in order to clarify the entire procedure and guarantee the correctness of the data gathered. The planning and design phase of a new layout configuration can benefit from these facts. Detail study of current process was conducted and collected all the data for each workstation for all three models. Process flow of both line is explained in following sections.

4.1.1 Process flow of Part A and Part B
Figure 3 shows current process flow and workstation sequence on which various post machining operations are done and this workstations are common for Part A and Part B. Product mix for this line is 40% Part A and 60% Part B with total demand of 14 blocks per day. Total Number of workstations is eleven in which some works in three shift and some for two shifts. Cycle time for Part A and Part B for each workstation and manpower required is shown in Table 1.
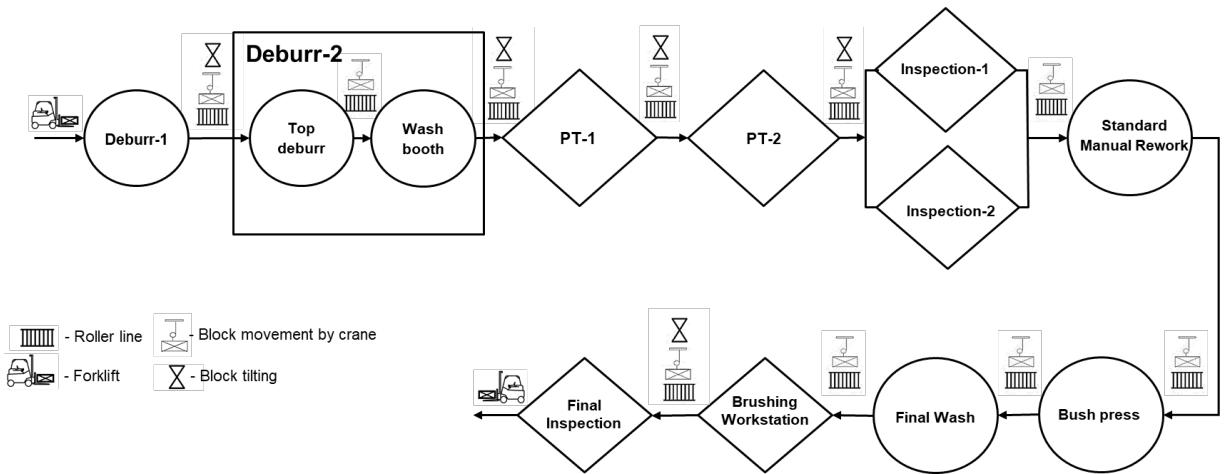
Figure 3. Detailed workstation sequence for Part A and Part B

Table 1. Summary of workstations for Part A and Part B

Sr. No.	Workstations	Part A CT (min) C_1	Part B CT (min) C_2	Average CT $C_1*0.4 + C_2*0.6$	Manpower		
					1st Shift	2nd Shift	3rd Shift
1	Deburr-1	70	80	76	1	1	1
2	Deburr-2	75	83	80	1	1	1
3	Pressure Test (PT)-1	60	70	66	1	1	1
4	Pressure Test (PT) -2	84	100	94	1	1	1
5	Inspection-1	150	150	150	1	1	1
6	Inspection-2	150	150	150	1	1	1
7	Standard Manual Rework	70	84	78	1	1	1
8	Bush Press	38	42	40	1	1	
9	Final Wash	41	41	41	1	0.5	
10	Brushing workstation	34	40	38	1	0.5	
11	Final Inspection	45	60	54	1	1	

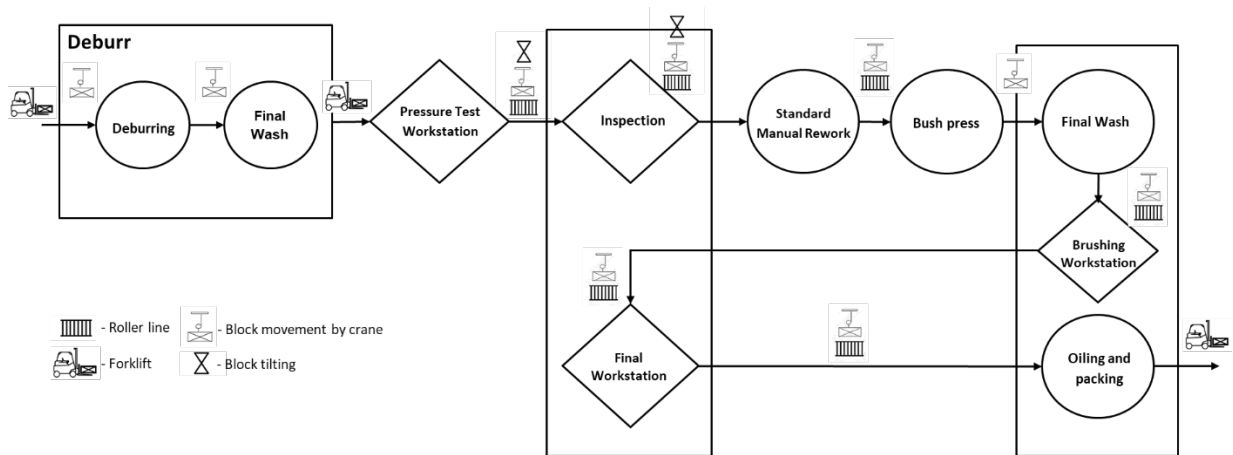## 4.1.2 Process flow of Part C

Figure 4. Detailed workstation sequence for Part C

The workstation sequence in Figure 4 shows process flow for Part C. Demand for Part C is 1 block per day. Total number of workstations is six which works for one shift. Cycle time for each workstation and manpower required is shown in Table 2.

Table 2. Summary of workstations for Part C

Sr. No.	Workstations	Part C (min)	Manpower		
			1st Shift	2nd Shift	3rd Shift
1	Deburr	375	1		
2	Pressure Test Workstation	369		1	
3	Inspection	240			1
4	Standard Manual Rework Workstation	300	1		
5	Bush Press	130	1		
6	Brushing, Final wash and Oil pack	120		1	

4.2 Designing proposed layout

After detail current process study, new layout must be design capable of giving the desired output. Now the demand for the engine cylinder block has been increased to 16 blocks per day for Part A and Part B, and 4 blocks per day for Part C (total 20 blocks per day). Product mix will be like 32% Part A, 48% Part B and 20% Part C. As all three-engine cylinder block has some similarity in their design so we can combine both current lines to make mixed product production line. To build a new layout, it is necessary to ascertain the number of workstations and operators needed in the new process flow.

4.2.1 Proposed process flow of Part A, Part B and Part C

Operations required and their sequence for all three models is same, so workstations need to be modified to achieve the desired demand and new takt time must be calculated which come to 63 mins/block by using following equation.

$$\text{Takt time} = \frac{\text{Total available time per day}}{\text{Demand per day}} = \frac{1260}{20} = 63 \text{ mins/block}$$

Now cycle time of each workstation in new proposed layout must be less than takt time to get the required output except for pressure test operations. For pressure test, separate workstations will be required for Part A & B and Part C as the element used are different for pressure test. So, the takt time calculated using above equation for pressure test of Part A and Part B is 78.75 min as total 16 block are required per day and for Part C is 315 min as 4 blocks are required per day. Company planned to automate operations like deburring, final wash and brushing by using robots. So new workstations have been added into new process flow which are robotic deburring by replacing deburring workstation and robotic washing by replacing brushing and final wash workstations. Manual deburring workstation also have been added after robotic deburring as there are some critical operations which are difficult to be done by robot and need to be done manually. There was similarity in operations like inspection, standard manual rework, bush press and oil pack so these operations can be done on same workstation for all three engine cylinder block. Proposed cycle time for each operation in new process flow is shown in Table 3.

Table 3. Proposed cycle time of operations of new line

Operations	Cycle time (min)			Average cycle time (min) $C_1*0.32 + C_2*0.48 + C_3*0.20$	Takt time (min)
	Part A (C_1)	Part B (C_2)	Part C (C_3)		
Robotic Deburring	45	50	55	49.4	63
Manual Deburring	30	30	30	30	63
Washing and air clean	53	53	53	53	63
Pressure Test (PT) of Part A and Part B	144	170	-	159.6	78.75
Pressure Test (PT) of Part C	-	-	369	369	315

Inspection	85	85	85	85	63
Std. Manual rework	40	45	50	44.4	63
Bush Press	38	42	100	52.32	63
Robotic washing	45	50	55	49.4	63
Final Inspection and oil pack	35	50	60	47.2	63

Using this proposed cycle time, yamazumi chart can be plotted against the takt time as shown Figure 5. which help to balance the overall cycle time of all workstations. From yamazumi chart, cycle time for pressure test (PT) of Part A and B, pressure test (PT) of Part C and inspection is more than takt time so we can add parallel workstations to balance the cycle time. Number of workstations required for operation can be calculated as

$$\text{Number of workstations} = \frac{\text{Cycle time of operation} \times \text{Desired output}}{\text{Total availble time}}$$

For pressure test of Part A and Part B,

$$\text{Number of workstations} = \frac{159.6 \times 16}{1260} \approx 3$$

Hence number of workstations required for pressure test of Part A and Part B will be three. Similarly, number of workstations required for pressure test of Part C will be two and for inspection will be 2.The final proposed workstation sequence is shown in Figure 6 in which PT-1, PT-2 and PT-3 are parallel workstations for pressure test of Part A and Part B where PT-4 and PT-5 are parallel workstations for pressure test of Part C.
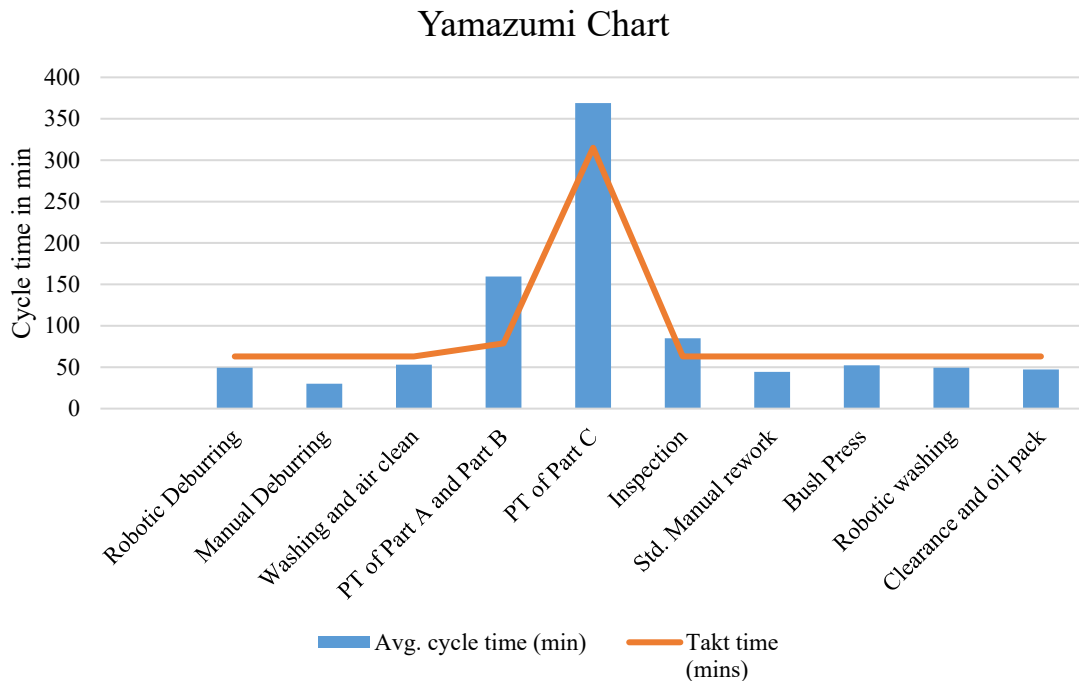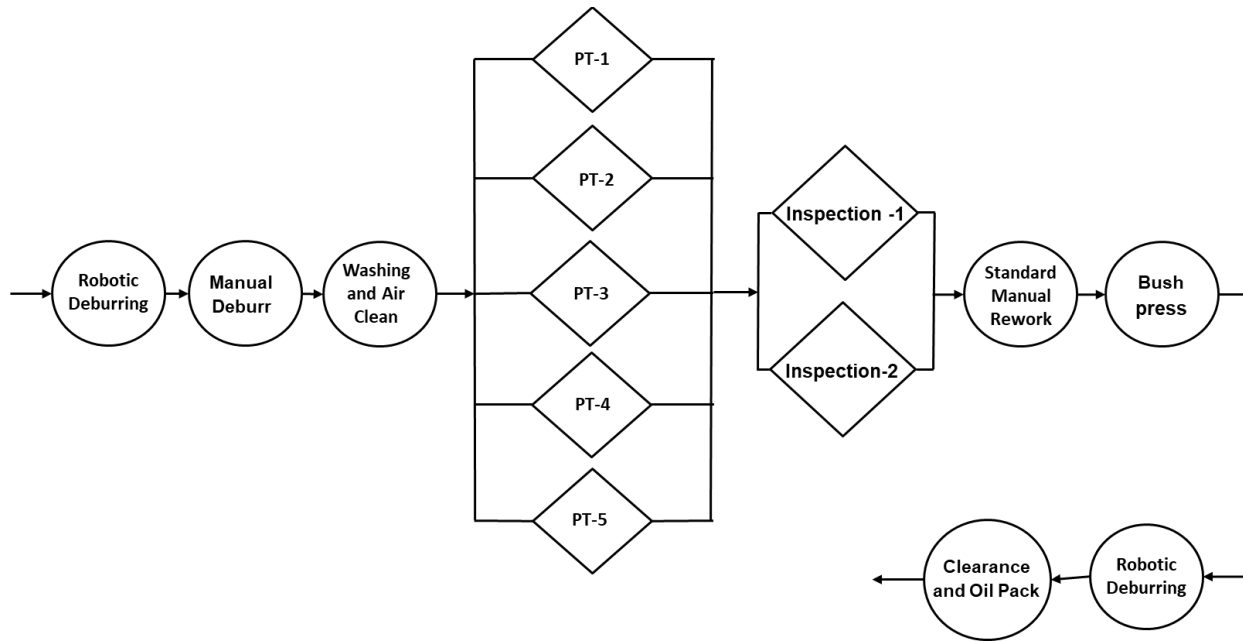

Figure 5. Yamazumi Chart

Figure 6. Proposed workstation sequence for Part A, Part B and Part C

Now for calculating the number of operators required, available time per shift must be known. Company works for three shifts, for 1ˢᵗ shift available time is 450 mins, for 2ⁿᵈ shift available time is 450 min and for 3ʳᵈ shift available time is 360 mins excluding lunch time and tea break. Based on their pace of work and skill level, the operators' performances can be graded in the range of 75%, 85%, 95%, 105%, 115%, and 125%. We consider the performance factor as 85%. Number of operators required at workstation can be calculated as

$$\text{No. of Operators} = \frac{\text{Cycle time of workstation} \times \text{Desired output} \times \text{No. of shifts}}{\text{Total available time} \times 0.85}$$

For example, number of operators required for inspection workstation will be

$$\text{No. of Operators} = \frac{80 \times 20 \times 3}{1260 \times 0.85} = 4.45 \approx 5$$

This method can be used to compute the number of operators needed for different workstations. Robotic deburring and robotic washing are fully automated workstations, requiring just the operator to load and unload the cylinder block. Hence one operator is assigned per shift for this workstation. Table 4 lists workstation, along with its cycle time, shift-wise operators required, and theoretical output per day. Based on this data new layout has been designed which is shown in the Figure 7.
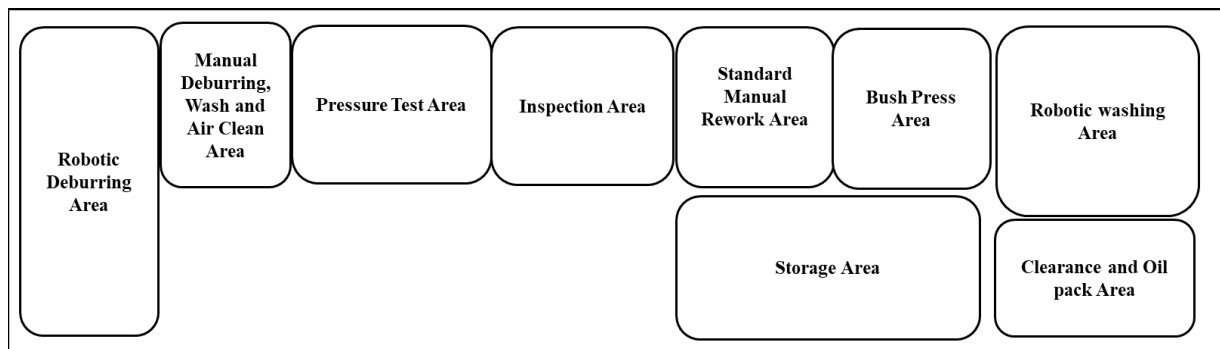

Figure 7. Proposed layout for Part A, Part B and Part C

Table 4. Summary of workstations of proposed layout

Sr. No.	Workstation	Avg. cycle time (min)	Manpower			Output / day
			1st Shift	2nd Shift	3rd Shift	
1	Robotic Deburring	49.4	1	1	1	22
2	Manual Deburring	30	1	1	-	26
3	Washing and Air Cleaning	53	1	1	1	20
4	Pressure Test workstation-1 (PT-1)	159.6	1	1	1	20.4
5	Pressure Test workstation-2 (PT-2)	159.6	1	1	-	
6	Pressure Test workstation-3 (PT-3)	159.6	1	1	-	
7	Pressure Test workstation-4 (PT-4)	369	1	1	-	
8	Pressure Test workstation-5 (PT-5)	369	1	1	-	
9	Inspection-1	85	1	1	1	22
10	Inspection-2	85	1	1	-	
11	Standard Rework	44.4	1	1	1	24.1
12	Bush Press	52.32	1	1	1	20.5
13	Robotic Washing	44.4	1	1	1	24.1
14	Final Inspection and Oil Pack	49.4	1	1	1	21.7

5. Results and Discussion
5.1. Simulation Model
The simulation of the production layout is carried out in order to evaluate the rationality and feasibility of the enhanced scheme, as well as to demonstrate a clear impact on the manufacturing process using Witness software. Model 1 shown in Figure 8 of proposed layout is made using witness software in accordance with Figure 6. Each workstation has given cycle time depending upon the input component type as shown in Table 3. Also, the operator at each workstation has been assigned according to the shift as shown in Table 4.
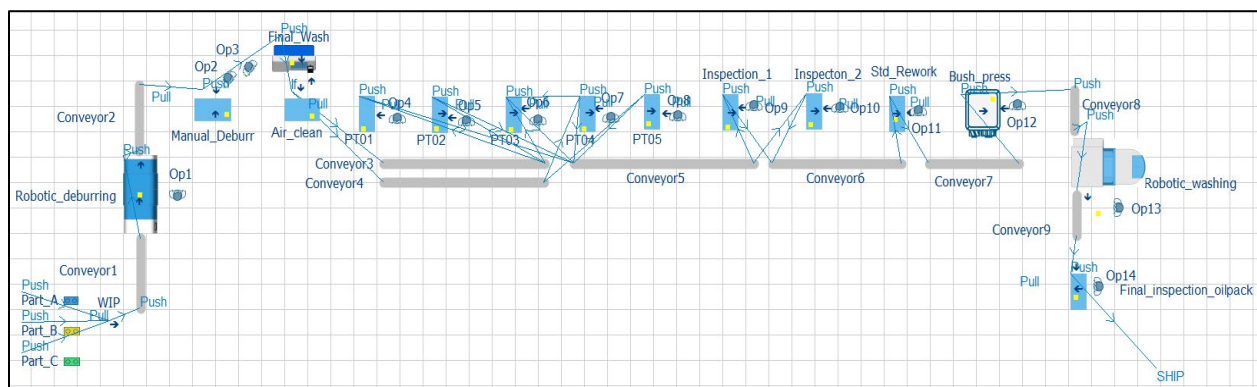

Figure 8. Model 1 of proposed layout

Table 5. Output results of model1 for 1 week (6 days)

Part_Name	No. Entered	No. Shipped	W.I.P.
Part_A	38	32	6
Part_B	55	47	8
Part_C	22	19	3

The simulation results have been analyzed after the model 1 has run for a week (6 days). As previously stated, this study primarily aims to improve the output from 15 to 20 block per day. So, the total required output after 1 week (6 days) is 120 blocks in which requirement of Part A is 38 blocks, Part B is 58 blocks and Part C is 40 blocks. Output results is shown in Table 5 are lower than the required output. Hence machine utilization and operator utilization results are further examined to identify the problem.
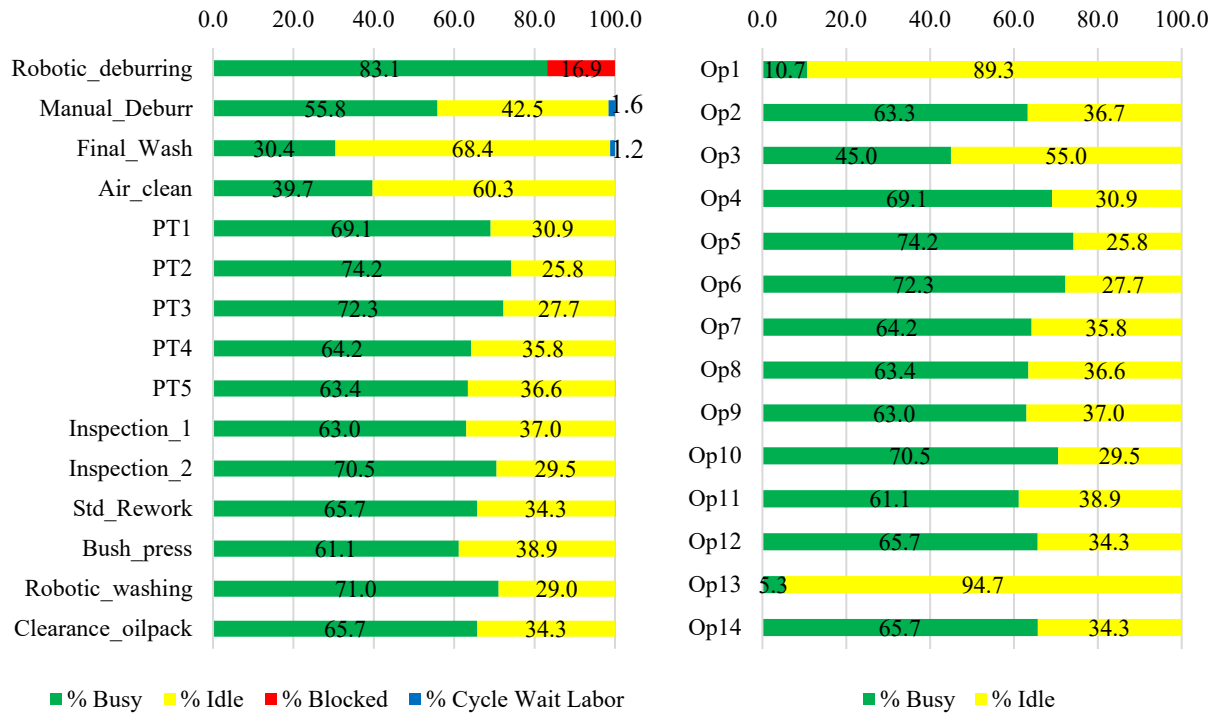

Figure 9. (a) Workstation utilization results for model 1 (b) Operator utilization results for model 1

Figure 9 (a) shows the workstation utilization percentage of each workstation. Simulation result show the robotic deburring is blocked for 16.9 % of total time and it is reason for subsequent workstation less utilization. According to theoretical calculation Manual deburr workstation will work for two shifts where robotic deburr workstation will work for three shifts hence it will be blocked for one shift. Also Figure 9 (b) demonstrate operator utilization where it shows Op1 and Op13 operator who are assigned to robotic deburring and robotic washing workstation will be more idle. Modification needs to be done to improve the process flow.

Figure 10 show the modified process layout model in which operator assigned to robotic deburring and robotic washing are removed as it only has loading and unloading work. In modified layout Op1 and Op2 operators are assigned in such way that they will work simultaneously on robotic deburring, manual deburring, final wash and air clean workstation for three shifts. Similarly for robotic washing workstation cylinder block loading will be done by Op11 operator and unloading by Op12 operator. After modification, model is tested by running it for 1 week and output has been shown in the Table 6 which is matching the required output of each part.
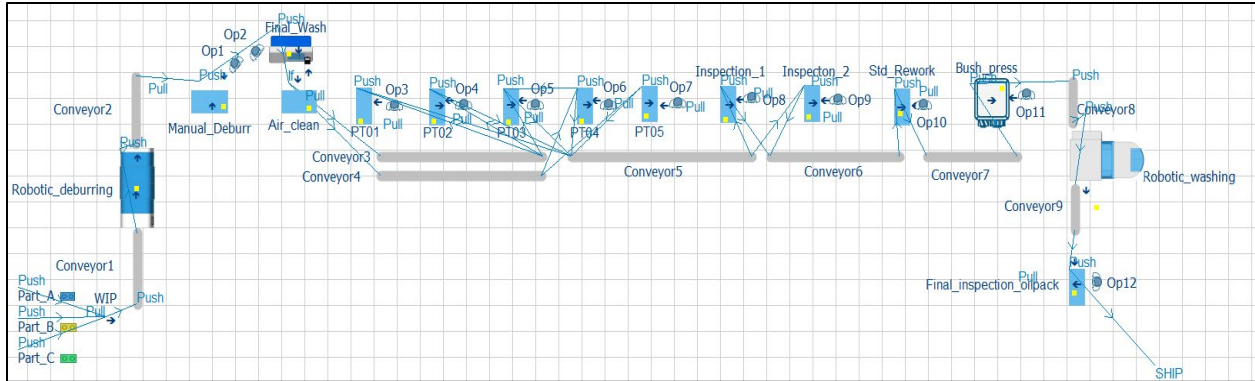
Figure 10. Model 2 of proposed layout

Table 6. Output result of model 2 for 1 week (6 days)

Part name	No. Entered	No. Shipped	W.I.P.
Part_A	43	38	5
Part_B	66	58	8
Part_C	28	24	4

Figure 11(a) shows the workstation utilization results which indicate that all workstations has more than 85% utilization expect for manual deburr, final wash and air clean workstations. Due to the shorter cycle times of the manual deburr, final wash, and air clean workstations, they become idle for 46.2%, 58.7%, and 46.22% of the total time, respectively and also operators Op1 and Op2 assigned to this workstation will remain idle for 39.2% of the total time, as shown in Figure 11 (b). Figure 11 (b) also indicate that other operators have good utilization percentage. Hence from result we can say that the modified proposed layout is feasible. Additionally, the model's modification allows for the elimination of 5 additional operators, resulting in a total 31 operators being needed by the new proposed layout. Summary of workstation after modification of proposed layout is shown in Table 7.
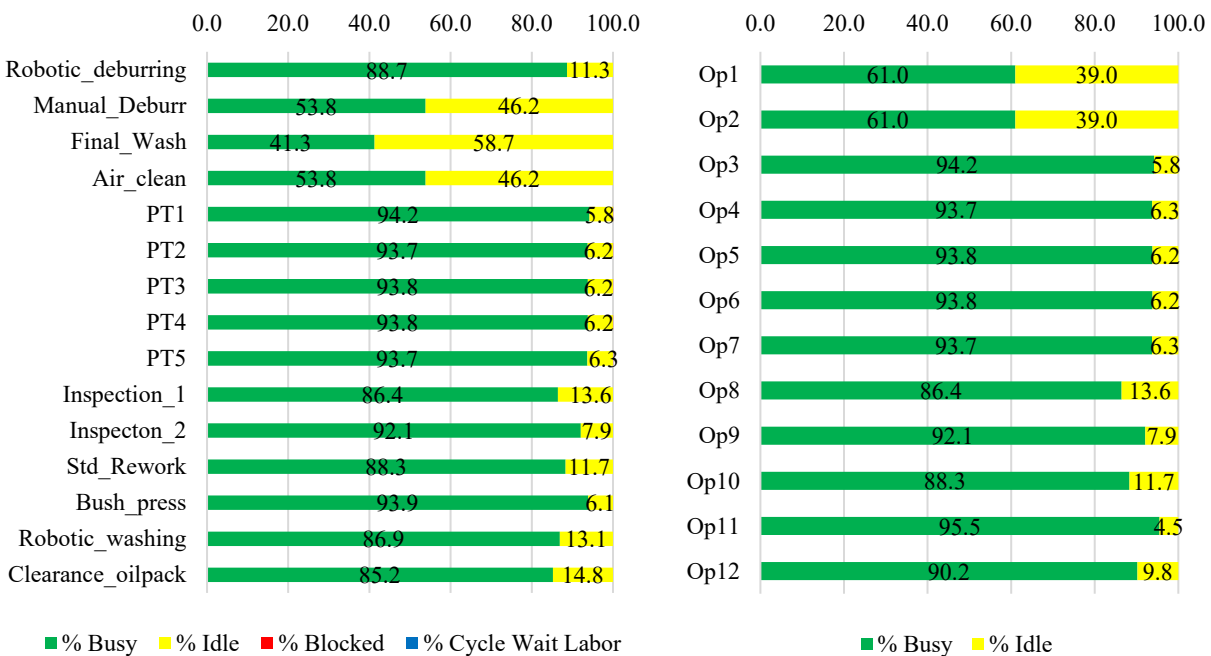

Figure 11. (a) Workstation utilization results of model 2 (b)Operator utilization results for model 2

Table 7. Summary of workstations of proposed layout after modifications

Sr. No.	Workstation	Avg. cycle time (min)	Manpower		
			1st Shift	2nd Shift	3rd Shift
1	Robotic Deburring	49.4			
2	Manual Deburring	30	2	2	2
3	Washing and Air Cleaning	53			
4	Pressure Test workstation-1 (PT-1)	159.6	1	1	1
5	Pressure Test workstation-2 (PT-2)	159.6	1	1	-
6	Pressure Test workstation-3 (PT-3)	159.6	1	1	-
7	Pressure Test workstation-4 (PT-4)	369	1	1	-
8	Pressure Test workstation-5 (PT-5)	369	1	1	-
9	Inspection-1	85	1	1	1
10	Inspection-2	85	1	1	-
11	Standard Rework	44.4	1	1	1
12	Bush Press	52.32	1	1	1
13	Robotic Washing	44.4	-	-	-
14	Final Inspection and Oil Pack	49.4	1	1	1

5.2 Comparisons

For comparison of existing and proposed line three performance measures has been considered and comparison has been done by considering the 20 blocks per day demand for both existing and proposed layout. For that purpose, number of head counts and workstations required for existing line for 20 block per day demand is calculated. If the suggested layout is implemented for the 20 blocks per day of demand, comparison Table 7 reveals significant headcount savings 43 percent and 37 percent reduction in floor space requirement due to the need for 8 fewer workstations than the current layout.

Table 8. Comparison of current and proposed layout for 20 block per day demand

Performance Measures	Current Layout	Proposed Layout	Saving	% Improvement
Manpower (Nos)	54	31	23	43%
Total no. of workstations (Nos)	21	14	8	33.3%
Total floor space required (sq. m.)	665	420	245	37%

6. Conclusion

In this study, the aim was to improve the productivity of engine cylinder block lines having three types of engine blocks to meet increase in demand and it is achieved by designing the mix product production line by merging the two-production lines. The WITNESS simulation software is used to create the proposed line model in order to analyses performance parameters such as output, average WIP, machine utilization rate and labor utilization. Simulation of model helps in process flow visualization, problem identification and modification which further contributes to reduction of head counts or manpower and also improved the output of model. Modification done using simulation software help in the improvement of percentage utilization of each workstation by more than 85% except for manual deburr, wash and air clean workstation. Simulation results also shown improvement in the output by 34.83% after doing modification than the current layout.

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