Optimize of Engineering Tools by Resource Utilization in A Tractor Manufacturing Plant

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Abstract—“Optimize of engineering tools by resource utilization in a tractor manufacturing plant” revolves around the management of the operations of the maximum cycle time as well as maximum waiting time on machines in Differential Casting Line and the Rear Cover Line. Waiting time consumes in their turn to be picked and processed of the work pieces & work piece get stocked up on the conveyor. Main happening is Slows down the process of production & increases the material handling requirements by this scenario.

A detailed study related to technicalities of the production process of all the machines in Differential Casting line and Rear Cover line has been done in order to achieve the purpose of cycle time reduction of bottleneck machines.

The complete study has been carried out using the concepts that fall under the paradigm of Lean Manufacturing, Work Study and Quality Tools. In addition to this, an investigation has been carried out of the differential line to check causes of a specific defect those were responsible for cycle timing. It has been kept on how the available resources can be most judiciously utilized.

The percentage reduction of the cycle time and waiting time is the results of the case study. Kaizen Ideas were discussed where general flaws were found in the production process and their direct effect on utilization of recourse was shown.

Keywords—Lean Manufacturing, Kaizen, Cycle Time, Machine Tools Operation

I. INTRODUCTION

A. Statement of the problem

The work purpose was to study all the resources of the plant (machines of H.M.S.) and see to it that all activities were value adding. The Paper also focuses on the problem of line throwback being caused by a particular kind of defect. For the purpose studying and fixing flaws the tools of Industrial Engineering were used and employed most judiciously.

B. Primary Objective

The primary objective of the research on “A case study- Optimize of engineering tools by resource utilization in a tractor manufacturing plant” was to manage the bottleneck machines, resource utilization and line throwback using tools of Work Study, Quality, T.O.C. and Lean Manufacturing.

This was done by identifying the loopholes in the present system and setting them right. It was made sure that there were no ‘Non-Value Added’ activities present in the production line. Care was taken that resource utilization was in the utmost manner. By employing techniques of Work Study and De-Bottlenecking it was seen how the load of the bottleneck machines of different production lines could be reduced by sharing method. Incorporation of Kaizen methods to improve the efficiency of the line was done. Analyzed the sequence and method in which operations were carried out at the Radial machines where human component was of prime importance.

C. Target Specifications

In the end result, we have found out several methods to shorten the waiting time of the various bottleneck machines that had maximum cycle time in the production line. As the waiting time is reduced the piece flow on conveyor would become much smoother and better production could be achieved, when implemented. Also some kaizen techniques have been mentioned to optimize resource utilization. In addition to this, investigation to causes of defect has been done to control line throwback.

It has been taken care of that no new equipment’s/machines had to be bought and installed, rather the focus has been on how to make the most of what all resources we already had by analyzing the production process in the H.M.S.

II. INTRODUCTION TO THE TOOLS EMPLOYED.

In the present context of the study, focus has been kept on the various methods that can be employed for the management of the operations of bottleneck machines, resource utilization and line throw-back. The section below represents the introduction to the tools employed and theory of it. Going through various research papers it was imperative to understand different type of Activities, The Theory of Lean and Agile Manufacturing, Kaizen, Work Study, Theory of Constraints (TOC) and Quality tools.

In any kind of industry all the activities that take place can be categorized as:

- Value-added (VA)
- Non-value-added (NVA)
- Necessary but Non-value-added (NNVA)
VA (Value adding) operations involve transformation of raw material or semi-finished product into finished product or in other words, these types of activities create most value to the customer.

NVA (Non-value-added) types of activities are pure waste which added cost to the product without adding value. An industry that wants to compete in present market has to eliminate these types to wastes.

NNVA (Necessary but non-value-added) activities are those activities which are wasteful but necessary under the present operating procedures. In order to eliminate necessary but non-value-added activities, organization have to make major changes such as creating a new layout or change in supply chain management. Such changes may not be possible immediately.

A. Theory of Lean Manufacturing

LM is a manufacturing strategy that aimed to achieve smooth production flow by eliminating wastes and by increasing the activities value. Some analysts even pointed out that if an organization ignores the LM strategy, the company would not be able to stand a chance against the current global competition for higher quality, faster delivery and lower costs.

Total 20 lean tools were identified and these lean tools were grouped into six categories as follows:

- Visual Management
- Policy Deployment
- Quality Methods
- Standardized work
- Just-In-Time
- Improvement Methods

B. 5S

It refers to the five words seiri, seiton, seiso, seiketsu, shitsuke. These words are shorthand expressions for principles of maintaining an effective, efficient workplace:

- Seiri(sorting)- It means eliminating everything not required for the work being performed.
- Seiton(simplifying)- It means efficient placement and arrangement of equipment and material.
- Season(sweeping)- It means tidiness and cleanliness.
- Seiketsu(standard)- It means ongoing, standardized, continually improving seiri, seiton, season.
- Shitsuke(sustain)- It means discipline with leadership.

C. TPM (total productive maintenance)

A series of methods, originally pioneered to ensure that every machine in a production process is always able to perform its required tasks so that production is never interrupted.

D. Andon is a system of flashing lights used to indicate production status in one or more work centers; the number of lights and their possible colors can vary, even by work center within a plant; however, the traditional colors and their meanings are:

- Green: No problem.
- Yellow: Situation requires attention.
- Red: Production Stopped.

E. Kanban is a communication tool in the just-in-time production and inventory control system which authorizes production or movement. It was developed by TaiichiOhno(1996) at Toyota. Kanban is a card or signboard (or any other authorizing device) that is attached to specific parts in the production line signifying the delivery of a given quantity.

F. Cellular Manufacturing is an approach in which manufacturing work centers [cells] have the total capabilities needed to produce an item or group of similar items; contrasts to setting up work centers on the basis of similar equipment or capabilities, in which case items must move among multiple work centers before they are completed; the term group technology is sometimes used to distinguish cells that produce a relatively large family [group] of similar items.

G. SMED (single minute exchange of dies) A series of techniques designed for changeovers of production machinery in less than ten minutes. Obviously, the long-term objective is always Zero Setup, in which changeovers are instantaneous and do not interfere in any way with continuous flow.

H. Lean six sigma is a data driven approach to find the root cause of the problems. To organize operating processes its uses define, measure, analyze, improve, maintain and control (DMAIC).

I. Kaizen It means continuous incremental improvement of the process, work methods and work site through employee’s ideas and activities just by their common sense.

J. Work Study.

Work Study is the systematic examination of the methods of carrying out activities such as to improve the effective use of resources and to set up standards of performance for the activities carried out. Another definition of Work Study could be

K. Theory of Constraints (Bottleneck) Assuming the goal of a system has been articulated and its measurements defined, the steps are:

1. Identify the system's constraint(s) (that which prevents the organization from obtaining more of the goal in a unit of time)
2. Decide how to exploit the system's constraint(s) (how to get the most out of the constraint)
3. Subordinate everything else to the above decision (align the whole system or organization to support the decision made above)
4. Elevate the system's constraint(s) (make other major changes needed to increase the constraint's capacity)
5. Warning! If in the previous steps a constraint has been broken, go back to step 1, but do not allow inertia to cause a system's constraint.

I. What are constraints?

A constraint is anything that prevents the system from achieving its goal. Constraints can be internal or external to the system. An internal constraint is in evidence when the market demands more from the system than it can deliver. If this is the case, then the focus of the organization should be on discovering that constraint and following the five focusing steps to open it up (and potentially remove it). An external constraint exists when the system can produce more than the market will bear.

III. METHODOLOGY AND FUNCTIONAL PARTITIONING OF PROJECT

This section shows the method used for studying the present scheme of things in the plant. Segregation of project into various components has been done to make it a systematic and easy to study.

- **Select**
  - Production Line,
  - Process, Product, Operations.

- **Record**
  - All details concerning the job,
  - Cycle time, operation time, changeover time, handling time, etc.

- **Examine**
  - Scrutinize the collected data,
  - Bottleneck machines, Work Load on a machine, sequence of operations, etc.

- **Define**
  - The methods used for refining the system (work study, lean manufacturing, VSM, etc.)

- **Install**
  - The new improved methods and practices.

- **Maintain**
  - The new improved methods over a period of time till new improved practices are found.

Fig.1: Methodology and functional partitioning of project

IV. STUDYING MACHINES AND THEIR OPERATIONS IN THE LINE

A. Machine 494.03. Machine 494.03 is a VMC (Vertical Machining Centre) which is also the first machine of the differential line.

The work-piece reaches the machine through gravity conveyor and the operator picks up the piece by fitting the tackles in specific holes and places it on the palette. The Method Study and sequence of operations in this machine are shown as under.

B. Machine 287.01. Machine 287.01 has cycle time of 6.97 minutes which includes the loading and unloading time as well. This time starts from the point the operator fits the tackle in the differential for loading on the machine table to the time operator removes the tongs after placing the work piece on the gravity conveyor. The operator loads the differential onto work table and clamps it. The worktable takes the work piece to the machining area. Two Cutters with wipers and inserts (wipers follow the inserts) are situated at both ends of the machine. These cutters are involved in removing the extra material of the differential casting.

C. Machine 486.01 (Duplex). Duplex Machine specializes in the operation of Boring. Once the piece is loaded by the operator on the work table the machine is equipped with spindles that carry boring tools in 2 different axis and hence the name ‘Duplex’. Initially, when the spindles enter the work piece, rough boring tools perform rough boring operation, on both axis. While the rough boring is being carried out, the finish boring tools are aligned outside the work piece such that they just manage to fit in a way that they do not touch the casting. This machine is dedicated to these type of operations only which makes it least flexible and hence shifting any operation to this machine is not viable. The rough boring dimension here is $\phi$ 130 mm with tolerance of $40 \mu$ and finish boring dimension $\phi$ 110 mm with tolerance of $35 \mu$.

D. Machine 489.02. Machine 489.02 is the next machine to 489.01 and is pretty similar in operation as well. It has 3 spindles that carry finish boring tools. Cycle time here is 5 minutes and 22 seconds.

E. Machine BFW II. BFW II is pretty similar machine in action to BFW I. Here once the piece is loaded in the machine Drilling is accompanied with Tapping on the non-trumpet sides. Since the machine is similar to BFW I the machining action of the tools is also same. Multiple spindles carrying drilling and tapping tools make the holes and tap them with single and simultaneous move, in one single action. The cycle time of this machine is 4 minutes and 36 seconds.

F. Machine BFW III. Machine BFW 3 is another multiple spindle machine that is similar to BFW 1 AND BFW 2. The differential casting reaches BFW 3 once all the operations of BFW 2 have been done. All operations on BFW 3 are performed on both Trumpet sides which were operated before at BFW1. BFW 3 is basically responsible for performing Tapping in the drilled holes of the trumpet sides where eventually the Trumpet itself fits.
G. Machine 437.12. Machine 437.12 is a radial machine that facilitates in multiple operations. The work-piece is loaded on the bed and all the operations are manually done by driving single vertical spindle up and down, left and right. Different tools are set by the operator manually depending on the operation requirement.

At times jigs are placed to guide the tool and keep the operation under tolerance limits.

In this machine operation of Tapping is done on 6 holes, on both trumpet sides. Again tapping is done on the 4 holes bottom side of differential housing.

*Note: The next two machines i.e. M/c 494.01 and M/c 404.07 potentially formed the Bottleneck machines with maximum cycle time of 14.90 minutes and 14.66 minutes respectively. Hence detailed Method Study and Time Study is done in the Examination section of the report.

V. RECORD THE VARIOUS MACHINES OF DIFFERENTIAL LINE.

Recording the right data using the right tools is very important to get right results. This is the initial and most critical stage in the complete process. Special care must be taken that the data so collected represent the system in the most rightful manner. For collecting the data the technique of Time Study under the paradigm of Work Study has been used here. Using Time Study method, the cycle time of all these machines is noted down with the help of Stop Watch.

Average of at least four readings is taken for every machine to remove chance of any ambiguity. All the readings shown in the table are in minutes.

*Note: In the above given data 494.01 and 494.07 are independent and similar machines. By independent and similar machines we mean that the work-piece that passes through one machine does not go to other machine as same operations have been already done on the previous machine. Also 437.30 and 437.17 are independent and similar machines with machining capacity of 2 pieces on each machine.
Table 1:  
Cycle Time and Waiting Time (in minutes)

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>READING 1</th>
<th>READING 2</th>
<th>READING 3</th>
<th>READING 4</th>
<th>AVERAGE</th>
<th>Waiting time</th>
</tr>
</thead>
<tbody>
<tr>
<td>494.03</td>
<td>6.55</td>
<td>6.31</td>
<td>6.27</td>
<td>6.36</td>
<td>6.37</td>
<td></td>
</tr>
<tr>
<td>494.01</td>
<td>14.6</td>
<td>15.26</td>
<td>14.55</td>
<td>15.21</td>
<td>14.9</td>
<td>(8.41/2)=4.2</td>
</tr>
<tr>
<td>494.07</td>
<td>14.43</td>
<td>14.26</td>
<td>15.45</td>
<td>14.52</td>
<td>14.66</td>
<td>(8.41/2)=4.2</td>
</tr>
<tr>
<td>287.01</td>
<td>6.85</td>
<td>7.37</td>
<td>6.21</td>
<td>7.47</td>
<td>6.97</td>
<td>(6.97-14.78/2)=-0.42</td>
</tr>
<tr>
<td>288.01</td>
<td>6.59</td>
<td>6.3</td>
<td>6.47</td>
<td>6.54</td>
<td>6.47</td>
<td>-0.5</td>
</tr>
<tr>
<td>499.02</td>
<td>2.52</td>
<td>3.26</td>
<td>3.31</td>
<td>3.01</td>
<td>3.02</td>
<td>-3.45</td>
</tr>
<tr>
<td>486.01</td>
<td>4.42</td>
<td>4.28</td>
<td>4.53</td>
<td>4.47</td>
<td>4.42</td>
<td>1.4</td>
</tr>
<tr>
<td>489.01</td>
<td>4.17</td>
<td>4.33</td>
<td>4.1</td>
<td>5.21</td>
<td>4.45</td>
<td>0.03</td>
</tr>
<tr>
<td>489.02</td>
<td>5.1</td>
<td>5.43</td>
<td>5.03</td>
<td>5.34</td>
<td>5.22</td>
<td>0.77</td>
</tr>
<tr>
<td>BFW I</td>
<td>3.41</td>
<td>3.27</td>
<td>3.39</td>
<td>3.56</td>
<td>3.4</td>
<td>-1.82</td>
</tr>
<tr>
<td>BFW II</td>
<td>4.29</td>
<td>4.55</td>
<td>4.13</td>
<td>4.47</td>
<td>4.36</td>
<td>0.96</td>
</tr>
<tr>
<td>BFW III</td>
<td>4.45</td>
<td>4.33</td>
<td>4.12</td>
<td>4.52</td>
<td>4.35</td>
<td>-0.01</td>
</tr>
<tr>
<td>437.12</td>
<td>7.37</td>
<td>8.11</td>
<td>8.41</td>
<td>8.53</td>
<td>8.1</td>
<td>3.75</td>
</tr>
<tr>
<td>437.3</td>
<td>14.47</td>
<td>14.55</td>
<td>15.03</td>
<td>14.38</td>
<td>14.6</td>
<td></td>
</tr>
<tr>
<td>437.17</td>
<td>14.54</td>
<td>14.51</td>
<td>15.23</td>
<td>14.18</td>
<td>14.61</td>
<td></td>
</tr>
</tbody>
</table>

Table 2:  
Histogram showing cycle time comparison.

VI. EXAMINATION AND DEFINITION OF THE DATA OF DIFFERENTIAL LINE

Calculation of the waiting times:

Waiting time of succeeding machine = Cycle time of succeeding machine - Cycle time of preceding machine

A positive value suggests that the piece is waiting at the preceding machine to move forward to succeeding machine and negative value suggests that the succeeding machine is idle and ready, by that much time value, to take in the piece.

Analysis of the data:  On analyzing the data it was clear that the machines having the maximum waiting time are 494.01 and 494.07 with waiting time of 4.20 minutes.

Note: Machine 494.01 and machine 494.07 are independent and similar machines. This means that the piece that goes through 494.01 does not pass through 494.07.

As a result the waiting time is halved as two machines pick up piece from the previous machine 494.03. Now the machines that are majorly concerned with production loss were identified. These are machine 494.01 and machine no 494.07 which are the real bottleneck machines in the production process (as the waiting time is maximum). From the theory of bottleneck it was clear that bottlenecks control the throughput of the whole production system.
When we want to improve productivity of such a system, it is very important to be aware of the fact that any loss of cycle-time on the non-bottleneck resource doesn’t have to cause any loss of total process time on the whole system but on the other hand every minute that is lost on the bottleneck cycle time definitely causes the loss of overall process.

As can be seen from the taken data the machines 437.30 and machine 437.17 are the two radial machines that take maximum time in the process. Here it is to be noticed that two pieces are processed at single machine 437.30 and same is the case with 437.17. All other machines in the production line, process only one piece at a time. This means from the cycle time calculations point of view the effective cycle time of 437.30 and 437.17 is halved as double production (2 pieces) is being achieved here. So 437.30 and 437.17 are not the effective bottleneck machines in the process with effective cycle-time of 7.30 minutes. Hence, the effective bottlenecks in the process are the machine numbers 494.01 and 494.07 with maximum waiting time of 4.20 minutes.

To understand the technical feasibility of different machines with different kind of operations it was required to understand the working of operations of all the machines of differential production line.

**Note:** The operations have been broadly classified and sub-operations have been included within the main operation.

**Abbreviations used in the table stand for-**

<table>
<thead>
<tr>
<th>Table 3: Operation time M/c 494.01 &amp; M/c 494.07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
</tr>
<tr>
<td>Rough Milling</td>
</tr>
<tr>
<td>Dowel holes</td>
</tr>
<tr>
<td>Drilling</td>
</tr>
<tr>
<td>Reaming</td>
</tr>
<tr>
<td>Finish Milling</td>
</tr>
<tr>
<td>Tapping</td>
</tr>
</tbody>
</table>

**Some critical findings:**

It was necessary to shift one or more operations of the bottleneck to some other machine with cycle time much less. Doing so will have double benefit –

1. It will balance the line, i.e. proper load sharing will be done to avoid breakdowns by overloading of M/c 494.01 and M/c 494.07.
2. What happens if one of the two machines break-down?

In this case the cycle time being highest, the working machine becomes critical bottleneck with waiting time of 8.41 minutes. So it becomes even more important to reduce the load of this machine.

VMC: Vertical Machining Centre.

HMC: Horizontal Machining Centre.

SPM: Special Purpose Machine.

A. **Machine 494.06 and Machine 494.02.**

Machine 494.06 and Machine 494.02 are the first two machines in the Rear Cover Line and are absolutely similar in operations. The operator loads the Rear Cover by picking it up from the supply conveyor through tackles and clamps it on the worktable. Here it is to be noted that operator needs to invert the Rear Cover before loading. Both the machines are CNCs and program Operation-10 is fed in the computer memory. All the operations are performed on the inside part of the Rear Cover Plate and along the inside circumference. The position of the spindle carrying all tools is vertical and hence it’s a V.M.C. (Vertical Machining Centre). The cycle time from the point Rear Cover enters the machine to the point it exits the machine is 16 minutes and 30 seconds. In these machines loading and unloading time is not taken as they are equipped with double palette.

**Method Study:** The figure given below shows the sequence of operations that are performed in this machine.

a. Rough Milling inner circumference and two points(4.03 mins)
b. Rough Milling inside points(0.51 mins)
c. Drilling 14 holes, Drilling & Chamfering 2 corner holes(1.41 mins)
d. Chamfering and Drilling along corner holes(0.35 mins)
e. Reamer along drilled corner holes(0.44 mins)
f. Drilling ½ 13mm holes following dowel holes(3.55 mins)
g. Finish Milling along inside circumference(6.61 mins)

B. **Machine 494.08 and 494.05.**

Machine 494.08 and machine 494.05 are the next two CNCs in the line. They are completely similar machines performing all the similar operations. The reason why similar machines were being used in the Rear Cover line was to reduce the overall time a single piece takes to get ready and roll out of H.M.S. It is pretty obvious that the part that goes to 494.08 does not go to 494.05 and vice-versa. Once the piece passes through M/c 494.06 and M/c 494.02 it reaches M/c 404.08 and 494.05. Here the operator inverts the piece while loading on the worktable as all operations are performed on the outer side of the Rear Cover plate as opposed to prior machines.
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a. Rough Milling on outer body
   (3.30 mins)
b. Milling cutter on outer selected points
   (1.30 mins)
c. Drilling outer holes
   (0.56 mins)d. Drilling bigger dia holes
   (0.32 mins)
e. Drilling smaller holes
   (1.08 mins)f. Drilling 4 holes
   (0.40 mins)g. Drilling 3 holes
   (0.34 mins)h. Boring
   (0.53 min)i. Finish Milling
   (1.18 mins)

C. Machine 498.01/498.02 and Machine 437.16.
   Machine 498.01 and machine 498.02 were similar machines performing same operations so the work piece that went to one machine skipped the other machine. This was done to make the line faster. The detailed study of these machines including Machine 437.16 has been done in the later section of examination as there were major findings on these machines.

D. Investigating which operation to be shifted to which machine.

   The operations being performed on the differential were on the lower side, i.e. side up after Inverter-I. Also this machine had a Vertical Machining Centre, i.e. the spindle carrying the tools was vertical. Any machine to which any operation could have been shifted meant two things:
   - It had to be capable of operating the machines with vertical spindle.
   - It had to be capable of performing operations on a particular side of the piece.

   On further diagnosis it was noticed and taken into consideration that the Special Purpose Machines were dedicated to perform only specific kind of tasks and so these were least versatile and flexible from the point of view of shifting the operation. This knocked out any possibility of using SPMs for operations shift.

VII. IMPLEMENTING METHODOLOGY FOR REAR COVER LINE

A. Selecting Rear Cover Line.

   The rear cover line consists of 4 Vertical Machining Centers, 2 Horizontal Machining Centers and 1 radial machine which are in working mode.

   Manly three models of rear cover are machines here, namely regular, CRE wet and CRE dry. The general layout of the rear cover line is shown below:

   ![Machines layout in Rear Cover](image)

   Fig 4: Machines layout in Rear Cover

B. Machine 494.06 and Machine 494.02.

   Machine 494.06 and Machine 494.02 are the first two machines in the Rear Cover Line and are absolutely similar in operations. The operator loads the Rear Cover by picking it up from the supply conveyor through tackles and clamps it on the worktable. Here it is to be noted that operator needs to invert the Rear Cover before loading. Both the machines are CNCs and program Operation-10 is fed in the computer memory. All the operations are performed on the inside part of the Rear Cover Plate and along the inside circumference. The position of the spindle carrying all tools is vertical and hence it’s a V.M.C. (Vertical Machining Centre). The cycle time from the point Rear Cover enters the machine to the point it exits the machine is 16 minutes and 30 seconds. In these machines loading and unloading time is not taken as they are equipped with double palette.

   Critical observation Rear Cover, when it arrives at the first machine is in position which needs inverting before loading in the machine. This inverting is done by removing one of the tackles and tilting the piece. Since the tackles don’t have a lock on them it becomes risky for the operator as there is a chance of the piece falling on operator and hence injury. The tackles should be provided with recess to form a lock and avoid the chances injury to operator.

C. Machine 494.08 and 494.05.

   Machine 494.08 and machine 494.05 are the next two CNCs in the line. They are completely similar machines performing all the similar operations. The reason why similar machines were being used in the Rear Cover line was to reduce the overall time a single piece takes to get ready and roll out of H.M.S. It is pretty obvious that the part that goes to 494.08 does not go to 494.05 and vice-versa.
Once the piece passes through M/c 494.06 and M/c 494.02 it reaches M/c 404.08 and 494.05. Here the operator inverts the piece while loading on the worktable as all operations are performed on the outer side of the Rear Cover plate as opposed to prior machines.

D. Machine 498.01/498.02 and Machine 437.16.

Machine 498.01 and machine 498.02 were similar machines performing same operations so the work piece that went to one machine skipped the other machine. This was done to make the line faster. The detailed study of these machines including Machine 437.16 has been done in the later section of examination as there were major findings on these machines.

VIII. RECORD & EXAMINATION THE CYCLE TIME OF REAR COVER LINE MACHINES.

Machine 494.06 and machine 494.02 perform operation 10, similarly machine 494.08 and machine 494.05 perform operation 20, machine 498.01 and machine 498.02 perform operation 30 and the radial machine 437.16 in the last performs operation 40.

So it was clear that the piece that passes through 494.06 does not pass through 494.02, piece passing through 494.08 does not pass through 494.05 and the piece passing through 498.01 does not pass through 498.02. To compare the cycle time of all the machines of Rear Cover a histogram has been developed as under:

The machines that took maximum cycle time were Machine 498.01 and Machine 498.01 with cycle time more than 20 minutes and the Radial Machine 437.16 at the end of the Rear Cover Line had least cycle time of less than 5 minutes.

It can be analysed that machine 498.01 and machine 498.02 consume maximum cycle time in the production line. Because of this it forms the reason for bottleneck as all other machines performing operation 10 and operation 20 consume less cycle time. From increasing the productivity point of view it was imperative to pay all attention on these two machines (498.01 & 498.02) performing operation 30. Any change in the cycle time of bottlenecks cause change in the overall time of the process and the vice versa is not true.

A. Examination of Operation 30

All the operations that were being performed at operation 30 of the bottleneck machines needed to be thoroughly recorded and examined using Method Study and Time Study techniques. Time per operation was recorded using a stop watch. Multiple readings were taken to avoid any ambiguity.

As can be seen from the above set of operations it is clear that various operations like boring, drilling, milling, tapping, reaming, etc are being carried out at both the faces of the piece.

A close observation at the production line reveals that operation 30 is being carried out at 498.01 and 498.02. Since, both the machines are performing the same operations we can save the face changing time by doing one side operations at one machine and other side operations at other machine upside shows one side of the typical rear cover piece during operation 30.

![Figure 5](image-url)  
The bored hole can be seen on this side of the piece. Similar hole is bored on the other side of the piece as well. These were.

a. Clamping Pressure.

The clamps that hold the piece on the worktable use hydraulic pressure of the oil. This pressure has a set minimum value which needs to be maintained for holding the piece at its place on the fixture. If this clamping pressure goes down a limit the worktable itself does not move into the machine. It has to be taken care of that this pressure is equally maintained at both the machines.

b. Tool wear rate.

The tools being used at the two machines should be so maintained so that tool wear at either one of the two machines does not cause the reason for variance. Proper check has to be kept at tool performance and tool life.

c. Locating Pins

Two locating pins are located on the work table that locates the work piece through dowel holes. After long loading and unloading cycles these locating pins become vulnerable to damage. Any smallest damage that happens to locating pins may change the reference points of the piece. This change can be so negligible that even the operator may not notice. As a result of this damage there comes a chance of variance. Hence, locating pins need to be maintained properly over a period of time.

d. Chips.

Management of the chips is the biggest challenge in HMS as heavy machining causes heavy metal removal in the form of chips. These chips if not cleared time to time have the tendency to stay on the table. Operator should clean the table with air gun before placing the work piece on the table.
Any chip lying under the work piece on the table will cause it to misalign to reference axis ever so slightly that it can only be noticed and analysed when the piece comes in rejection.

Once we are able to control the above mentioned factors the benefits can be reaped.

All the time wasted in revolution of the work piece can be then saved by managing one side operations on one machine and other side operations on the other. The saved time in percentage is shown in the result analysis section of the report.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Reading 1</th>
<th>Reading 2</th>
<th>Reading 3</th>
<th>Reading 4</th>
<th>Average</th>
<th>Waiting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>494.06</td>
<td>16.22</td>
<td>16.39</td>
<td>16.15</td>
<td>16.41</td>
<td>16.29</td>
<td>-</td>
</tr>
<tr>
<td>494.02</td>
<td>16.56</td>
<td>16.37</td>
<td>16.12</td>
<td>16.38</td>
<td>16.35</td>
<td>-</td>
</tr>
<tr>
<td>494.08</td>
<td>14.32</td>
<td>14.11</td>
<td>14.29</td>
<td>15.01</td>
<td>14.43</td>
<td>14.98-16.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= -1.33</td>
</tr>
<tr>
<td>494.05</td>
<td>15.36</td>
<td>15.21</td>
<td>16.17</td>
<td>15.45</td>
<td>15.54</td>
<td>14.98-16.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= -1.33</td>
</tr>
<tr>
<td>498.01</td>
<td>22.39</td>
<td>23.10</td>
<td>22.43</td>
<td>22.56</td>
<td>22.62</td>
<td>22.47-14.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 7.49</td>
</tr>
<tr>
<td>498.02</td>
<td>21.45</td>
<td>22.16</td>
<td>23.19</td>
<td>22.54</td>
<td>22.33</td>
<td>22.47-14.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 7.49</td>
</tr>
<tr>
<td>437.16</td>
<td>4.52</td>
<td>4.36</td>
<td>4.41</td>
<td>4.37</td>
<td>4.41</td>
<td>4.41-11.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= -6.82</td>
</tr>
</tbody>
</table>

**Table 5:**

Histogram for cycle time comparison (minutes)

**B. Scrutinizing further**

Our aim was to reduce the cycle time of op-30. For this purpose it was necessary to shift one or two operations to a machine with much less cycle time. Ideally, if any operation could be shifted to radial machine 437.16 it would make production line more efficient. Generally radial machines are well suited for operations like drilling small diameters and tapping. This is because the tool in the radial machine is more susceptible to movements under large forces. Generally jigs are used when using radial machines to guide the tool and keep the operation under tolerance limits.

**Two Conditions Need To Be Followed While Shifting An Operation From Bottle-Neck:**

1. Operation shift to a machine should be such that the time added to the new machine in the same production line should not make it a bottleneck, i.e. its cycle time should be much lesser than all other machines in the production line.
2. It should be technically viable to shift the operation without affecting the quality of the product.
Why Other Machines Except Radial Machine 437.16 Were Not As Well Suited?

Reason: This is for the very reason that Operation 10 and Operation 20 being carried out on the remaining 4 machines are actually VMCs, i.e., their spindles carrying the tool were vertical whereas the Operation 30 is done at HMC, i.e., horizontal machining center. That means there was a technical constraint. Radial machine also has a vertical machining center but this problem has been dealt with in the following discussion.

Secondly, VMCs machines have cycle time much more as compared to M/c 437.16, so therefore any shift to them from bottleneck machine may have caused bottleneck shift.

C. Identifying the operation to be shifted.

As discussed earlier the typical kind of operations well suited to Radial Machines are small hole drilling and tapping where forces on the tool are less and tool guiding can be done with or without the jigs. In operation 30 the piece is subjected to such operations of drilling two holes of small diameter 6.8mm and tapping in the same holes M8 *1.25. On observing closely it was found that the operation of tapping M8 *1.25 can be successfully shifted to the Radial machine 437.16. As this operation is tapping so the tool guiding problem will also not come.

D. Constraint to operation shift and its solution.

The Radial machine being used in the Rear Cover production line is not capable of performing the horizontal machining operations. For this reason it is suggested to use the work table that is capable of rotating 90 degrees in either direction. A typical radial machine (437.08) is being used in the LMS section of the plant a figure of which is shown in the figure below.

Also it is the work table that carries the fixture. The fixture is fitted onto the worktable by using T-Bolts. Hence the same fixture being used on the old radial machine can be detached and reattached to the worktable capable of rotating.

E. Shifting the operation.

Multiple readings were taken on operation 30 for a particular operation of Tapping 2 holes (M 8*1.25) to get the time taken by this single operation in the cycle. The table below shows these readings. Shifting any operation from one machine to another requires technical feasibility. The operation to be shifted should be such that it is possible for the other machine to perform without affecting the original quality of the operation. Secondly, it also needs to be made sure that the cycle time of the machine where the operation needs to be shifted allows this shift. Thirdly, this shift also needs to comply with the operator.

The table given on the next page shows all the operations of the Machine 498.01 and Machine 498.02 along with cycle time. As discussed earlier most suitable operation was chosen for shifting purpose.

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Individual operation time for op-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Avg. Time</td>
</tr>
<tr>
<td>Rough Boring</td>
<td>1.33</td>
</tr>
<tr>
<td>Rough Boring</td>
<td>1.32</td>
</tr>
<tr>
<td>Finish Boring</td>
<td>1.02</td>
</tr>
<tr>
<td>Finish Boring</td>
<td>1.01</td>
</tr>
<tr>
<td>Milling</td>
<td>1.38</td>
</tr>
<tr>
<td>Milling</td>
<td>1.49</td>
</tr>
<tr>
<td>Finish Milling</td>
<td>0.30</td>
</tr>
<tr>
<td>Finish Milling</td>
<td>0.19</td>
</tr>
<tr>
<td>Boring</td>
<td>2.58</td>
</tr>
<tr>
<td>Drilling</td>
<td>0.11</td>
</tr>
<tr>
<td>Tapping</td>
<td>0.13</td>
</tr>
<tr>
<td>Drilling</td>
<td>0.10</td>
</tr>
<tr>
<td>Drilling</td>
<td>0.22</td>
</tr>
<tr>
<td>Tapping</td>
<td>0.32</td>
</tr>
<tr>
<td>Drilling</td>
<td>0.23</td>
</tr>
<tr>
<td>Reaming</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Note: These readings did not include the side change and tool change time.

The tapping operation shortlisted to be shifted to the radial machine takes 0.13 minutes. This reading includes only the operation time. In reality the tool change time should also be included as this is the time taken by the magazine to install new tool into the spindle. Including the tool change time and the operation time the total time for tapping comes out to be 1.09 minutes. The significance of this operation shift has been discussed in the result analysis section.

IX. Investigating Probable Causes.

The probable causes that lead to the problem to fitment error of studs in the Trumpet hole are shown in the figure on the next page. This figure is known as the Ishikawa Diagram or the Fish Bone Diagram because of the way it looks. All these probable causes have been discussed in detail in the commencing sections and their possibility to cause the error effect has also been discussed.

Casting Defects Casting Defects can cause major irregularities in the casting that may lead to imperfections during machining operations. Probable casting defects are studied as under.
A. Shrinkage defect. These occur when standard feed metal is not available to compensate for shrinkage as the thick metal solidifies. Shrinkage defects can be split into two different types: open shrinkage defects and closed shrinkage defects. Open shrinkage defects are open to the atmosphere, therefore as the shrinkage cavity forms air compensates. There are two types of open air defects: pipes and caved surfaces. Pipes form at the surface of the casting and burrow into the casting, while caved surfaces are shallow cavities that form across the surface of the casting. Closed shrinkage defects, also known as shrinkage porosity, are defects that form within the casting. Isolated pools of liquid form inside solidified metal, which are called hot spots. The shrinkage defect usually forms at the top of the hot spots. They require a nucleation point, so impurities and dissolved gas can induce closed shrinkage defects. The defects are broken up into macro porosity and micro porosity (or micro shrinkage), where macro porosity can be seen by the naked eye and micro porosity cannot.

B. Gas Porosity. Gas porosity is the formation of bubbles within the casting after it has cooled. This occurs because most liquid materials can hold a large amount of dissolved gas, but the solid form of the same material cannot, so the gas forms bubbles within the material as it cools. Gas porosity may present itself on the surface of the casting as porosity or the pore may be trapped inside the metal, which reduces strength in that vicinity. Nitrogen, oxygen and hydrogen are the most encountered gases in cases of gas porosity.

C. Pouring Metal Defects. Pouring metal defects include microns, cold shuts, and inclusions. A misrun occurs when the liquid metal does not completely fill the mold cavity, leaving an unfilled portion. Cold shuts occur when two fronts of liquid metal do not fuse properly in the mould cavity, leaving a weak spot. Both are caused by either a lack of fluidity in the molten metal or cross-sections that are too narrow. The fluidity can be increased by changing the chemical composition of the metal or by increasing the pouring temperature. Another possible cause is back pressure from improperly vented mold cavities.

D. Metallurgical defects. There are two defects in this category: hot tears and hot spots. Hot tears, also known as hot cracking, are failures in the casting that occur as the casting cools. This happens because the metal is weak when it is hot and the residual stresses in the material can cause the casting to fail as it cools. Proper mold design prevents this type of defect. Hot spots are areas on the surface of casting that become very hard because they cooled more quickly than the surrounding material. This type of defect can be avoided by proper cooling practices or by changing the chemical composition of the metal.

E. Thermal Dimensional changes. The process of machining is followed by rise in temperature of both tool and work piece. The problem of Stud miss fitment is due to the fact that the studs being set into the Trumpet drilled holes were tight, i.e. the diameter of hole was less than 10.2 mm, and were not doing the complete drilled hole distance of 26mm. This meant that either the drilled holes were smaller in diameter or tapping in the holes was not proper for threads to align or both. The operation of drilling and tapping was carried out at BFW 1 and BFW 3 respectively. Since there was possibility that due to dimensional changes the studs were not fitting so the machining temperatures need to be monitored. Rise in the machining temperature changes the dimensions of the work piece such that the when the piece is hot it expands and when it loses heat and cools, it contracts. This expansion and contraction is microscopic in nature and thus such changes can’t be monitored by naked eye. Figure below shows how the temperature of tool and work piece rises in different zones during machining.

F. Chattering Tools and Machine. While carrying out any machining operation it is very important that both work piece and tool are very stable and do not distort in any manner. During the operation of Drilling on BFW1 and the operation of Tapping on BFW 3 machining forces on both may cause vibrations and chattering which may result in slight disorientation of the tool or work piece or both. Proper clamping for the stability of work piece and maintenance of the machine should be incorporated to avoid such errors.

G. Chips on workable. On BFW 1 a total of 52 holes are drilled all in single pass of multiple drills. 36 of these holes are of diameter 10.2 mm, 12 holes have diameter of 6.8 mm and 2 holes have the diameter of 29 mm. It needs to be noticed here that drilling of the two holes of 29 mm diameter creates considerable amount of chips and without any mechanism of chip disposal it becomes necessary to manage the chips most effectively. On closely observing the operations of BFW 1 it was seen that chips were lying on the worktable which were not removed by the operator every time before loading the next piece. This meant that the next work piece was loaded on the worktable with chips lying underneath its body. The chips lying under the body of the casting was completely undesirable as it caused very minor disorientation in the placement of the casting. This disorientation, although being minor, was sufficient to change the angle and positioning of work piece against the set tools. As a result the drilled holes may get shifted by very minute angles, not visible by eyes, and may cause misalignment of drilled holes. The work piece goes to BFW 3 for Tapping operation once Drilling is done on BFW 1. In the case where chips lying on the worktable disoriented the drilled holes, tapping into these holes may not be proper.
A tap needs a straight drilled hole to travel the hole distance and any misalignment between the two may hinder proper tapping. If the tapping is not proper the studs will not go inside the drilled hole to entire length as threads will be missing. So it is imperative that the operator makes sure before loading every single piece on the worktable that it is free from any chips that may be lying on the bed. For this purpose every single machine of the Differential Line has access to air gun that blows away all the chips with compressed air.

**H. Clamping Error.** BFW 1 and BFW 3 have hydraulic clamping mechanism where the operator manually loads the work piece from the conveyor to the machine and clamps it. Any leakage in the supply line of the hydraulic oil may make the clamping process faulty. In this case the work piece would not be sufficiently stable and may disorient during operation of drilling or tapping. It should be ensured by the operator that clamping is proper and no oil leakage is there in the clamping procedure. In case of faulty clamping these machines are equipped with auto cut off mechanism in which the machine does not take in the work piece and the machining does not start.

**I. Tool Wear** In all the probable causes of the misfitment of studs in the trumpet holes the most significant cause is Tool Wear. It is most probable that if the studs are miss-fitting then there must be some problem with the drilled hole. For the drilled hole to be improper there must be problem with the tools involved in operation. In this case the focus is on the drill bit which may wear down with time.

**J. Electrochemical Effect.** It has been argued that since sufficiently high temperatures exist on the chip tool interface a thermoelectric e.m.f. is setup in the closed circuit due to the formation of hot junction at the tool chip interface between the dissimilar tools and work material. This current may assist wear process at the rake face in some way by aiding the diffusion of carbon ions from the carbide tool to the flowing chip.

**K. Understanding the operations and tool wear in BFW 1 and BFW 3.** The operation of Drilling and Chamfering is done at BFW 1. These two operations are of drilling and chamfering are done by the same combination tool. It is a typical example of how the efficiency of the tool is increased by simple changes in its design to serve more than one purpose. In total 52 holes are drilled here with drill length of 26 mm and diameter ranging from 10.2 mm to 29 mm. The combination tool is drill with chamfer as shown in the figure as under. It needs to be considered here that what is the purpose of chamfer? Hole chamfers are usually specified simply to make it easier to insert a screw, pin, bushing, or other assembly component. The component doesn't bear on the chamfer, so diameter and angle tolerances are usually not critical to the part's performance and hence tolerance levels are not tight.

In addition to make the insertion easier the chamfered holes serves in debarring as well. Hole chamfers are different from countersink holes as a countersink is a functional surface upon which a fastener head bears. Because fastener performance is so important, countersink tolerances are critical. The countersinks on an aircraft's skin are an excellent example. If the countersink is too deep, there may be inadequate skin material for the rivet to hold against the underlying frame. If a countersink is too shallow, the rivet head will protrude, increasing air resistance. Nevertheless, the dimension of chamfered hole also has its own importance because of the various purposes that it serves. As a result, in our case under consideration, if the chamfered hole is not operated properly it may cause problems at a later stage. The machine BFW 3 performs the operation of Tapping in those previously drilled holes on BFW 1 using the Tap tool. The spindles those carry tap tools are equipped with Safety Clutch Adapter. The safety clutch has the mechanism which stops the spinning of the tap tool incase some external hindrance appears.

**X. Result Analysis**

A. Result Analysis for shifting the Tapping operation in Differential Line from Machine 494.01 and Machine 494.07 to Machine 437.30 and 437.17.

The operation shift from M/c 494.01 and M/c 494.07 to Radial machine 437.30 and M/c 437.17 has resulted in the reduction of waiting time in front of the bottleneck machine which was earlier having maximum waiting time in the production line. Some calculations below show how much of a difference has it made.

The tapping operation that took 1.42 minutes on the CNC can be shifted to radial machine. This would reduce the load of CNC by 1.42 minutes.

Calculations for reduction in cycle time:

Avg. Cycle time of CNCs = 14.78 mins.

Waiting time of CNCs without operation shift = 4.20 mins.

Waiting time of CNCs with operation shift = 4.20 – 1.42

Waiting time of CNCs with operation shift = 2.78 mins.

Now,

Cycle time of Radial Machines for 1 piece = 7.30

Cycle time of Radial Machines with operation shift = 7.30 + 1.42

Cycle time of Radial Machines with operation shift = 8.72 mins.

Waiting time without operation shift = -0.40 mins.

Waiting time of Radial Machine with operation shift = - .40 + 1.42

Waiting time of Radial Machine with operation shift = 1.02
Comparing the results by the effect of operation shift on CNC machine and Radial machine it can be seen that adding 1.42 minutes operation to the Radial Machine takes its cycle time per piece to 8.72 minutes. This cycle time is much less than the new cycle time of bottleneck CNC, i.e. 13.36 minutes. On the whole we have reduced 1.42 minutes from the CNC to a machine that was being underutilized in the production line.

Note: This scenario of operation shift becomes even more efficient when the either one of the two CNCs breakdown. Also this operation of Tapping is to be performed on the lower side of the Differential. So an extra 30 seconds should be kept as an allowance for radial machine for rotating the piece by 90 degrees. When the differential is kept on the table of the radial machine for this operation it will be absolutely horizontal without any inclination due to its design and hence no problem will come while performing the operation.

B. Result Analysis for Machine 498.01 and Machine 498.02 to avoid side change while performing operations CNCs 498.01 and 498.02 being similar are sharing the load of the line. Calculations have been made to see how many times the work table actually rotates inside the machine and how much of a time can be saved by doing one side operations at one machine and other side operations at other machine applying all conditions that have been discussed earlier in the section.

Total Number of rotations by 180 degree = 3
Total time taken to rotate including tool retract time = 3.01 + 2.23 + 1.13
Total time taken to rotate including tool retract time = 6 minutes
Cycle time without side change operations = 22.62 – 6
Cycle time without side change operations = 16.62
Reduction in waiting time with new cycle time = 16.62 – 15.54
New waiting time with new cycle time = 1.08
Original waiting time = 7.49 minutes
%age reduction in waiting time = 6.41/7.49*100 %
%age reduction in waiting time = 85.5 %
%age reduction cycle time = 6/22.62*100 %
%age reduction cycle time = 26.52

Assumptions: These results holds true only when the conditions to avoid the variance in the boring holes diameter are controlled and regular check is maintained as the tolerance of 40 microns is very tight. In future if there’s a design change that doesn’t require maintaining tight tolerances of these bores, the suggested change can be even more successfully implemented.

C. Result Analysis for operation shift from Machine 498.01/498.02 to Machine 437.16.

The operation of tapping was shifted from the M/c 498.01 and M/c 498.02 to save some time as the cycle time here was maximum and so was the case with waiting time. Tapping operation was selected to be shifted to Radial M/c 437.16 with much less cycle time. The effect of this operation shift on the production line has been studied as under:

Operation 30-
Cycle time of Operation 30 = 22.47 minutes
Waiting time before Operation 30 = 7.49 minutes
Tapping M 8*1.25 TWO HOLES = 1.09 minutes
New waiting time without Tapping operation = 6.4 minutes
Therefore %age reduction in waiting time = 14.55%
Operation 40-
Cycle time of operation 40 = 4.41 minutes
Waiting time of operation 40 = -6.82 minutes
New cycle time with operation shift = Old cycle Time + Operation Time + Side change Time + Tool change Time
New cycle time with operation shift = 4.41 + 1.09 + 1.10 + 0.30
New cycle time with operation shift = 6.9 minutes
New waiting time with operation shift = Old waiting Time + Operation Time
New waiting time with operation shift = -6.82 + 2.49
New waiting time with operation shift = -4.33 minutes

The waiting time of the radial machine performing operation 40 does not go into positive and remains in negative even after operation shift. This means on the overall line efficiency this shift has a positive effect on the whole. This is because of the reason that Operation 30 is a bottleneck operation which decides the production limit of the production line and when tapping operation was shifted to radial machine the cycle time was reduced. As the cycle time of radial machine was very less as comparison to bottleneck it had no negative effect on the overall efficiency of production line.

D. Result Analysis for Stud-Trumpet miss-fitment problem. The various reasons possible for causing the defect were discussed in the appropriate section of the report. Quality tool of Ishikawa Diagram was used to analyze all the causes like Casting Defects, Tool wear, Machine chattering, Chips management, Thermal defects and Clamping errors and were discussed in detail with appropriate solutions suggested.
XI. Conclusion and Future Scope

In the Paper work the focus was kept on the utmost of utilization of the resources and methods of identification of scope for doing so without spending on adding any new resources.

The study has revealed that the machines taking maximum cycle time in the production process and those have the maximum waiting time actually decide the capacity of the production line. By putting all the focus on these bottleneck machines, methods were devised to reduce their cycle time by shifting some possible operations to other machines which were being underutilized and had much lesser cycle time in the batch production line. By doing so a fair share of work was divided among all machines without overloading some selected machines.

Secondly, it was seen that when two machines were present in production line, which were similar in working, side changing operations should be avoided. This side changing was unnecessary time wasted which actually could be saved. This meant that resources those were present with us were not utilized in the best possible manner. By allotting one side operations to one machine and other side operations to other machine useful production time was saved and hence the overall effectiveness of the line was increased.

Thirdly and finally an investigation was run on the probable causes of a particular defect that caused line throwback in differential. For this a quality tool was used to reveal and fix those probable causes.

Overall the Paper work was carried out using the tools of work study, lean manufacturing and quality to tackle the production line problems.

REFERENCES.


