

PRODUCTIVITY IMPROVEMENT OF AUTOMOTIVE ASSEMBLY LINE THROUGH LINE BALANCING

Swapnil T. Firake, Dr. K. H. Inamdar

Dept. of Mechanical Engineering
WCE, Sangli

Abstract— Poor layout design is determined as a major problem in small and medium industry. These particular problems thus affect the productivity and the line efficiency as well. In automotive industries, assembly line is the major area to be taken into consideration for increasing productivity. The focus of this paper is to identify the bottleneck workstations in the current layout and eliminate those activities that are taking time on that workstations. The time study is done by using camera. The current layout is redesigned by computing takt time and processing times in each workstations. The case study shows how the takt time calculation is done and from this takt time the processing time is decided for all workstations. The time consuming activities are reduced and thus the processing times at all workstations is made possibly equal. The time reduction increases productivity in the form of increased number of units of production in the same previous time.

Line efficiency is also found to be improved which is described with the terms Overall Line Efficiency (OLE) and First Pass Yield (First Time Through) units.

Keywords— Line balancing, productivity, efficiency, bottleneck.

I. INTRODUCTION

Productivity of a manufacturing system can be defined as the amount of work that can be accomplished per unit time using the available resources.

Line balancing (LB) is usually undertaken to minimize imbalance between machines or personnel while meeting a required output from the line. Line balancing is a tool to improve the throughput of a work cell or line which at the same time reducing manpower and cost needed. It is often used to develop product based layout. LB job description is to assign tasks to a series of connected workstations where the number of workstations and the total amount of idle time are minimized for a given output level. The line is balanced if the amount of work assigned to each workstation is identical.

Line balancing is commonly technique to solve problems occurred in assembly line. Line balancing is a technique to minimize imbalance between workers and workloads in order to achieve required run rate. This can be done by equalizing the amount of work in each station and assign the smallest number of workers in the particular workstation.

Generally, LB technique is used by many companies to improve the productivity, decreases the man power, decreases idle time and buffer or even to produce more than two products at the same time. LB technique is used to achieve the minimization of the number of workstations, the minimization of cycle time, the maximization of workload smoothness and the maximization of work relatedness [1].

II. CRITERIA IN LINE BALANCING

There are some criteria which should be considered in a line balancing process. These are takt time, cycle time, downtime and minimum number of workstations which can be explained as below

A. Takt Time

Takt time is pre-requisite procedure in doing line balancing task. Takt time is the pace of production that aligns production with customer demand. It shows how fast the need to manufacture product in order to fill the customer orders. Producing faster than takt time results in over-production which is a type of waste whereas producing slower than takt time results in bottlenecks where the customer orders may not be filled in time. The takt time is determined by using Eq. 1.

$$\text{Takt Time} = \frac{\text{Available time per day}}{\text{Customer demand per day}} \quad (1)$$

B. Cycle Time

Cycle time shows how often the production line can produce the product with current resources and staffing. It is an accurate indicator to represent of how the line is currently set up to run. cycle time is the expected average total production time per unit produced. On an assembly line or in a work cell with multiple operators, each operator will have his own time associated with completing the work he is doing.

Takt time and cycle time are definitely not the same. Takt time represents the maximum time allowed to meet the customer demand whereas cycle time is the actual time necessary for an operator to perform an activity or complete one cycle of his process. Both takt time and cycle time are determined by customer demand.

Using Eq.2, we can calculate the cycle time for one engine complete assembly.

$$\text{Cycle Time} = \frac{\text{Production time per day}}{\text{Required time per day (Unit)}} \quad (2)$$

Equation 3 shows the cycle time is the time in which the both value added and non value added activities are done. Thus by eliminating the non value activities through continuous improvement and waste reduction, the cycle time can be reduced.

$$\text{Cycle Time} = \text{Value added activiti} + \text{Non value added activities}$$

(3)

C. Downtime

Downtime can be defined as that time that is non value added. It is often related with the 7 wastes that are: defects, overproduction, waiting, transportation, unnecessary inventory, unnecessary motion and inappropriate processing.

D. Minimum Number of Workstations

A workstation is a physical area where a worker with tools, a worker with one or more machines, or an unattended machine performs particular sets of work together. Number of workstations working is the amount of work to be done at a work center expressed in number of workstations.

Minimum number of workstation is the least number of workstations that can provide the required production. Actual number of workstation is the total number of workstations required on the entire production line, calculated as the next integer value of the number of workstations working [2].

III. CASE STUDY

A. Background Introduction

An engine assembly line for TML 3-wheeler engine is studied in this paper. The engine is assembled on conveyor which is already available. The conveyor used is power and free conveyor. The management fixed the target of 16% improvement in the engine assembly units. The output previously was 225 engines per shift on normal working day.

There are three departments generally called ATP that are assembly, testing and pre-dispatch inspection and application (PDI). There are 30-Online workstations and 9-Offline workstations on the conveyor. The engine is dispatched in testing department after assembly and thereafter is transported to PDI department.

B. Problem Definition

The main focus of this paper is line balancing of assembly line and thus reduce the cycle time, idle time, number of workstations and hence increase the number of engines assembled in the same time of one shift. This leads to increase in productivity. The line efficiency is also taken into account as a cross check, which is measured with terms OEE and first pass yield

C. Line Balancing of Assembly Line

The line balancing is done taking in account the takt time, cycle time and the time and motion study is done for the assembly line. The various activities on each workstation are distinguished within value added, non value added and non value added activities. The activities are arranged at each workstation such that the assembly is easily done and also the time required at each workstation is identical to complete those activities.

1. Data before Line Balancing

The observations before the improvements for assembly line related to total workstations, total capacity of the line and the output per man are made which are as below:

Number of workstations: 39 (Online- 30, Offline -10)
Capacity (Engines/Shift) = 225 Engines
Output/Man:
Total Team Associate (TA) = 35
Output/TA = 225/34 = 6.42 Engines/TA

2. Data Analysis

Total shift time available: 8 Hour 30 minute
Actual production time = Time available – Unproductive time
= 450 minute = 27000 second
Now, Eq. 2 is used to calculate the cycle time.
Cycle Time(CT) = 450 / 225 = 2 minute = 120 Sec.

Since the conveyor used is power and free conveyor, the time required to move pallet from one station to next station is 13 seconds. Thus the available working time at each workstation is 107 seconds. Now, the target fixed is 16% improvement, that is, nearly 262 engines per shift. Thus the total takt time available is 107 seconds. Thus the time available at each workstation for assembly is 90 seconds, decreasing the pallet movement time. Thus all the workstations should be balanced for 90 Sec, which is the takt time for the all workstations.

The balancing is done only for online workstations. Rebalancing should be done in order to gain the cycle time of 90 second. The set of activities are analyzed and find out the value-added, non-value-added and non-value-added but required activities at the every workstation. For example, a) at workstation Online-09 the activities are sorted like below:

Workstation- Online-09: Oil pan tightening, LOF adaptor fitment

The color codes are defined for identifying and marking of activities as below for various activities like value added, non-value-added, non-value-added but required activities.




- Value-added activity(VA) – 
- Non-value-added activity(NVA) – 
- Non-value-added but required activity – 

Table II shows the total activities performed on the station. The activities are identified as VA, NVA and NVA but required activities. The different activities are marked with different colors specified above. The times taken by these activities are also identified so that we can reduce or eliminate the NVA activities by continuous improvement [3].

The non-value-added activities or motions are eliminated/reduced with the help of proper kaizen improvements.

Rebalancing is done by the proper shifting or distribution of activities at various workstations such that identical time is required at all workstations to complete the activities distributed on them.

TABLE I. Identification of VA, NVA and NVA but Required Activities (WS-Online-09)

Sr. No.	Activity	Time reqd (sec)	Activity Identified
1	Position gauge for D-clamp position	4	b

2	Tighten adaptor bolt-2 nos	5	a
3	Apply torque 2.5kg-m manually	7	b
4	Dummy bolt tightening by Pneumatic Nut Runner (PNR)	3	c
5	Apply torque 2kg-m of dummy bolt	4	a
6	Remove nuts by PNR- 3nos	10	b
7	Oil pan torquing	46.2	b

Thus from Table I, it is noticed that the time required to complete all the activities at the station is 79.2 seconds. Table II shows the time before (P) line balancing and the time required after (Q) line balancing at all workstations. Action taken to reduce the timing at each workstation is also included in the table. All the time study is done in seconds. For workstation Online-09, the time after line balancing is reduced to 67.8 seconds. The manual torquing for 2.5 kg-m torque is now done by pneumatic nut runner which was not available before line balancing.

This is repeated for all the workstations considering all the small activities. The various activities are arranged on the workstations such that they are taking the cycle time allotted to them, here 90 seconds also the activities are arranged progressively such that they don't disturb the next workstation activities.

The motions are reduced using the continuous improvement approach that is kaizen improvements. To reduce the other wastes that are related to reducing the cycle time on the assembly line is related to material which is solved by supermarket concept that is c-class material near the line itself. Thus the time is reduced also the materials that do not require any quality inspection or washing is supplied directly on the line. This comes under the direct on line concept which reduces the time for the availability of the material.

The other concept is 5S's system which is housekeeping of all the nearby environment. This helps to easily identify the instruments/material that we required on the time. This avoids the time for searching the instruments/material we required.

Thus the activities are rebalanced by proper placing the activities and also by reducing the motions that are non value added by proper placing the material or instruments.

Table II shows the times for before and after improvements and also the actions that are taken to that are taken at the respective workstations are also included in the table.

TABLE II. Data of Before and After Time and Actions Taken

WS No.	P	Q	Actions Taken
01	74.4	85	Activity rebalanced for 90 sec
02	94.2	88	Activity rebalanced for 90 sec
03	52	52	IPV-1 (End Float) Man-less
04	123.6	82	Layout changed & rebalancing done
05	126	81.4	Motion loss reduced
06	88.8	81.6	Motion loss reduced
07	121.2	69	Motion loss reduced
08	67.2	82	Activity rebalanced for 90 sec
09	79.2	67.8	Activity rebalanced for 90 sec

10	124.8	82.2	Activity rebalanced for 90 sec
11	85.2	81.6	Activity rebalanced for 90 sec
12	85.2	85.8	Activity rebalanced for 90 sec
13	62	62	IPV-2 Torque To Turn (Man-less station)
14	81.6	79.2	Motion loss reduced
15	81	84	Activity rebalanced for 90 sec
16	126	72	Motion loss reduced
17	81	66.6	Activity rebalanced for 90 sec & motion loss reduction
18	67.8	87	Activity rebalanced for 90 sec
19	85.2	75.6	Activity rebalanced for 90 sec
20	120.6	69	Motion loss reduced
21	78.6	90	Activity rebalanced for 90 sec & motion loss reduced
22	78.6	78	Activity rebalanced for 90 sec
23	73.2	82	Activity rebalanced for 90 sec
24	86.4	85	Activity rebalanced for 90 sec
25	0	82	Idle station used to utilize conveyor & Activity rebalanced for 90 sec
26	77.4	83.4	Activity rebalanced for 90 sec
27	121.2	73.2	Motion loss reduced
28	0	0	Idle station
29	0	0	Idle station
30	84	72.6	Motion loss reduced

Thus, the total task time required before line balancing is 2426.4 seconds and that required after line balancing is 2180 seconds.

3. Data after Line Balancing

a. Production capacity:

Before Improvement = 225 Engines/Shift

After Improvement = 262 Engines/Shift

Hence, Percentage Improvement = 16% improvement.

b. Production lead time: Time from start of physical production of first sub-module/part to production finished (ready for delivery).

From Table II, the production lead time before was 2426.4 seconds and that after line balancing is 2180 seconds. Thus production lead time is also found to be reduced.

c. Product yield per employee or Output/Man = 262/34 = 7.71 engines, which was 6.67 engines before improvement. Here, the TA are taken 34 since one of the stations among Offline workstations is reduced and activities are allotted to another online workstations.

It determines optimize use of labor. It measures effectiveness of manufacturing process and productivity of employee. Thus, in this case study, it is found to be increased.

d. Additional 925 (= 37×25) engines can be made in one shift basis only in a month.

e. With 225 engines/shift we can ran single shift up to maximum 5625 engines/month but with 262 engines/shift, we can achieve 6550 engines per month with the same manpower.

4. Results Observed after Line Balancing

a. Productivity Improvement

Equation 1 shows that increase in the number of engine assembly leads to increase in the productivity. Here, the number of engines assembly is increased from 225 to 262 engines per shift. Percentage improvement observed is 16% improvement. This shows that the manufacturing lead time is also reduced since there is increase in the number of engine assemblies in the same amount of time.

b. Line Efficiency

Equation 8 below shows the formula for calculating the efficiency of the assembly line [4].

$$\text{Line Efficiency} = \frac{\sum \text{Task time}}{(\text{Number of workstations} \times \text{Largest cycle time})}$$

(4)

From Table II, adding the data for before line balancing, the equation gives the line efficiency before improvement.

$$\text{Line Efficiency} = 2426.4 / (30 \times 126) = 64.19\%$$

Now, adding the data for after line balancing, the Line Efficiency becomes,

$$\text{Line Efficiency} = 2180 / (30 \times 90) = 80.74\%$$

Thus, as we can see there is improvement in line efficiency from 64.19% to 80.74%.

Line efficiency can also be measured with Overall Line Efficiency (OLE) and First Pass Yield units, which includes the quality measurable like downtime, defective units, etc [5].

The data used for this is for one normal working day and here it is taken for Feb. 14, 2014.

i) Overall Line Efficiency

Overall Equipment Effectiveness (OEE) is a preminent practice for monitoring and improving efficiency of the manufacturing processes such as machines, cells, assembly lines and etc. OEE when applied to assemblies is called as Overall Line Efficiency (OLE). OEE is simple and practical yet a powerful calculation tool. It takes the most common sources of manufacturing productivity losses and places them into three understandable categories which are Availability, Performance and Quality.

Availability is the ratio of operation time which is simply planned operation time less downtime to planned operation time and accounts for downtime loss. Performance takes into account speed loss which includes any factors that cause the process to operate at less than the maximum possible speed or rated speed when running. This includes machine wear, substandard materials, misfeeds and operator inefficiency. Quality takes into account quality loss which accounts for produced pieces that do not meet quality standards including pieces that require rework.

Equations 5-8 below are different formulae for calculating OLE. Availability is calculated as below and it shows the speed loss.

$$\text{Availability} = \frac{\text{Operating time}}{\text{Planned production time}}$$

(5)

$$= 361/430 = 0.8395 = 83.95\%$$

(Downtime loss = 69 minutes, since material shortage)

Performance is calculated as shown below and it account for performance loss.

$$\text{Performance} = \frac{\text{Ideal cycle time} \times \text{Total pieces}}{\text{Operating time}} \quad (6)$$

$$= 0.9556 = 95.56\%$$

Quality is calculated as below and it accounts for the quality loss.

$$\text{Quality} = \frac{\text{Good pieces}}{\text{Total pieces}}$$

(7)

$$= 0.9913 = 99.13\%$$

From these equations, the Overall Line Efficiency is calculated as follows,

$$\text{OLE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

(8)

$$= 0.8395 \times 0.9556 \times 0.9913 = 0.7952 = 79.52\%$$

Thus, it can be seen that excluding downtime loss, our assembly line OEE matched a World Class OEE, which is around 85% or better and thus it can be said that our line balancing of assembly line is efficient [6].

ii) First Pass Yield

It is also called as First-Time-Through (FTT) capability. It measures the percentage of units that go through production process without being scrapped, rerun, rested, returned by the downstream operation, or diverted into an off-line repair area. Equation 9 shows the formula for calculating FTT capability.

$$\text{FTT} = \frac{[(N_{in} - (N_s + N_{rer} + N_{rt} + N_{rep}))]}{N_{in}} \times 100$$

(9)

where,

- N_{in} – number of input units
- N_s – number of scrapped units
- N_{rer} – number of reworked (rerun) units
- N_{rt} – number of retested units
- N_{rep} – number of repaired units

Here, we observed the following observations and calculated the FTT capability.

$$\text{FTT} = (230 - 228) / 230 \times 100 = 0.8695 = 86.95\%$$

The first time through yield helps to identify efficiency and changes in the performance in the production process [7].

Any sudden deviation between these two parameters, OLE and FTT denotes the deviation for line efficiency and thus the attention is to be given to find out problem and its satisfactory solution.

IV. CONCLUSION

This paper describes assembly line balancing is one of the major step to be taken into consideration while increasing productivity of

automotive industries. Line balancing is done with taking in account the takt time, cycle time and downtime and thus reduces the production lead time with increased number of output engines. Continuous improvement is the step to reduce unnecessary downtime losses. The productivity of engine assembly line is thus found to be increased.

The line efficiency is also measured with OEE and FTT and can be used as a signal to perform further analysis and improvements if it exhibits sudden changes.

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