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Systematic Layout Planning and Balancing of Engine Production Processes for After Test and After Paint Assembly Lines

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ABSTRACT:

This paper is aimed at reducing the costs, maintaining the quality and designing the plant layout that is flexible to meet the customer demand. A number of stations in the after test assembly and after paint assembly are selected for capturing the production process requirements. Then, failure mode and effects analysis of after test assembly is carried out. Layout designs for the after test assembly and after paint assembly are developed using systematic layout planning and are validated using Spaghetti diagrams. With the improved layout, considerable reduction in the distance moved by the operator has resulted in 20% cost saving at 80% Takt time.

KEYWORDS:

Systematic layout planning; Assembly line design; After test assembly; After paint assembly; Spaghetti diagram

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1. Introduction

Due to rapid increase in demand of automobiles, manufacturing sector needs to increase its potential in the production of automobile engines. The production process needs to be fortified with the capability to have lower cost with higher effectiveness. To achieve the above requirements, there are many techniques to solve the problems concerning to the productivity increase [1]. Lean production has been considered as a well consolidated strategy for cutting down costs, especially costs related to production processes and to accelerate product lead times inside plant layout. Yookkasemwong et al [2] studied the production process for cable box to form metal. The problem was that the work could not be finished within 8 hours. The problem was then studied from data collection, the actual time load, plant layout, and the duration of the process. The "Eliminate, Combine, Rearrange, and Simplify" principle was adapted to reduce the waste and arrange the repeated steps, resulting changes in plant layout and staff workload. The impact of improper plant layout on the manufacturing process for production of valve and metal parts has been studied. The plant layout was changed to comply with the international standards through Systematic Layout Planning (SLP) method [3].

Sucharitkul et al [4] studied the possibility of plant layout and installations for aluminium foundry. Plant layout was done in accordance with the steps in systematic plant layout design. Yujie et al [5] studied the general plans of long yards using SLP. The best layout showed good workflow and practical significance.

Virtual design tools such as 3D modelling and simulation are becoming increasingly sophisticated and integrated. A 3D model of the considered engine is shown in Fig. 1. Their potential is best realized when they feed into an advanced design process that brings to life into the interactions between designers and design element. This process, known as building information modelling, is transforming the way that we design cities, buildings and systems to perform better throughout their entire life cycle.

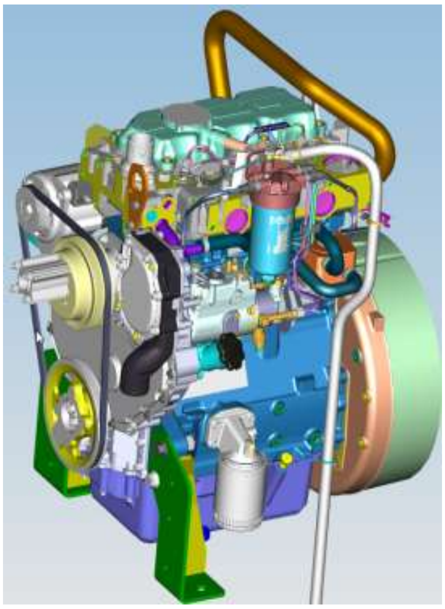

Fig. 1: 3D model of full engine assembly

The plant layout is one way to reduce the cost of manufacturing and increase the productivity by ensuring good workflow in production process. Motion study is a part of SLP using Spaghetti diagrams to achieve the demand within the acceptable Takt time and to produce engines efficiently with high quality. This research, as outlined in Fig. 2, describes the plant layout designs for the after test assembly (ATA) and after paint assembly (APA) and validation of the designed plant layouts using spaghetti diagrams. Failure mode and effects analysis is undertaken to identify the materials and process equipments for the production processes.

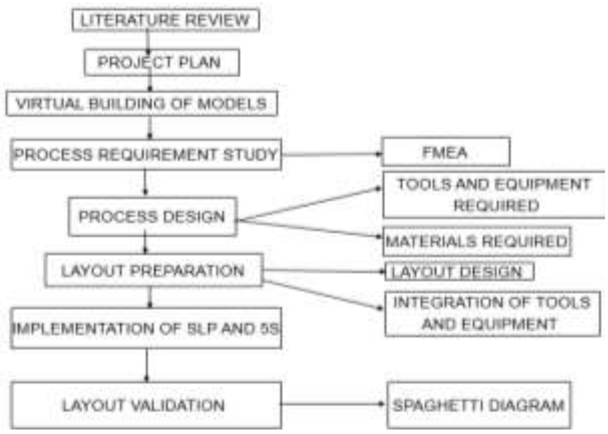

Fig. 2: Process flow chart for plant layout design

2. Failure mode & effects analysis

The objective of this study is to develop a plant layout for Caterpillar 1100 series engine and test the assembly in the process using SIEMENS Team center. Design analysis is carried out using AutoCAD for layout design. The layout is validated by drawing spaghetti diagrams for each station in ATA and APA. Lean manufacturing principles are used to reduce the non value adding activities like excess motion, defects, over processing, waiting time and transportation. Table 1 presents the identified requirements for materials and process equipments for ATA and APA stations. Failure mode and effects analysis provides a documented method for selecting a design with a high probability of successful operation and safety. Table 2 represents the outcome of failure mode and effects analysis along with control plan for ATA stations. The risk associated with potential problems identified during a failure mode and effects analysis is analysed using Risk Priority Number. The RPN method then requires The analysis team uses past experience and engineering judgment to rate each potential problem into its severity, likelihood occurrence and detection of the failure.

Table 1: Requirements analysis for ATA & APA stations

Station	Materials required	Equipments required
ATA1_7000	Flywheel housing, A-bolts, dust shield, A-dowels, alternator bracket, A-flanged bolts, radiator bracket	Torque gun, 0.5ton capacity crane, DC guns, tool box, computer
ATA2_7100	Plugs and masks	
ATA3_7200	None (Spare station)	
ATA4_7300	None (Spare station)	
QG03_7400	None (Quality gate)	
APA1_8100	Elbow flange, radiator stay bracket, alternator, timing belt, starter motor, radiator hose, breather hose	Torque gun, tool box
APA2_8200	Fan, air filter, radiator	Torque gun
APA3_8300	LHS and RHS fan guards, flywheel, ring starter, alternator, water separator, preservative and label flanged bolts and clips, A-pin, A-bolts and A-washers	Torque gun, tool box, 1.5ton capacity crane, DC torque machine, tod adapter, computer
APA4_8400	None (Spare station)	
APA5_8500	None (Spare station)	
QG05_8600	None (Quality gate)	

Table 2: Failure mode and effects analysis chart for ATA stations

Process	Failure mode	Failure effects	Control plan
Fit fly wheel housing dowels to block, if required remove bobbin	Fail to select dowels	Unable to locate flywheel housing	Training and standard work, Bill of material (BoM)
Align handler with block and fit flywheel housing over dowels	Housing fitted over dowels	Housing not fitted	Training and standard work, BoM, visual inspection
Plate housings only – fit pins to top bolt holes in block	Pins fitted block in required holes	Fail to fit pins	Training and standard work
Start all remaining fly wheel housing bolts by hand, at least 2 threads	All bolts started by hand	Bolts not started by hand	Training and standard work
Rundown back bolts with ratchet spanner if required	Fail to release housing	Line will need to be stopped	Training and standard work, visual inspection
Where fitted ensure dust shield is still in correct place	Check dust seal is fitted to underside of housing	Dust shield becomes dislodged when fitting housing	Training and standard work, visual aids, Once second inspection
Plugging and masking	Fail to fit plugs and caps	Painted starter motor pocket	Inspection
Fit and rundown radiator bracket	Fail to fit radiator bracket	Disruption in process	DC tooling in place for rundown

3. Line balancing

Layout design for ATA and APA lines was done by following the principles of SLP which combines the detail of the process with restrictions of work periods and production quantity requirements to provide data to base the machine, man power, material handling and storage requirements. Product layout involves arranging the various manufacturing processes to fit the sequence required by the product, low unit costs for high volume, specialized equipment, efficiency improvement and optimisation of materials movement. The detailed design involves allocating work tasks to locations. The Takt time (T) is defined as,

$$T = Ta / D \quad (3)$$

Where Ta is the total time (in hours) available for production and D is customer demand (in units). For typical working pattern per operator, covering 5 days a week for 48 weeks a year, the Takt time for 16000 engines production is worked as,

$$T = (14.5 \times 5 \times 48) / 16000 = 0.2175 hrs = 783 s.$$

For the line balancing, 80% of Takt time, 626.4 seconds per operation, is used as a measure to identify the over load or under load at the ATA and APA stations. Tables 3 and 4 presents The cycle time for both 1103 & 1106 series engines is calculated before and after line balancing. The ATA stations did not require a line balancing since the average cycle time is less than 80% of Takt time as shown in Table 3. However for APA (see Table 4), The stations at APA3 and APA5 had experienced higher cycle time than the 80% Takt time and hence these stations of APA are balanced.

Table 3: Cycle time for ATA stations

Station	cycle time (Seconds)		
	1103 engine	1106 engine	Average
ATA 1	330	450	390
ATA 2 (Spare)	0	0	0
ATA 3	270	360	315
ATA 4	120	210	165
ATA 5 (Quality)	180	180	180

Table 4: Cycle time for APA stations before & after line balancing

Station	cycle time (in seconds) before line balancing			cycle time (in seconds) after line balancing		
	1103 engine	1106 engine	Average	1103 engine	1106 engine	Average
APA 1	420	480	450	420	480	450
APA 2 (Spare)	0	0	0	0	0	0
APA 3	**690**	**900**	**795**	**330**	**420**	**375**
APA 4 (Spare)	0	0	0	**360**	**480**	**420**
APA 5	600	**750**	**675**	600	**510**	**555**
APA 6 (Spare)	0	0	0	0	**240**	120

4. Motion study and validated layouts

Spaghetti diagrams are visual representations of the work unit flowing through a process. They illustrate the flow sequence of the information or component and record their functional dependencies and responsibilities for each step in the process. The spaghetti diagram for the ATA1 station of engine before and after SLP validation is shown in Fig. 3 and 4 respectively. Table 5 summarises the outcome of motion study of different operations at ATA1 station through improved layout.

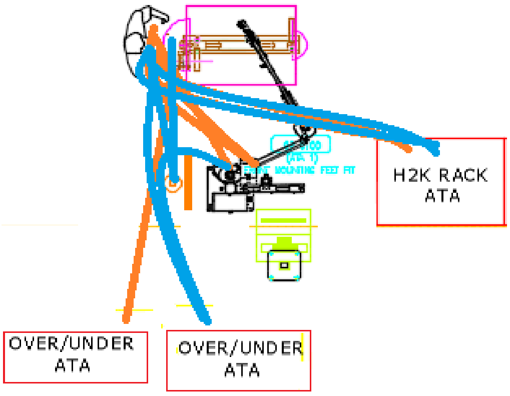

Fig. 3: Spaghetti diagram for existing ATA 1 station layout

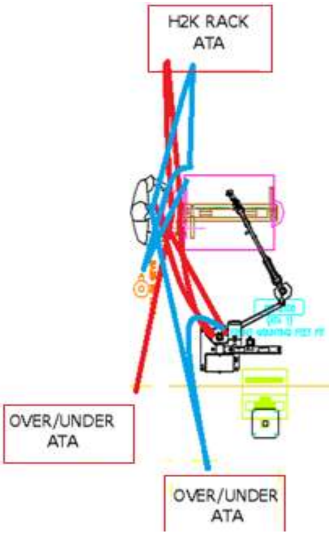

Fig. 4: Spaghetti diagram for ATA 1 station layout after SLP

Table 5: Motion study on ATA1 station activities

Activity at ATA 1 station of engine assembly	Distance (m), Existing layout	Distance (m), Improved layout
Bring front feet support	2.8	2
Move engine to H2K rack	2.5	1.4
Bring bolts and bud it to engine	2.5	1.4
Move engine towards manipulator	1.1	1.3
Bring manipulator to engine and rundown bolts	1.1	1.3
Leave manipulator in position	1.0	1.3
Move engine towards alternator and radiator bracket rack	2.3	1.6
Bring brackets towards the engine	2.3	2.4
Move engine towards H2K rack	2.1	1.4
Bring the bolts from H2K rack and bud it	2.1	1.4
Move engine to DC hand tool	0.7	1.1
Move towards the bracket and torque it	0.7	1.1
Total distance	**21.2**	**17.7**

After validation of ATA 1 station, the total distance moved by the operator has been reduced from 21.2m to 17.7 m. The excess motion of 3.5 m has been prevented by changing the position of material storing racks. Similarly, all other stations have been validated. Figs. 5 and 6 show the validated plant layouts for the ATA and APA lines post motion study respectively. These validated layouts yielded 20% reduction in the total cost. From the ergonomics point of view, we cannot reduce the distance and time further. The analysis has been made to work for less than 80% of Takt time due to practical losses. It has been designed to work at the peak and low production demands.

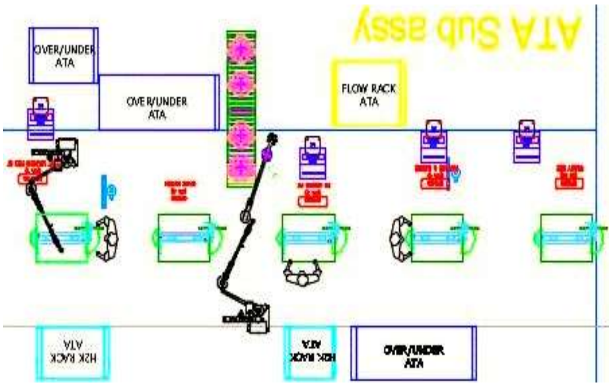

Fig. 5: SLP validated layout for ATA line

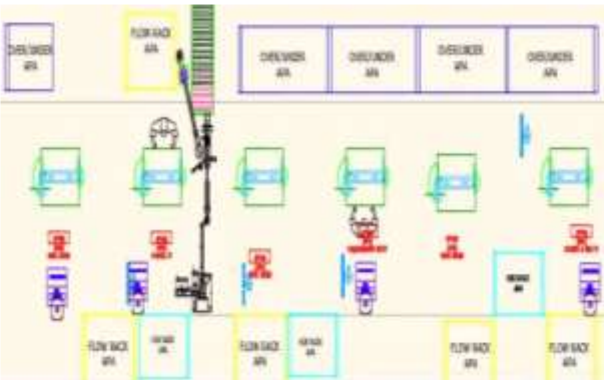

Fig. 6: SLP validated layout for APA line

5. Conclusion

The systematic plant layout system promotes production process for ATA and APA lines of the 1100 series (1103, 1104 and 1106) medium engines production. This work has added value to engine manufacturer through the successful execution of the project. Spaghetti diagrams are clearly indicating the demand pattern and how to meet the Takt time. From this study, the cost has been reduced by 20% without any compromise to the quality for 16,000 production units per year.

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