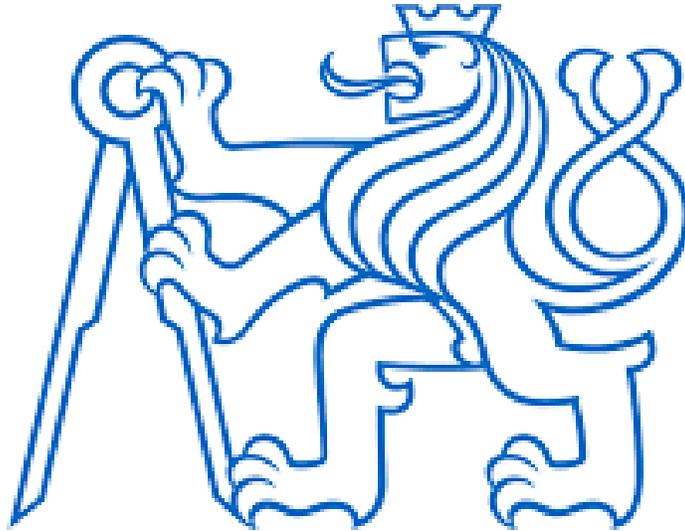


CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF MECHANICAL ENGINEERING

DEPARTMENT OF PROCESS ENGINEERING



IMPROVEMENT IN PRODUCTION LINE OF MOTOR ASSEMBLY

MASTER THESIS

2019

SELVAN

LAXMINARAYANAN



MASTER'S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Selvan Laxminarayanan** Personal ID number: **473332**
Faculty / Institute: **Faculty of Mechanical Engineering**
Department / Institute: **Department of Process Engineering**
Study program: **Mechanical Engineering**
Branch of study: **Process Engineering**

II. Master's thesis details

Master's thesis title in English:

Improvement of the production line of motor

Master's thesis title in Czech:

Zlepšení výrobní linky motorů

Guidelines:

Make a literature research focused on types of production layouts. Define the current layout used in motor line production. New type of layout shall be proposed for improvement of production. The production efficiency of the new line shall be calculated and compared the current layout. Kaizens shall be proposed for further improvisation in production. In the conclusions benefits of the new type of layout shall be summarized.

Bibliography / sources:

According to the recommendation of the thesis supervisor.

Name and workplace of master's thesis supervisor:

Ing. Michal Netušil, Ph.D., ŠKODA AUTO a.s.

Name and workplace of second master's thesis supervisor or consultant:

Date of master's thesis assignment: **31.10.2019** Deadline for master's thesis submission: **10.01.2020**

Assignment valid until: **09.02.2020**

Ing. Michal Netušil, Ph.D.
Supervisor's signature

prof. Ing. Tomáš Jirout, Ph.D.
Head of department's signature

prof. Ing. Michael Valášek, DrSc.
Dean's signature

III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

31 -10- 2019

Date of assignment receipt

Student's signature

DECLARATION BY THE CANDIDATE:

I hereby declare that the diploma thesis entitled "IMPROVEMENT IN PRODUCTION LINE OF MOTOR ASSEMBLY" is a record of project work carried out by me under the supervision of Ing. Michal Netušil, Ph.D.

I further declare that the work reported in this project has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this university or any other institute or university.

In Prague:.....

Signature:.....

Acknowledgment:

The delight and contentment that follow any successful completion of a task would be incomplete without whose relentless guidance and encouragement, crown all our efforts with success.

First of all, I would like to thank my university for providing me an opportunity to study under the field of engineering. I would like to thank my professors and colleagues for being a backbone for the completion of master thesis. I would also like to express my profound gratitude to the doc. Ing. Lukas Kratky, Ph.D., for providing me a letter of recommendation to do a master thesis in the mechanical industry.

I would like to sincerely thank my thesis advisor Ing. Michal Netušil, Ph.D., who has been continuous support till the completion of the master thesis for permitting to carry out a master thesis under his supervision. I really loved working under his supervision due to his patience, motivation, and advice which took me on the right path for the completion of my master thesis.

Finally, I would like to thank my family and friends for their endless support, encouragement, and motivation throughout my study years which provided me hope and energy to complete my study program.

Thank you.

2019

SELVAN LAXMINARAYANAN

ANNOTATION SHEET:

Name: LAXMINARAYANAN

Surname: SELVAN

Title Czech: Zlepšení výrobní linky motoru

Title English: Improvement in production line of motor assembly.

Scope of work: Number of pages: 74
Number of figures: 32
Number of tables: 06
Number of equations: 15
Number of appendices: 04

Academic year: 2019-2020

Language: English

Department: Mechanical Engineering

Specialization: Process Engineering

Supervisor: Ing. Michal Netušil, Ph.D.

Reviewer: Petr Kozeny

Tutor:

Submitter: Czech Technical University in Prague,
Faculty of Mechanical Engineering
Department of Process Engineering

Abstract

In company XYZ, numerous products are manufactured. More specifically, for the vehicle, different kinds of wiper motors are manufactured according to customer needs. In the assembly, there are five lines namely Stator, Rotor, Pivot housing, Motor, and Wiper line. Every Motor line is divided into segments. Every segment consists of many workstations. Each workstation consists of many processes. Each segment has its own bottleneck and also takt time. Each workstation has its own cycle time. The current layout used in the Motor line is I shaped layout (I-type layout). Since the length of the line is too long, it creates more trafficking of materials in line thereby resulting in the decrement of production efficiency. Hence, a new type of layout is proposed which is U shaped layout (U-type layout) for preventing the trafficking of materials. The proposed line is designed and implemented not only for avoiding material traffic and better operator ergonomics but also for single piece flow which is the prevention of building up of stacks of inventory between the process steps in workstations. The production line efficiency is calculated for both layout and is compared to observe the increment in production efficiency of U type layout. Also, individual operator efficiency has been calculated for both layout and compared. For further improvement in production, KAIZEN (continuous improvement) has been proposed and implemented in the line for some workstations with the help of Group leader and team member.

Keywords: Bottleneck, Single-piece flow, U-shaped line, I-shaped line, Cycle time, Downtime, Takt time, Kaizen

Contents

1 Introduction	10
2. Research	12
2.1 Types of line layout	12
2.2 Process Flow Diagram.....	19
2.2.1 Sequence of Process	19
2.2.2 Reasons to use Process flow diagram	19
2.2.3 Commonly used symbols in detailed PFD	20
2.3 Production efficiency definition.....	22
2.4 Definition of cycle time and takt time	27
2.4.1 Cycle time	27
2.4.2 Takt time	27
3 Practical part.....	29
3.1 Purpose of the project	29
3.2 Process flow diagram for production of the motor assembly.....	30
3.3 Assembly line layout	35
3.4 I-shaped assembly line layout and its calculations	36
3.4.1 Workstations in I-shaped Assembly line layout	36
3.4.2 Calculation of takt time.....	43
3.4.3 Calculation of Cycle time	44
3.4.4 Calculation of production efficiency	46
3.5 U-shaped assembly line layout and its calculations	52
3.5.1 Takt time	54
3.5.2 Calculation of cycle time	54
3.5.4 Calculation of Production efficiency	55
3.6 Continuous improvement activity	58
3.7 Comparison of results produced by I-shaped and U-shaped assembly line	64
3.7.1 Comparison of cycle time	64
3.7.2 Comparison of production efficiency and operator efficiency	65
4 Conclusion.....	67
References	69
Appendix	72

List of figures

Figure 1: Line layout strategies	11
Figure 2: Types of the layout of line	12
Figure 3: I-shaped line layout	13
Figure 4: material trafficking in I-line.....	14
Figure 5: L-shaped line layout	14
Figure 6: An example of an L-shaped line layout.....	15
Figure 7: S-shaped line layout	16
Figure 8: Types of U-shaped line layout depending upon demands.....	17
Figure 9: An example of a U-shaped line layout.....	18
Figure 10: Symbols used in the process flow diagram	21
Figure 11: Cycle time Vs Takt time	28
Figure 12: Assembly floor flowchart	30
Figure 13: Process flow diagram of motor assembly part 1	31
Figure 14: Process flow diagram of motor assembly part 2.....	34
Figure 15: Network diagram of I-shaped line layout	35
Figure 16: I shaped floor layout of assembly line C1.....	40
Figure 17: Cycle time for I-shaped line	45
Figure 18: Shift data for production efficiency calculation for I-line	46
Figure 19: Comparison of different cases of production efficiency	50
Figure 20: U shaped floor layout of assembly line C1	53
Figure 21: Cycle time for U shaped line.....	54
Figure 22: Shift data for production efficiency calculation for U-line.....	55
Figure 23: Comparison of Production efficiency Vs Rejected pieces.....	57
Figure 24: Cycle time Vs Takt time before implementing improvements.....	59
Figure 25: Conveyor used in station 1P	60
Figure 26: Rotating table with pockets.....	61
Figure 27: Before kaizen implementation in workstation M6	63
Figure 28: After implementing kaizen in workstation M6.....	63
Figure 29: Comparison of average cycle time for the whole line (I-line Vs U-line)	64
Figure 30: Comparison of average cycle time for workstations in I-line and U-line.....	65
Figure 31: Comparison of Factors of production efficiency for I-line and U-line.....	65
Figure 32: Comparison of individual operator efficiency for I-line and U-line	66

List of tables

<i>Table 1: Total units produced in a shift for I shaped line</i>	45
<i>Table 2: Individual operator efficiency for I-line</i>	51
<i>Table 3: Total units produced in a shift for U shaped line</i>	55
<i>Table 4: Comparison of different cases with lesser rejections</i>	56
<i>Table 5: Production efficiency values of I-line and U-line</i>	57
<i>Table 6: Individual operator efficiency for U-line</i>	58

<i>Equation 1: Production line efficiency</i>	22
<i>Equation 2: Availability</i>	22
<i>Equation 3: Performance based on ideal cycle time</i>	22
<i>Equation 4: Performance based on ideal run rate</i>	23
<i>Equation 5: Quality</i>	23
<i>Equation 6: Takt time</i>	43
<i>Equation 7: Performance efficiency based on Utilization</i>	47
<i>Equation 8: Production efficiency based on Utilization</i>	47
<i>Equation 9: Availability efficiency based on Utilization</i>	47
<i>Equation 10: Operational efficiency</i>	47
<i>Equation 11: Rate efficiency</i>	47
<i>Equation 12: Availability efficiency and Operational efficiency</i>	47
<i>Equation 13: Availability</i>	48
<i>Equation 14: Utilization</i>	48
<i>Equation 15: Individual operator efficiency</i>	50

Appendix

1. My design of U-shaped layout.....	72
2. I-shaped line with dimensions.....	73
3. U-shaped line with dimensions.....	74
4. Data and calculations in MS Excel (added in CD)	

1 Introduction

An assembly line layout or production line layout refers to a system in production wherever the workstations, tools, and equipment are situated on the line of production. Generally, in any industry, a work unit is advanced along the line (which depends on the line layout shape). To utilize an assembly line layout, the full work to be accomplished should be divisible into little tasks that may be allocated to every workstation. In every workstation on the line, a little amount of work is performed. Since a small amount of work is performed in each station, the operators operating in stations utilize specific methods and equipment given to perform the job they are assigned. This will conclude in an expanded rate of production. Assembly lines are planned and designed for the consecutive organization of operators, equipment, tools, machines, and parts. The movement of workers is reduced greatly to an extent doable. This is achieved by the fact that every part that is in the assembly are transported either by mechanical apparatus such as conveyors or by using motor vehicles such as forklifts, or gravity, with no manual trucking. Heavy lifting is performed by using heavy machines such as cranes or forklifts. Every worker routinely performs one effortless operation.

The fundamentals of assembly are as follows:

- (1) Operators and tools that should be used for the sequence of operations must be placed in a certain position so that the comfortable working environment is created.
- (2) Slides or chutes should be used so that the operator can place the assembled part after the completion of the operation in the same place. The Position of the chutes or slides should provide convenience for the operator's hand while placing the completed assemble part.
- (3) A sheet describing the sequence of operations with pictures of the operations should be provided at each workstation so that it makes the jobs easier for the new operators learning the job and also for other operators working in the station during the absence of allotted station operator.
- (4) Sliding mechanisms in the assembling lines such as conveyors should be used by which the parts to be assembled are delivered at convenient distances^[1].

As time moved on, customer demand increased in the past, is still increasing in present, and also will increase in the future. In order to tackle the increasing customer demands many strategies are implemented to improve production efficiency without sacrificing the quality of products produced. One of those strategies includes implementation of a new line layout of an assembly line which can provide the expected production results. In every industry, it is always considered that the layout of the assembly line can be of greater influence in the production rate. The new line layout that is designed to be implemented should consider avoiding material trafficking and provide ergonomics for the operators to work. Anything that brings a burden to the operator while working always results in the decrement of production efficiency and it's a total waste of time in designing anything that brings a burden. The person designing the line layout should always keep this in mind. In order to check the improvement observed in the new line layout comparing to previous line layout, strategies such as cycle time calculation, takt time calculation, productive efficiency also called production efficiency for both line and individual operator, continuous improvement, line imbalance, etc., are used^[1].

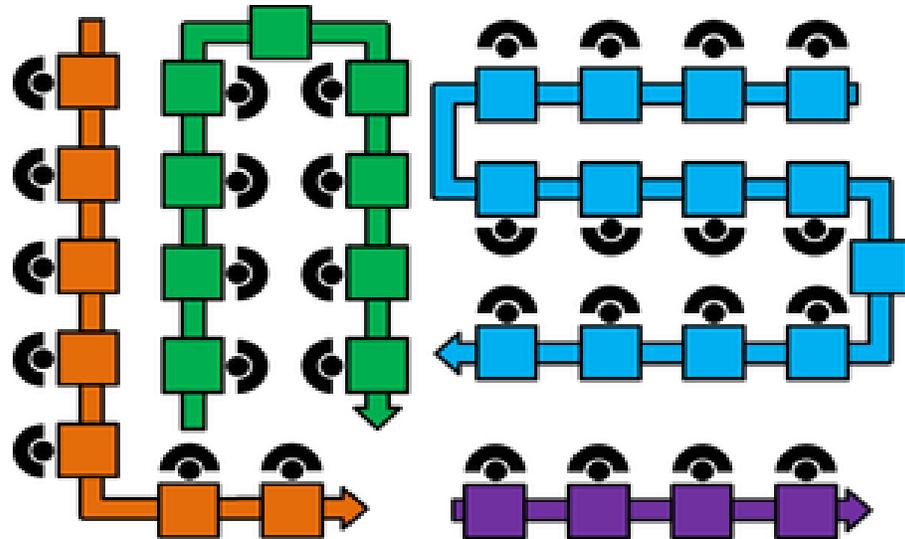


Figure 1: Line layout strategies^[2]

These strategies may sound simple and easier to be calculated, but it really plays a crucial role in every industry growth in terms of improvement in both quality and quantity. Almost every industry in the world uses these strategies to face the customer demands and consider them as their backbone for gradual growth year by year. It should be noted that it

takes a lot of time, manpower and expense for planning, designing, cross-checking and implementing the new shaped line layout by rearranging the workstations and equipment from the previous layout. The important point is that reducing even a single whole second in the production time of a work unit will result in greater profit for the industry in the future. For further reduction in production time, the specific target will be provided to the teams taking care of each assembly line to find where the waste of time in workstations is noticeable and can be reduced. This can be implemented in stations only after performing a prototype, followed by test run and further approval of the head of the department. The other way possible to reduce the waste of time in the assembly line is by introducing automation in the line wherever is possible.

2. Research

2.1 Types of line layout

The production rate of an assembly line depends on the design format of its layout by some means. The layout of a line is classified into four types based on the shape or design format of the line^[3]. The types of layout of a line are shown in figure 2.

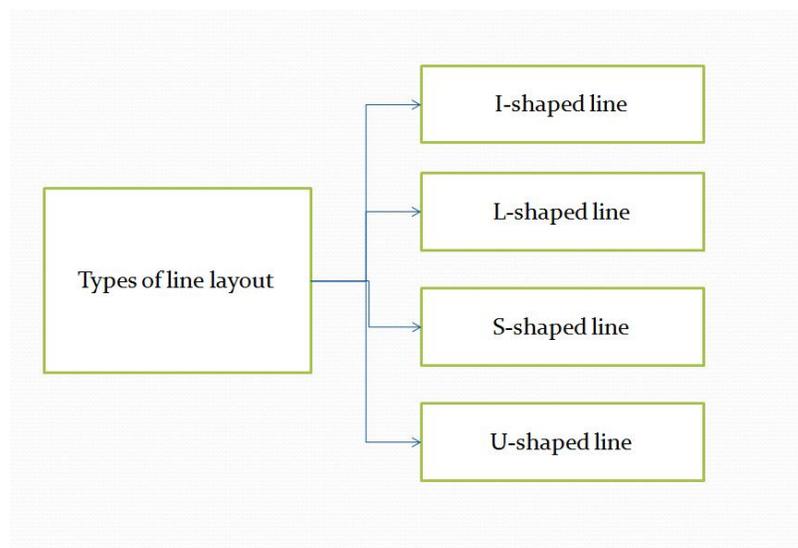


Figure 2: Types of the layout of the line^[3]

The easiest and basic layout that is utilized in industries is a line layout that is of I-shaped. As the L-shaped line is the extension of the I-shaped layout so the design format of L-line is like I-line. S-shaped line layout is used only for larger production lines and it is very

common in automotive industries. U-shaped line layout is a famous layout and is regularly portrayed as the best line layout for manual manufacturing lines. Though it is the best line layout, it cannot be the solution for everything. The U-shaped layout is divided into varieties depending upon the demand of the product^[4].

I-shaped line

I-shaped production line layout is always the most used layout in many industries. Assembly lines with smaller process steps always utilize these kinds of production layouts. This is also known as a straight-line layout since the flow goes in a straight line where the raw material enters from one end and the finished product comes out at the other end. It is also used in places wherever there shouldn't be any bends for the process in the line due to some technical issues, for example, long metal sheets or other automotive parts in a production line cannot be sent through bent production lines^[4].

The basic sketch of the I-shaped line layout is shown in figure 3. The yellow box indicates the workstations.

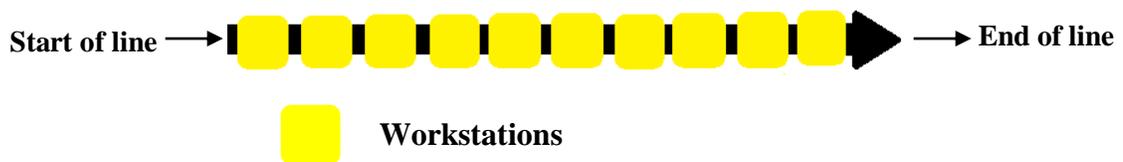


Figure 3: I-shaped line layout^[drawn in MS Excel]

The straightforward entry from either side for both material and operators make this line layout essential for companies to implement wherever such a requirement is needed. However, if the line is too long, it will occupy a larger space within the building area. Additionally, a lengthy I-Line may act as a barricade, unless a form of a bridge or alternative crossing is created to allow both material and operators to move around the line. Managing and supervising the line demands a lot of time and effort from the supervisor due to its greater length. An operator could also be able to perform his own process and perhaps the two adjacent processes. However, working on other processes would be difficult as it may involve an excessive amount of walking. Line trafficking, also known as material trafficking, that occurs in a long I-shaped line layout is shown in figure 4^[2].



Figure 6: An example of an L-shaped line layout^[5]

S-shaped line

The S-shaped assembly line is used usually in places where an industry requires longer lines, for instance, the lines that are used in the automotive industry. The S-shaped lines are usually around 1000 metres long. The major complication of having a straight production line in the automotive industry is the management of space inside the building area and difficulty faced in logistics. If an organization needs a more efficient line also a significant improvement over a straight line, the S-shaped line is a suitable option to choose from. Simplifying logistics to a greater extent could also be accomplished. For instance, forklifts can have access points in different parts of the line without having to travel around the entire line. The operators of an S-Line are limited to usually tend only to the facet right next to them as the aisles must be broad enough to allow easy access of forklifts. In some cases, it might be feasible for them to work on other facets when there is only limited material handling. The basic sketch of the S-shaped line layout is shown in figure 7^[2].

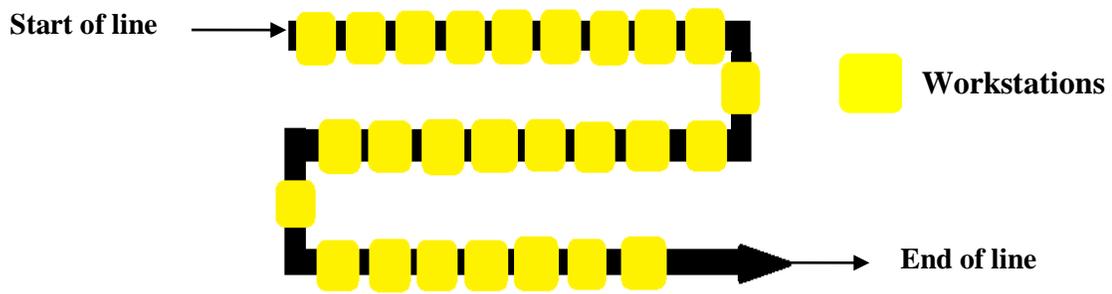


Figure 7: S-shaped line layout^[Drawn in MS Excel]

U-shaped line

The U-shaped line layout is divided into segments depending upon the customer demands as

- Low demand
- Medium demand
- High demand
- Very high demand

In the case of very high demand, operations are performed by assigning an operator at each workstation and as a result, the rise in total production is noticed. In the case of high demand, operations are performed by allocating each operator to take care of two workstations so that the required demand is fulfilled. If the demand is medium, the operations are performed by allotting few operators to handle each workstation by equally dividing the work for them. If demand is lower, more and more operators are reduced from the line, until such a situation comes where only a single worker handles all the processes, producing only fewer parts. Obviously, it should be made sure that the machines are quick enough, and that the operators operating in the different stations have similar workloads to avoid waiting times of operators. The different types of U-shaped layout based on demand is shown in Figure 8^[2].

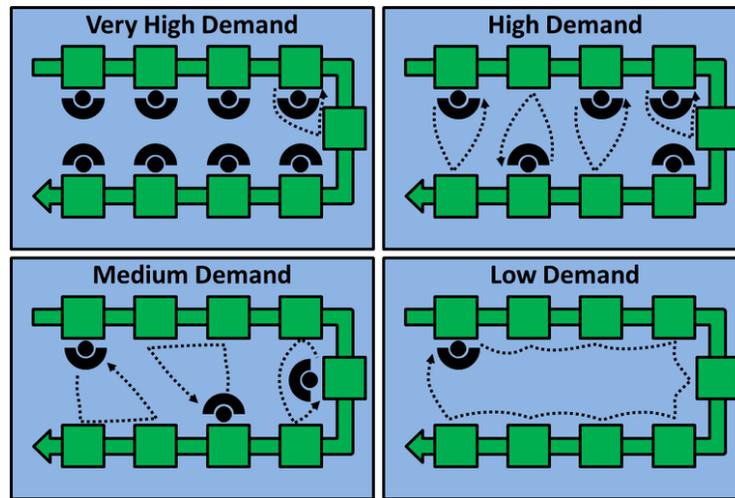


Figure 8: Types of U-shaped line layout depending upon demands ^[2]

In modern times, the U-shaped production line layout is most used in manufacturing industries. In many manufacturing industries, the U-shaped production line layout has replaced the long-established straight-line layout (I-shaped layout). The application of the U-shaped layout in the production has quite a few advantages. The U-line is widely considered to be the best production line layout. The major advantage of the U-line is the presence of multiple operators in one line, who are present in the interior side of the “U” in the line. The outside of the “U” is solely used for material supply. Special devices and tools are required for delivering the material to the workstations from the outside to inside across the entire line. Slides and roller chutes are generally used to bring the material over the line, and conveyors are also utilized to bring the material from under or the top of the line. The material provided by logistics from the outside is usually refilled by a separate operator. Although refilling material in a U-line is not as efficient and effortless as in the I-Line, the other relative advantages justify this extra effort ^[6].

Another major advantage of this line is that the operators working inside the production line are cross-trained which allows them to utilize every equipment within the production line and take responsibility for its output. Since the operators are cross-trained to work in every workstation, boredom is not the main factor here. This also motivates the operators to take more responsibility. In case of a problem or a breakdown in the line, an operator can temporarily neglect the other part of the line as he/she tends to the issue. Breakdowns and other problems faced in U-line could potentially be fixed faster than in other lines. The ease of access an operator has to multiple workstations allows for lesser walking

time and effort. This could also be scaled up to a large extent very efficiently by adding multiple operators. Another advantage of the U-shaped line layout is that it provides faster processing time compared to other line layouts, provides much lesser material handling, and lesser setup time which is all most probably tend to produce positive outputs when this line layout is implemented ^[7]. An example of a U-shaped layout is shown in figure 9.



Figure 9: An example of a U-shaped line layout^[8]

Another advantage of implementing a U-shaped line layout is for achieving "one-piece flow" or "single-piece flow". Technically, one-piece flow can be defined as a concept of moving parts through workstations from step to step with no work-in-process in between wither one piece at a time or a small batch at a time ^[9].

The single-piece flow has many benefits. It leads to a better quality where it is much easier to build in one-piece flow since every operator is cross-trained and can act as an inspector to fix any problems before leaving the respective workstations. The problems will be quickly found, and a solution will also be provided. It also creates real flexibility to equipment, creates higher productivity, frees up floor space occupied in other layouts, Improvement in overall safety, Morale improvement of operators working in stations, Reduction in the cost of the inventory ^[10].

2.2 Process Flow Diagram

A Process flow diagram is an image of separate steps in sequent order. It is a typical process analysis tool and one of the 7 fundamental quality tools. Segments that may be inserted in a flowchart are series of actions, materials or services entering or exiting the process (inputs and outputs), decisions that must be made, people who become involved in the process, time involved at every step and process measurements^[11].

2.2.1 Sequence of Process

The sequence of process is a set of sequences that are followed in each line to assemble that set of parts in a specified time without any compromise in quality standards. For example, in workstation 1P the order of sequence to complete an assembly process is as follows.

1. The worm wheel is taken, and the deceleration plate is placed in the provision given for the plate in the worm wheel.
2. The worm wheel is then placed in the fixture of the pressing machine.
3. The machine is switched on by keeping both hand thumb in the switch sensor so that the deceleration plate is pressed by machine.
4. After pressing the plate, the worm wheel is taken out from the fixture and the retainer ring is placed on the shaft of the worm wheel.
5. Then the washer is placed on the shaft of the worm wheel.
6. The worm wheel is then sent to the next workstation. These all sequence of operations in the above order is meant as a process.

2.2.2 Reasons to use Process flow diagram

- To have a clear understanding of how many and what are the sub-assembly steps required for completion of one main assembly step.
- This diagram is generally used in industries in order to study the process so that improvements can be brainstormed and implemented.
- This is used to make the employees from other departments understand how the process is being performed.
- This is also used when a better interface is needed between two people.
- This diagram is mainly used for documentation of the project and also for planning a project^[11].

2.2.3 Commonly used symbols in detailed PFD

These symbols play an important role in understanding the process flow at ease. The following symbols are normally used in the process flow diagram of every industry.

-  This is used if there is one step in the process. The steps are normally written inside the box. Usually, there are many steps involving in a process flow diagram and these steps are interconnected by arrows. This is shown in figure 10.
-  This arrow indicates the flow of direction from one step to another. These arrows connect one step with another step which technically means that after completion of one step the next following step will be performed. This is shown in figure 10.
-  This is used for the decision based on a question. The question is written inside a diamond. More than one arrow goes out of the diamond, each one showing the answer to the question (which is yes or no). From figure 10, there are two diamonds with an arrow joining from step noise and vibration control (diamond on left side) to repair (diamond on the right side). This means that the fully assembled motor unit is checked for noise and vibration control where there is a possibility to feel abnormal noise and vibration which is very bad for a motor. The checked motor is marked to indicate whether the motor is OK or NOT OK. The OK motor proceeds to the next step and NOT OK motor proceeds for repair. A question will arise whether the motor can be repaired or not. This is indicated by arrows flowing towards the direction of the answer. The fixable motor proceeds for repairing and not-fixable parts are kept as not repairable parts^[10]. This is shown in figure 10^[11].

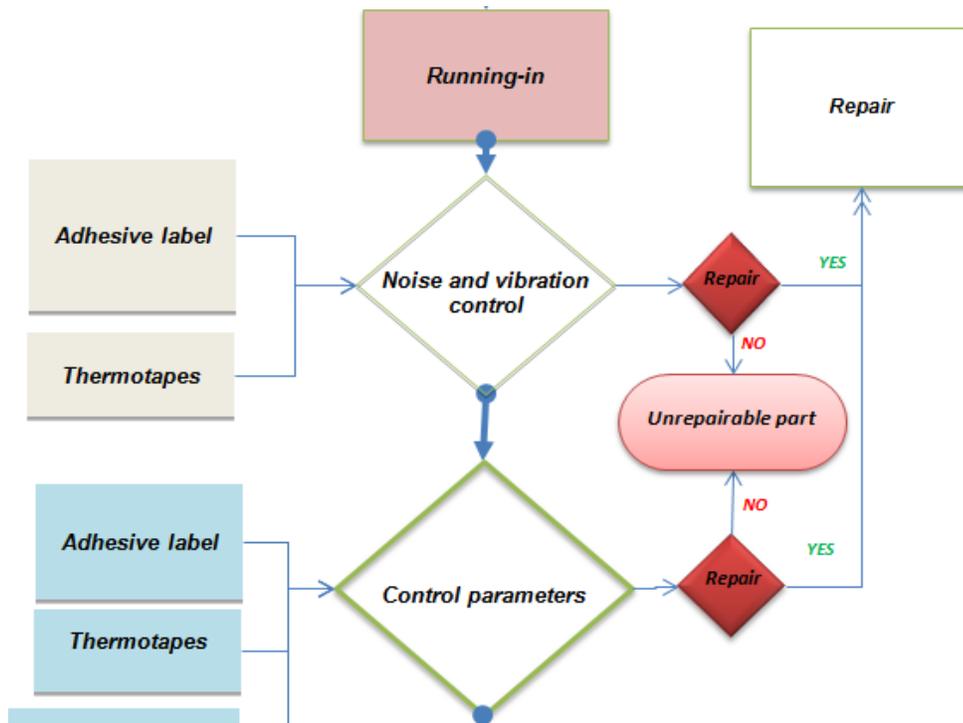


Figure 10: Symbols used in the process flow diagram *(Note: XYZ confidential)*

-  This symbol is used for a large process flow diagram as a link to another page or another flowchart. In case a process flow diagram contributes two pages' this symbol is usually used at the bottom of the first page of the process flow diagram and top of the second page of the process flow diagram. This symbol is used in the bottom in order to indicate that the process flow diagram continues to the next page. This symbol is used in the top in order to indicate that this page is a continuation of process flow from the previous page^[11].
-   Replacement symbols for beginning and ending points. In the figure below, these symbols are used as endpoints for the whole process flow. From the above figure, the NOT OK parts are sent to the irreparable part section. This is shown in figure 10.

2.3 Production efficiency definition

Production efficiency is an operational state where industry cannot increase the output of a good or a product without reducing the output of other goods or products produced and considered also without additional cost^[12]. The production efficiency depends on 3 factors and those are Availability, Performance, and Quality.

$$\text{Production line efficiency} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

Equation 1: Production line efficiency^[14]

Availability

Availability takes Down Time Loss into account which is the time during which the machine is not available to be operated. It is the ratio of time required for operation to planned production time. Operating time is the time available for operation after deducting break time and downtime from shift time. Planned production time is the time with just break time being deducted from shift time^[13]. The equation is as follows.

$$\text{Availability} = \frac{\text{Time required for operation}}{\text{Planned Production Time}}$$

Equation 2: Availability^[14]

Performance

Performance is all about the speed of the manufacturing process. It is the ratio of Ideal cycle time to operating time and total pieces produced divided by the operating time and the equation is as follows:

$$\text{Performance} = (\text{Ideal Cycle Time} \times \text{Total pieces}) / \text{Operating Time}$$

Equation 3: Performance based on ideal cycle time

Ideal Cycle Time is the minimum cycle time that a process could be expected to attain in optimal circumstances. It is otherwise called Design Cycle Time, Theoretical Cycle Time or Nameplate Capacity^[13].

Ideal Run Rate is the reciprocation of Ideal Cycle Time^[13], $\text{Ideal cycle time} = \frac{1}{\text{Ideal run rate}}$

And hence Performance can also be calculated as:

$$Performance = \frac{(Total\ Pieces / Operating\ Time)}{Ideal\ Run\ Rate}$$

Equation 4: Performance based on ideal run rate^[14]

Quality

Quality takes Quality Loss into account, in other words, it is all about the quality of the producing products that live up to standards and is calculated as:

$$Quality = \frac{(Total\ Pieces\ produced - Reject\ pieces)}{Total\ pieces\ produced}$$

Equation 5: Quality^[14]

Good pieces are the pieces where total pieces produced are deducted from rejected pieces. The advantage of Production line efficiency is that it does not deliver just one magic number. It delivers three important numbers, which are all helpful individually as the situation changes from day today and it also helps in visualizing performance. To put it simply – a very practical simplification^[13].

There are several ways to improve production efficiency. There are certain ways when implemented that can deal with a huge difference in production efficiency over time. Those ways are as follows.

Step-1: Improving the production process

Whatever is the size of an industry, there may be a chance where people will tend to fall victim to their own habits. It means that the employees could be blindly following outdated practices that end up affecting efficiency. These processes would require re-evaluation to ensure optimal production line. Most of the time, the industry will upgrade the equipment used for production to the latest technology for increased output rate but often forget to evaluate the technology of the resources that aid the production equipment. This will definitely lead to a waste of maximum efficiency potential that the equipment has to offer. Therefore, it is always crucial to allocate time to review and re-evaluate the current production process and also to find areas where the process can be improved and reorganized. Improved results can be observed once the processes have been optimized^[15].

Step-2: Providing updated technology to employees

In the industry, both the hardware and software technology that employees are using should be known. Unless the teams are provided with updated technology, they cannot cope with the competitors. Technology debt has been always considered unpleasant and unacceptable. For example, if an employee uses a laptop that takes 7 minutes time delay to load and send information to the production line, at the end of the year there would total of 31 hours of time delay just because of this laptop and employee. Therefore, it is definitely important to update the technology used by employees which not only improves the production efficiency but also their efficiency and morale. If this is implemented, in case of any problem, the information about the problem can be sent to the appropriate team immediately. Another advantage is that the usage of modern technology attracts more customers^[15].

Step-3: Discovering and improving time management

Processes are hard to evaluate but there is always space for improvement. It should be remembered that a one-second delay in the production line can contribute to a huge loss for the industry. Therefore, it is necessary to track the process that is not time-efficient and fix the issue. Some of the most successful companies use the 'KAIZEN' concept. This could lead to an improvement in production times^[15]. There is a total of 7 types of waste of time that can cause delay further leading to reduced production efficiency. Those types of waste of time are as follows.

- Waste of time due to overproduction: It is a waste that is achieved from excessive production. It is divided into two types. Firstly, the production of more parts than the required quantity. Furthermore, Production of parts earlier than required. This waste is critical because it can create all kinds of waste of time.
- Waste of time due to inventory: This waste refers to the excessive holding of the stock. The result of holding a higher amount of running inventory than necessary between processes or from purchasing excessive quantity. This waste of time causes the real root cause of sudden breakdown and shortages.
- Waste of time due to waiting: This is a waste of time where the employee waits for some time to receive the parts in order to complete the process.
- Waste of time due to transport: It refers to a waste of time occurring due to unnecessary transportation of parts^[18].

- Waste of time due to processing: This type of waste of time occurs due to the unnecessary processing of anything that does not contribute to the advancement of the processor to the accuracy of the finished part
- Waste of time due to motion: This time waste refers to the unwanted movement of employees in the working area which does not add value to the process.
- Waste of time due to repair: This is a kind of time waste that occurs from correcting the defects. All material, time, man-hour and energy are again involved in repairing the work^[16].

Step-4: Bottleneck area identification

A bottleneck station is defined as a work stage that gets more work requests than it can process at its maximum throughput capacity. That causes an interruption to the flow of work and delays across the production process^[16]. In most cases, the cause of the bottleneck has been incorrectly assumed to be the machines or equipment. It is rather due to human error in most industries. There could be various factors leading to a bottleneck, and they must be accurately identified and rectified to relieve the bottleneck, thereby improving production efficiency. If there is no immediate solution to a bottleneck, identification still helps to improve the situation and it can then slowly be rectified^[16].

Step-5: Better communication and creating an open workflow

Large industries are always seen to benefit from having an open work floor. The Supervisors could maintain tabs on the actions of every employee and thus the ineffectiveness stood out. One should keep in mind that operational transparency is the key to achieve high productivity. By using project management tools, the progress of different processes can be followed, thereby making the areas that can be trimmed easily identifiable^[15].

It should also be noted that any workplace without good communications has less production efficiency. Communication skill is also vital where the employees are told to do a specific task. Employees should be informed about the long-term and short-term goals that must be achieved including deadlines so that they will understand what they are working towards. The priorities should establish from a higher position to lower position employees as things move forward so that the issues can be reported according to the

priorities. Also, the employees who exceed the productivity goals must be rewarded which may induce heavy competition among employees gradually resulting in improved efficiency^[15].

Step-6: Recycle materials

Reuse of the manufacturing materials is obviously one of the best ways to cut costs. If the industry has a well-equipped facility, then the waste for recycling and reusing can be sorted out. Anything can be brought back into the production process, it can be even leftovers or scraps. It always promotes cost-cutting in the industry^[15].

Step-7: Production smoothing

It is mostly called as Heijunka in industries. It is also known as production leveling. Production smoothing is a manufacturing technique used to reduce the amount of time waste within the production system so that the company's production efficiency is improved. Providing goods at a constant rate has always been the main purpose of production smoothing, so that further processing to be carried out at a continuing and inevitable rate may be allowed. Theoretically, leveling of production can be easily performed wherever the demand from customers is constant, however, in reality, what happens is that the actual customer demand oscillates. To manage the demand oscillations 2 proposals are followed, which are demand leveling and production smoothing. These proposals have been followed to help prevent the variations in production, which is completed by attempting to keep the variation in the final assembly line to zero^[19].

Step-8: The improved training process for employees

It is natural to find people who are inefficient, and sometimes they are even unaware of this fact. The optimal performance of an employee can be achieved through training them and standardizing the working process. The main purpose of these training processes is to help them understand the standard operating procedures and work according to their roles. It is extremely important to make sure that the standardized operating procedures are in place after eliminating the issues and before creating the training programs. It is better to incorporate these procedures into a software solution that would enable any relevant process to be at the team's fingertips irrespective of location^[15].

For calculation the production efficiency of a motor assembly two practice is required so that the three factors on which the production efficiency depends on, can be evaluated. Those two are,

- Cycle time
- Takt time

For every industry, those two practices are extremely important as they are the root of everything starting from finding the capacity of a production line to finding a solution for a problem.

2.4 Definition of cycle time and takt time

2.4.1 Cycle time

Cycle time or otherwise known as CT in industries is the time taken from the start of production of one unit to finishing in a workstation. That is the time taken to complete the production of one unit in the workstation. Cycle time measures the work done. The cycle time can be found by using either a stopwatch or by video time analysis. The video time analysis is a method where video of the processes in a workstation is taken for 5 to 30 units and then the cycle time is found out by playing the video on the computer. This analysis is also helpful in finding a minor problem in the production lines. But, in this thesis, the stopwatch is used for cycle time measurement. If the production line isn't able to achieve the customer demand, the cycle time should be improved^[20].

2.4.2 Takt time

Takt time is the rate of time at which the production processes of an assembly line should be completed in order to meet customer demand. In other words, takt time measures customer demand. In German, the word takt means pulse. Like the heartbeat which can be either low or high the takt time of an industry can be either low or high. Usually takt time is used for identification and elimination of under and over-production. After finding the takt time, the systems are optimized according to customer demand to make sure neither resource nor time is wasted by machines and employees^[20].

There are various benefits of calculating takt time.

1. Bottleneck removal

2. Elimination of waste
3. Productivity increment
4. Quality increment and error reduction
5. Better management of time
6. Helps in cost-cutting
7. Helps in production planning

In reality, most of the time, it is often misunderstood that the cycle time and take time are the same things. It should be known that both are different things and the differences must be understood in manufacturing environment ^[21]. A basic example image of comparison of cycle time and take time is shown in figure 11.

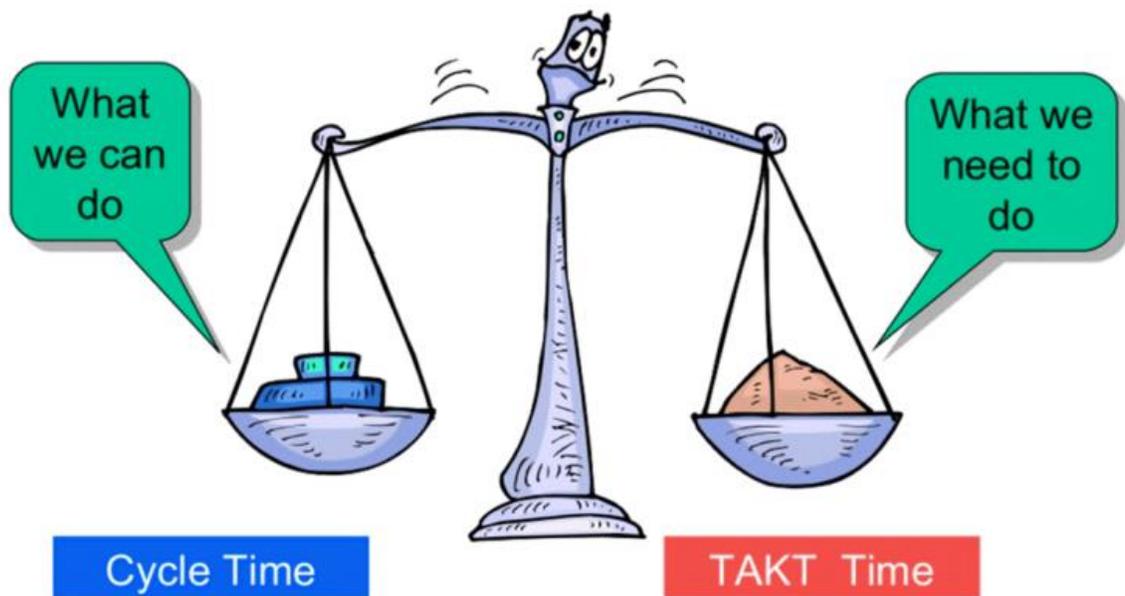


Figure 11: Cycle time Vs Takt time^[21]

3 Practical part

3.1 Purpose of the project

The main purpose of this project is to achieve single piece flow and reduced material traffic as well as improved production efficiency by proposing, designing a new shaped layout and replacing it with an I-shaped assembly line layout that has been used for long time. The following steps are performed to achieve the objectives.

- Study the process flow diagram of motor assembly in detail.
- Study the workstations in the motor assembly line in detail.
- Analyze customer demand and measure takt time.
- Measure cycle time for an I-shaped assembly line layout.
- Determine the factors of production efficiency and calculate production efficiency for an I-shaped assembly line layout.
- Calculate individual operator efficiency for I-line.
- Choosing the best suitable layout for replacing the I-shaped assembly line layout.
- Designing and implementing the U-shaped assembly line layout.
- Measure cycle time for the U-shaped assembly line layout.
- Wastefulness of time is noted for improvement.
- Implementing continuous improvement activity.
- Calculate production and individual operator efficiency for the U-shaped layout.
- Comparison of the output values of the I-shaped and U-shaped line layout.

In the company, there are stator assembly lines, rotor assembly lines, pivot housing assembly lines, 5 active motor assembly lines (which are of I-shaped) and wiper assembly lines. Each I-shaped assembly line can produce 1250 to 1290 pieces per shift. Due to the increased demand in pieces by the customer to 1400 pieces, the current I-shaped line faces too many problems such as material trafficking. One of the main problems faced inside the assembly line is that the operator waits for some time until the operator receives the material and the sub-assembled unit from the previous workstation. This results in a decrement in production efficiency. Since the main objective is to improve the production efficiency of motor assembly by designing and implementing the U-type line layout and checking the improvement through comparison with the I-type layout, the U-type line is chosen not only for

reducing material traffic but also for single-piece flow. Focusing on single piece flow results in better workplace safety. Reducing the waste of time caused by inventory, walking, waiting, etc. (especially in Bottleneck stations) is also done to further improvement in the production of the motor. The assembly floor flowchart of the company is mentioned in figure 12.

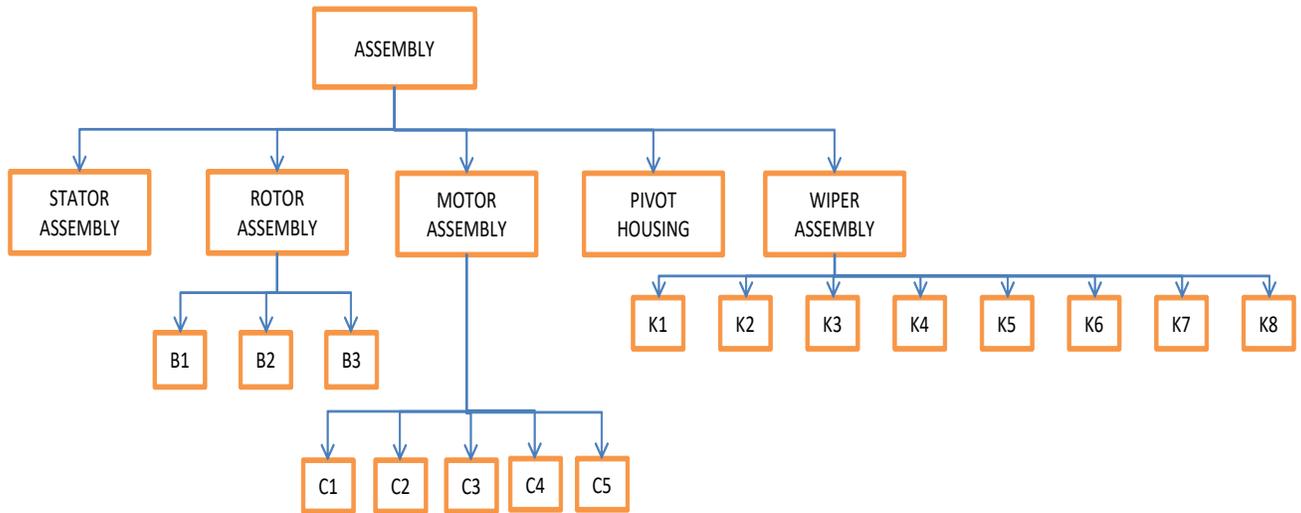


Figure 12: Assembly floor flowchart

B1, B2, B3 indicates various machines used in the company to produce the rotor assembly.

C1, C2, C3, C4, C5 indicates various assembly lines used in the company to produce the motor. These assembly lines are identical in shape and workflow. Hence, the output produced by these lines is almost same.

K1, K2, K3, K4, K5, K6, K7, K8 indicates various assembly lines used in the company for wiper motor assembly.

3.2 Process flow diagram for production of the motor assembly

The process flow diagram for the production of motor assembly is divided into two parts. Figure 13 & 14 indicates the first and second part of process flow diagram of the motor assembly. The numbers used in figures 13 & 14 indicates the steps used in motor production.

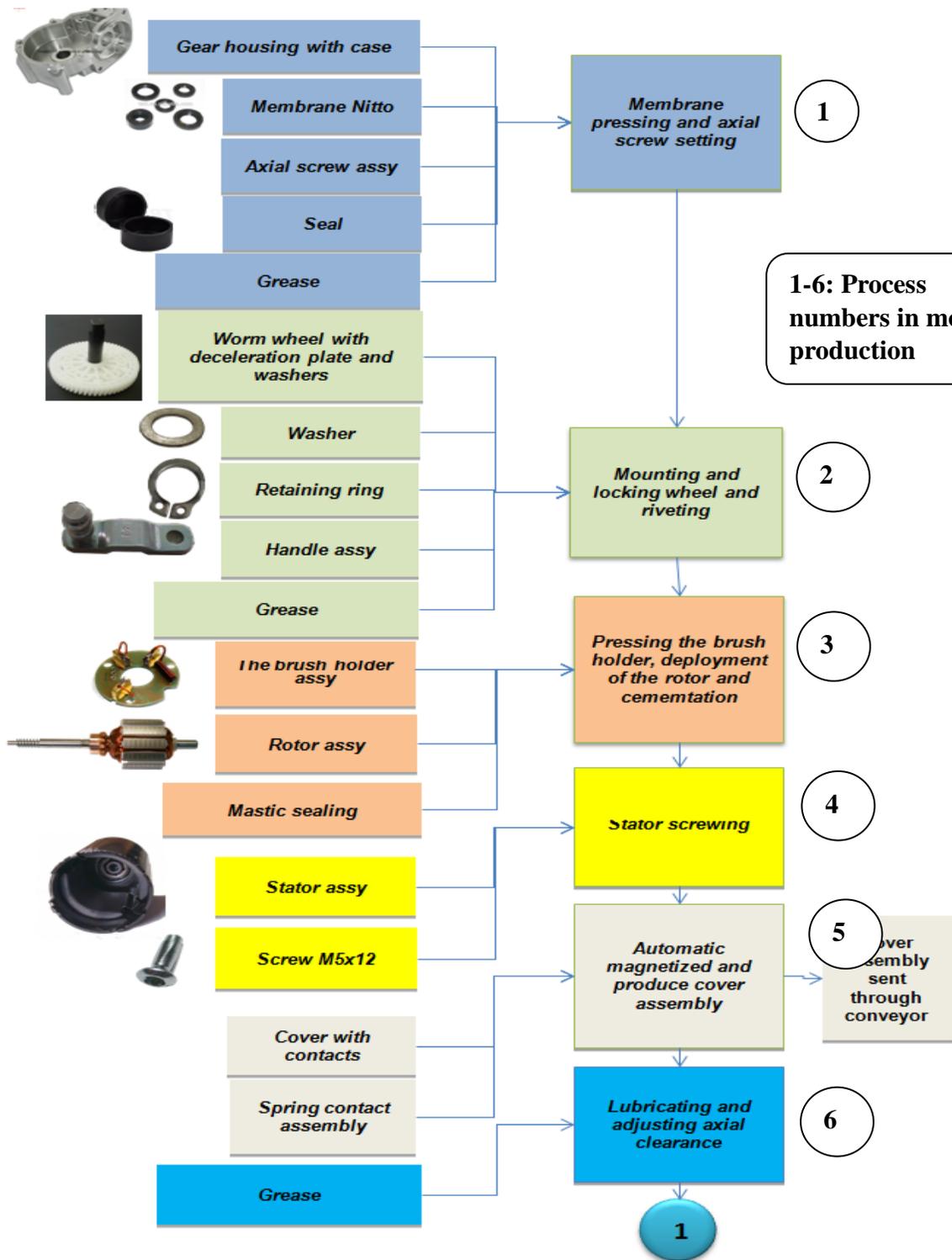


Figure 13: Process flow diagram of motor assembly part 1^[Note: XYZ confidential]

- **Process number 1: Membrane pressing and axial screw setting**

The first process number in the process flow diagram to produce motor assembly is membrane pressing and axial screw setting. To achieve this, the motor housing with the case is taken for pressing membrane Nitto and seal followed by screwing it with axial screw along with greasing is done. An example of motor housing, black membrane and seal is shown in Figures 13.

- **Process number 2: Mounting, locking wheel and riveting**

The second process number in the process flow diagram to produce motor assembly is mounting and locking wheel followed by riveting. To achieve this, a worm wheel along with deceleration is placed in the fixture of a pressing machine. The machine presses the plate in the wheel. Washers and retaining rings are placed in the shaft of the worm wheel. Then the worm wheel is pushed into the motor housing. The sub-assembled motor housing is placed in the fixture for riveting the handle assembly. The handle assembly is then riveted in the motor housing. An example image of a worm wheel, washer, retaining ring and handle assembly is shown in figure 13.

- **Process number 3: Pressing the brush holder, deployment of rotor and cementation**

The third process number in the production of motor assembly motor production is pressing the brush holder, deployment of the rotor and cementation. To attain this, the mastic sealing is applied to the housing. The brush holder is then taken and pressed manually into the motor housing. The rotor is then pushed inside the slot of the brush holder, followed by cementation (the process of heating metal for altering it by contacting it with powdered solid) of the brush holder. The rotor is rotated manually a few times. An example image of a brush holder and rotor is shown in figure 13.

- **Process number 4: Stator screwing**

The fourth process number in the process flow diagram is stator screwing. This is done by screwing the screws of size M5 X 12 with stator containing permanent magnets. An example image of screw M5 X 12 and stator is shown in figure 13.

- **Process number 5: Automatic magnetized and produce cover assembly**

The fifth process number is automatically magnetized and produce a cover assembly. This is done by placing the sub-assembled motor from the fourth step in the magnetizer machine to magnetize the permanent magnets inside the stator. Simultaneously, spring

contact assembly is fixed on the gearbox cover and it is sent to another workstation through a conveyor. This conveyor acts as a bridge for two workstations.

- **Process number 6: Lubricating and adjusting axial clearance**

The sixth process number in the process flow diagram is lubricating and adjusting axial clearance. Greasing is done for lubrication.

- **Process number 7: Cementation**

The seventh main process number in the process flow diagram is cementation. It is done once again in the brush holder. Mastic sealing is applied to the motor housing for attaching housing cover.

- **Process number 8: Deployment of cover and screw**

The eighth process number in motor production is deployment cover and screw. The cover that has been sent through the conveyor from the fifth step is received and it is placed over the mastic sealing in the gear housing followed by pressing the cover manually. After pressing, the cover is screwed with three screws of size M3.5 X 10.

- **Process number 9: Screwing**

The ninth process number is screwing. The screwing of cover with three screws of size M3.5 X 10 is done once again. so, a total of six screws are screwed to connect the cover with the motor housing. An example image of screw M3.5 X 10 is shown in figure 14.

- **Process number 10: Running-in**

The tenth process number is running-in which means that the sub-assembled DC motor is placed in a fixture and electricity is provided to make the motor run for a particular period of time.

- **Process number 11: Noise and vibration control**

The eleventh process number in the process flow diagram is noise and vibration control. The sub-assembled motor is placed in a fixture and a test run is performed to check if there is any abnormal noise or vibration is felt. If the motor is OK, adhesive labels and thermo tapes are pasted on the stator. If the motor is NOT OK, the motor is checked if it can be repaired. The motors that can be repaired are sent to be repaired. The motors that cannot be repaired are sent to an irreparable section.

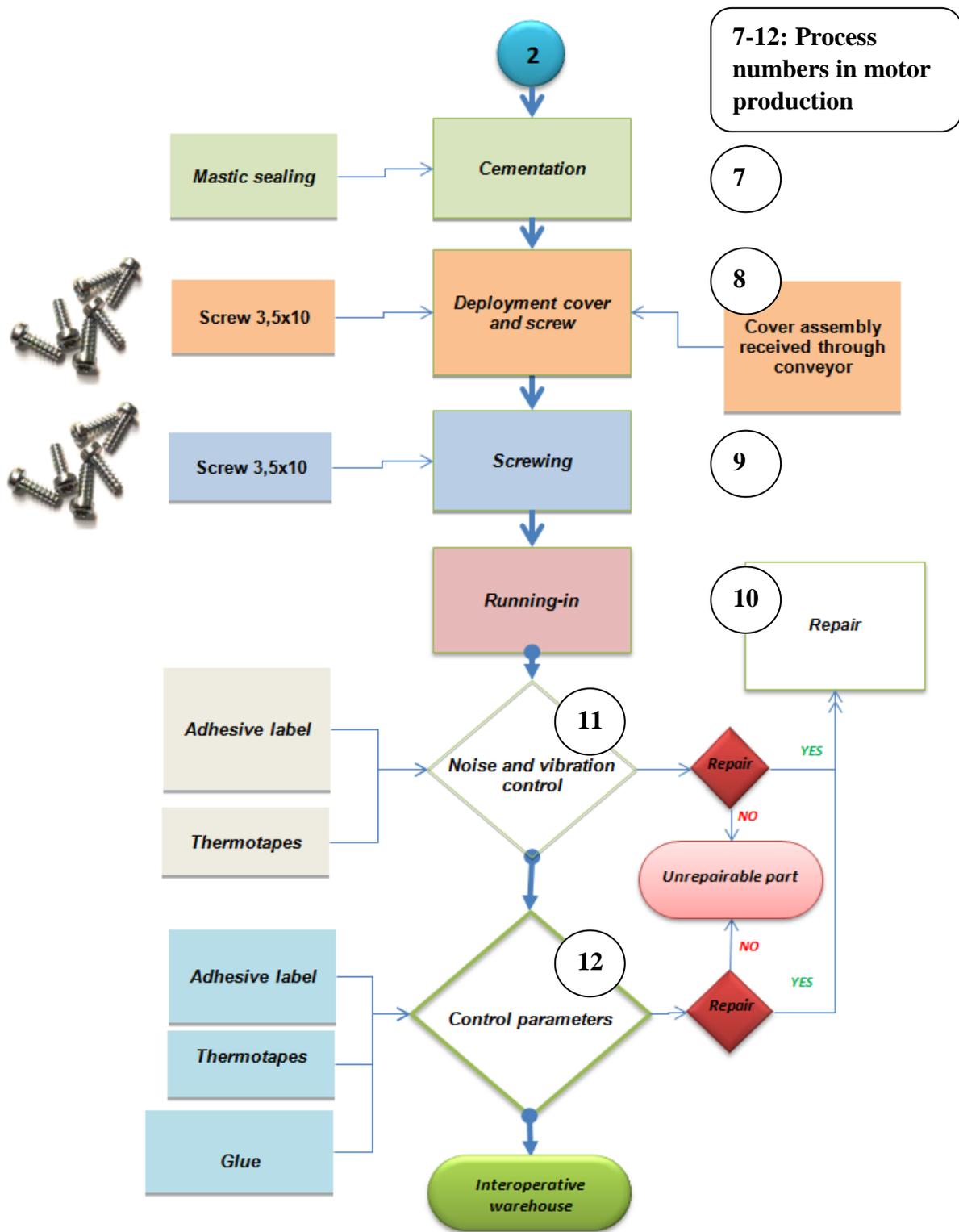


Figure 14: Process flow diagram of motor assembly part 2 [XYZ confidential]

- **Process number 12: Control parameters**

The final process number in the process flow diagram for motor production is control parameters. The motors are placed in a fixture for a test run and are once again checked at certain rpm. The motor is then taken out of the fixture followed by pasting adhesive labels and thermo tapes.

After the completion of twelve steps, the assembled motor is then sent to the inter-operative warehouse where the motor is placed in order according to the customer despatch dates. The motor is then sent to the container for the delivery to the customer. The whole process flow diagram to produce motor assembly is shown in figure 17.

3.3 Assembly line layout

Only the motor assembly is chosen since the assembly line consists of numerous workstations where manual work is visible. The assembly line C1 is chosen. The network diagram of the I-shaped assembly line layout and U-shaped assembly line layout is shown in figure 15. The line starts from workstation 1P and ends at the workstation 11P. The numbers from 1P to 11P mentioned in Figure 15 indicate respective workstations. The letters M81, Z, and ZA indicate respective machine stations.

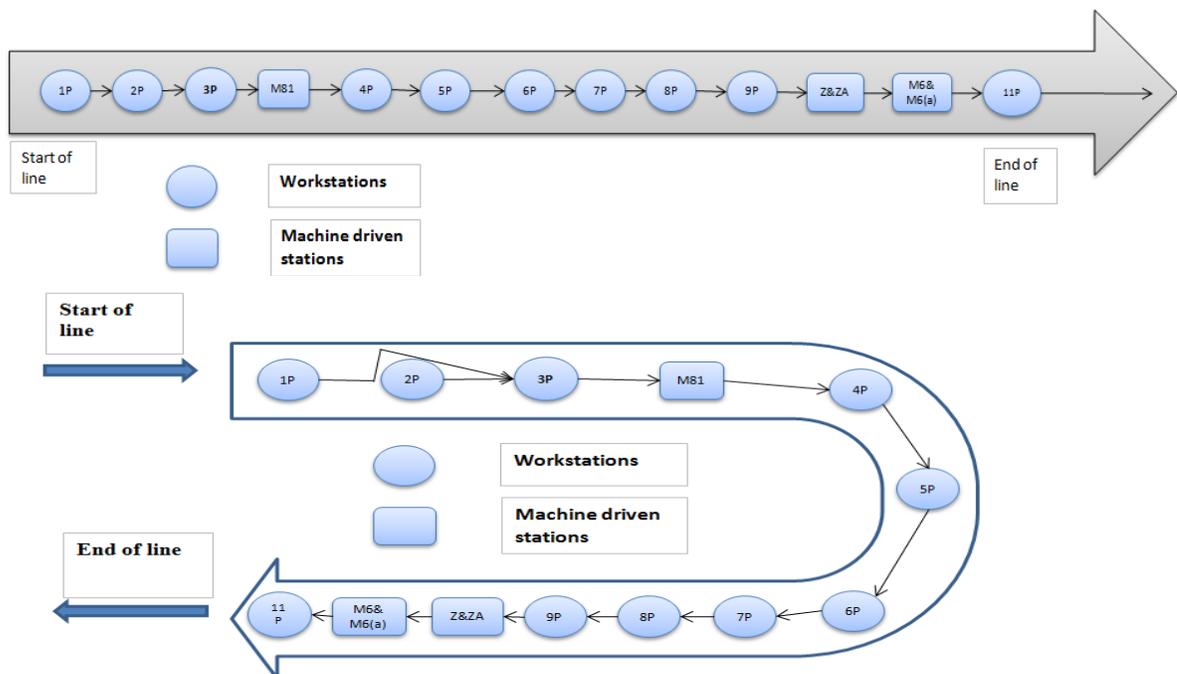


Figure 15: Network diagram of I-shaped line layout^[XYZ confidential]

Each station has a sequence of the process to be completed by the operator. The job to be done in the respective workstation is clearly made visible by hanging the SOP sheet (standard operating procedure) opposite to the operator's vision. The SOP sheet is a sheet that describes the sequence of operations with pictures of operations which makes the jobs easier for new operators learning the job and for other people such as manager, supervisor, etc., visiting the workstation.

The operator who completes his/her allotted job is assigned to provide materials to other workstations from the behind. In case of complications for delivery of partly assembled parts by the operator to other workstations, small size conveyors are used to connecting the workstations which act as a bridge for material delivery ensuring the operator works without any burden. Also, in the workstations, two different colored bins are provided, and they are green and red bins. The green bins indicate bins used for placing “OK” materials and motor pieces. Red bins indicate bins used for keeping “NOT OK” pieces.

3.4 I-shaped assembly line layout and its calculations

The I-shaped assembly line layout is the long-established layout used in the company. It has a total of 13 workstations where 4 stations are sitting operation and remaining are standing operation. Processes done in each workstation is explained below. Out of thirteen workstations, three workstations are machine-driven stations. The floor layout of the I-shaped assembly line is shown in figure 16.

3.4.1 Workstations in I-shaped Assembly line layout

Workstation 1P

It is a sub-assembly station. In station number 1P, the gear wheel is placed in a bin on the left side of the operator. The deceleration plate, retainer ring, and washer are placed in small boxes on the right side of the machine in which the operator has work to do. These all are within the reach of the operator. The operator first takes the gear wheel from the bin, then takes the deceleration plate and places it in the provision provided for the plate in the gear wheel. The gear wheel with the deceleration plate is placed on the fixture of the pressing machine. The operator then makes the machine run by pressing the switch. The machine presses the plate on the gear wheel. The gear wheel is then taken out from the fixture. The retainer ring and washer are taken and placed on the shaft of the gear wheel. The assembled

gear wheel is placed on the bin which is located on the right side of the operator. This bin will be sent to workstation 3P by the operator working in station 1P whenever it gets full. (Note: In case of U-line assembly, the motor assembly is sent to workstation 3P through a conveyor which connects station 1P and 3P). It took 18.548 seconds to complete the processes in this workstation.

Workstation 2P

This is the main assembly station. The gearbox which has to be assembled is placed in the bin on the left side of the operator working in the station. The membrane Nitto and seal are placed in plates right next to the pressing machine in the workstation. The operator first takes the gearbox from the left side and then places the gearbox on the fixture of the pressing machine. The operator then takes seal and membrane Nitto for placing it in the slot provided for it in the gearbox. The operator then operates the machine which presses the Nitto and seal into the gearbox. After this operation is performed, an axial screw assembly is done. The assembled gearbox is taken out of the jig, followed by sending it to the next workstation 3P through an inclined metal sheet that connects workstations 2P and 3P. It took 18.556 seconds to complete the processes in this workstation.

Workstation 3P

This is the main assembly station. The operator receives the assembled gearbox on the left side in an inclined metal sheet from workstation 2P. The bin containing the assembled gear wheel is placed on the right side of the operator working in the station 3P. The operator simultaneously takes the gearbox from the left side and gear wheel from the right side. The operator places the gear wheel in the slot provided for it in the gearbox. The operator then presses the gear wheel manually by using the thumb finger till the wheel shaft fits into the gearbox completely. The box containing handle assembly for the gearbox is placed opposite to the operator in the worktable within the reach of the operator's hand. After pushing the gear wheel into the gearbox, the operator takes the handle assembly using right hand and places the handle assembly provision provided for it in the gearbox, followed by pressing it manually so that it fits in the gearbox. The assembled gearbox is then placed in the jig of the machine M81. It took 18.548 seconds to complete the processes in this workstation.

Workstation M81

The workstation M81 is a machine with 4 jigs for placing the assembled gearbox in it. The main purpose of this machine is to perform a diameter check and riveting of the gearbox. The assembled gearbox from workstation 3P is placed in jig on the top right side of the operator. Once it is placed, the machine starts scanning the gearbox followed by rotation the handle assembly in the gearbox. Once the machine completes the operation it moves the jig to such a position which is on the top left side of the operator working in station number 4P. It took 9.967 seconds to complete the processes in this workstation.

Workstation 4P

This is the main assembly station. The operator working in this station receives the assembled gearbox from the machine M81 on the top left side. The bin containing a brush holder is placed on the left side of the operator and the bin containing rotor assembly is placed on the bottom left side of the operator. The operator first simultaneously takes the assembled gearbox from the top left side and fills the slot provided for the brush holder with mastic sealing. After mastic sealing is filled, the operator takes and places the brush holder in the slot provided for it in the gearbox and presses it until the brush holder seats on the gearbox. This operation is followed by the cementation of the brush holder. The operator then takes rotor assembly from the left side bin and places it on the slot provided for it in the gearbox. The rotor shaft passes through the brush holder and it is pressed till the rotor shaft seats perfectly. The operator has to check if the rotor is seated properly by rotation the rotor for few times. Once all these operations are done, the operator places the assemble motor piece in the bin located on the right side. It took 18.67 seconds to complete the processes in this workstation.

Workstation 5P & 5P(a)

In this workstation both assembly and sub-assembly work is performed, that is the reason it is named as 5P and 5P(a). The bin located on the left side of the operator contains assembled motor pieces from the previous workstation 4P. The bin located on the right side of the operator contains stator. The operator first takes the assembled motor piece from the left side and places it on the jig of screwing machine so that the stator from the right side is then taken placed directly over the slot provided for it. The operator then takes two M5X12 screws

from the boxes placed next to the screwing machine and places it in the screwing machine followed by operating it. The screwing machine screws the stator on both sides. After screwing, the stator is placed in a magnetizer. The main purpose of using the magnetizer is to provide magnetic fields to the magnets inside the stator. (Note: In case of U-line assembly the motor assembly is placed in a rotating table after magnetization is done which is located on bottom right side of the operator). It took 19.603 seconds to complete the processes in this workstation.

Workstation 6P

Once the magnetizer completes its operation, the operator working the workstation 6P takes the motor assembly from the magnetizer and places it on bin located on the right side. The gearbox cover is placed in bin located on the left side of the operator. The spring assembly is placed on a cover with contacts. The gearbox cover assembly is sent to workstation 8P through a conveyor connecting stations 6P and 8P. It took 18.584 seconds to complete the processes in this workstation.

Workstation 7P

The bin located on the left side of the operator working in station 7P contains assembled motor units from the previous workstation. The cementation is done once again on the brush holder. This is followed by the greasing which is done manually by the operator in the gearbox. Once the greasing is done, the operator places the motor assembly in the fixture of the machine situated on the right side. The main purpose of the machine is to perform the gluing process. Once the gluing is done, the machine moves the fixture to the other side (near the left side of the operator working in station 8P). The operator simultaneously performs his work while the machine performs the gluing process. It took 19.60 seconds to complete the processes in this workstation.

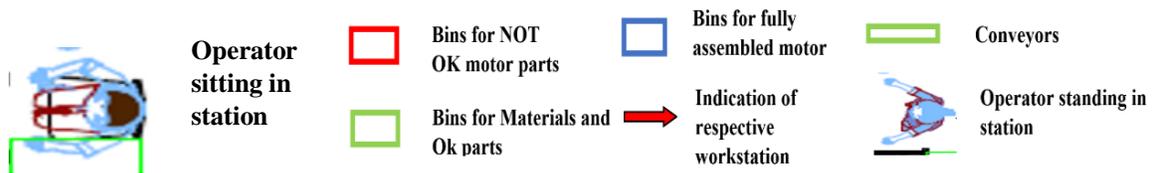
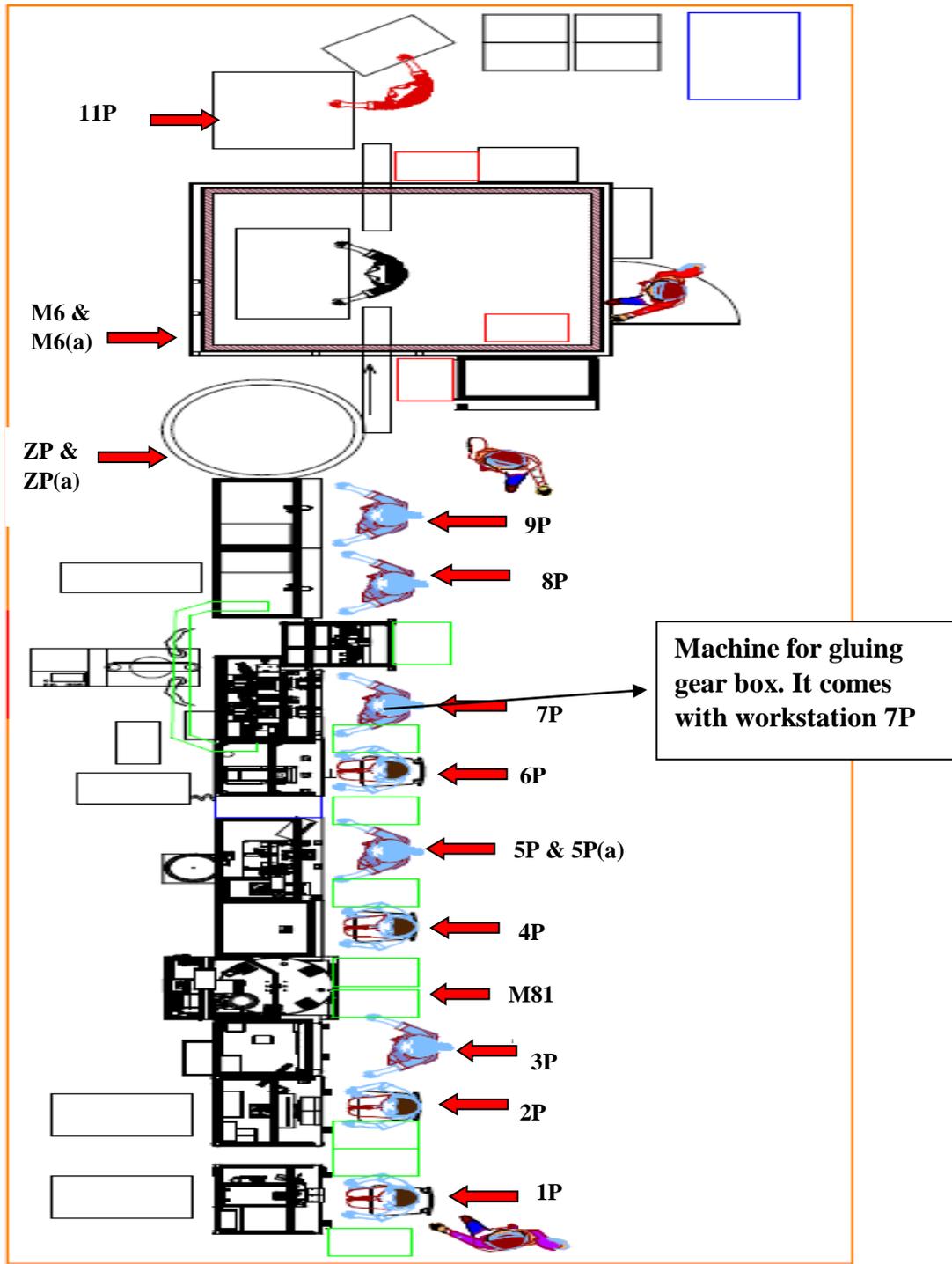


Figure 16: I shaped floor layout of assembly line C1 [Note: XYZ confidential]

Workstation 8P

The operator working in this station receives gearbox cover assembly through the conveyor from workstation 6P. The operator then takes the motor assembly which is glued on gearbox from the machine on the left side and places it on the fixture of the screwing machine. The operator takes gearbox cover and places it directly over the glued area and presses it till the cover seats perfectly. The operator places both thumbs in the sensor so that the machine locks the motor in the fixture. The operator takes three M3.5 X 10 the screw from the box located next to the screwing machine and places screws in slots one by one for screwing the gearbox cover with the gearbox. (Note: In case of U-line assembly, six M3.5 X 10 screws are taken and screwed). After screwing is performed, the operator places both thumbs in the sensor to unlock the motor assembly from the fixture. Once the machine unlocks the motor assembly, the operator takes it from the fixture and sends it to the next workstation 9P. It took 12.259 seconds to complete the processes in this workstation.

Workstation 9P

The operator receives the motor assembly with three screws from the previous workstation 8P and places it on the fixture of the screwing machine. The operator places both thumbs to lock the motor assembly in the fixture. The operator then takes three M3.5 X 10 screws from the box located next to the screwing machine. The operator places screws one by one for screwing the gearbox cover with gearbox. The operator then places both the thumbs in the sensor to unlock the motor assembly from the fixture. Once it is done, the operator places the motor assembly in the machine ZP. (Note: In case of U-line assembly, the operator receives the motor assembly with 6 screws from the previous workstation, then checks it followed by placing it in the workstation ZP). It took 13.511 seconds to complete the processes in this workstation.

Workstation ZP & ZP(a)

This workstation is a machine where the motor assembly is placed in a fixture through which the motor is connected with a cable plug and electricity is provided. There are green and red lights in the fixture which indicates whether the motor runs or not. The assembled motor is made to run for a certain amount of time until the machine shows a green signal. If the green signal is shown, the operator takes it from the fixture and places it in the conveyor

which sends the motor assembly to the next workstation M6. If the machine shows red light, the motor is faulty and then it is placed in the bin provided for NOT OK motor pieces. It took 18.512 seconds to complete the processes in this workstation.

Workstation M6 & M6(a)

This workstation is a noise and vibration control chamber. This is a soundproof chamber. The operator inside this chamber receives the motor assembly from the previous workstation through a conveyor. The operator takes the motor assembly from the conveyor and places it in the fixture which connects the motor with a cable plug. The machine provides electricity and the motor is made to run in order to check the vibration produced by the motor. The condition of the motor is monitored on the computer and it is also checked whether the motor makes abnormal noise. If the motor assembly is OK, the operator pastes thermo tapes and adhesive labels with barcodes. Once it is done, the operator then places the motor assembly in the convey which sends the motor assembly to the next workstation. If the motor assembly is NOT OK, then it is placed in the bin provided for NOT OK pieces. This bin is then repaired by sending it to the repair area. The motor that cannot be repaired is sent to an irreparable section. It took 19.68 seconds to complete the processes in this workstation.

Workstation 11P

This workstation is meant for the final testing of the motor. The operator working in this workstation takes the motor assembly from the conveyor from the previous workstation and places it on the fixture of the testing machine which connects the cable with the motor. The electricity is provided and the motor assembly is made to run in certain RPMs and is once again checked. The motors are monitored in computer and if the motor is OK, then the motor is taken out of the fixture followed by pasting adhesive label and thermo tapes. After completion of these processes, the assembler motor is sent to the inter-operative warehouse where the motor is placed in orderly sequence according to customer despatch dates. If the motor assembly is NOT OK, then it is sent to the repair section for repairing. In case the motor could not be repaired, it is sent to the irreparable section. It took 18.474 seconds to complete the processes in this workstation.

3.4.2 Calculation of takt time

Takt time is the average time taken to finish the whole assembly process of an associated unit to satisfy the customer demand (that is, it denotes the time at which the motors should be produced in a production line). The production starts are set so that it matches the customer demand rate. Assuming a product is formed one unit at a time at a relentless rate throughout the net available work time, the takt time is the period that must elapse between two consecutive unit completions to satisfy the demand from customers. Takt time can be first determined with the following formula^[22].

$$\textit{Takt time} = Tw/Du$$

Equation 6: Takt time

Tw = Net time available to work. (example: Work time per period)

Du = Demanded number of pieces

Net available time is the quantity of time available for work that has to be done. This time doesn't include times allotted for the tea lunch break and any expected stoppage time (for example scheduled time for maintenance, team briefings, etc.)^[22].

Customer demand = 1400 pieces

$$\textit{Takt time} = \frac{\textit{Net working time}}{\textit{Pieces demanded}}$$

Networking time

= 24600 seconds (excluding lunch break, tea break and other time which is 70 minutes)

$$\textit{Takt time} = \frac{24600}{1400} \text{ seconds}$$

Therefore, Takt time for the company XYZ is 17.57 seconds.

Takt time might even be adjusted to keep up with the needs of the company. For instance, if one department delivers components to many producing lines, it is usually sensible to use similar takt times on all lines to unwind flow from the preceding workstations. Customer demand will still be met by adjusting the daily operating time, minimizing times on machines and so on.

3.4.3 Calculation of Cycle time

The time is given to a process member to complete a particular process. However, it depends on the variants. That is the time taken from the start of the process of one unit to start off the process of the next unit in a workstation. For example, from figure 17, it is clearly visible that it takes 18.548 seconds for the operator from the start of the process of one motor unit to start off the process of the next motor unit in the workstation 1P.

There are five assembly lines in total for producing motor assembly namely C1, C2, C3, C4, and C5. Out of five active assembly lines, one line is chosen for comparing the production efficiency. The chosen assembly name is C1. The cycle time for both I shaped line and U-shaped line is taken for each workstation in the motor assembly line C1 for 30 times. Only the average values are mentioned in the tables since 30 trials require a lot of space (but they are mentioned in appendix). It took 18.556 seconds for the operator working in the station 2P to complete a sequence of operations for I-shaped layout. Since 30 trials of cycle time have been performed for each station, the sum of the cycle time of each trial is divided by 30 so that the average cycle time for the particular station can be obtained for an I-shaped layout. Since it is necessary to find the number of pieces produced in a shift, The total production time has been divided by the station with the highest cycle time (that is, bottleneck time). It is shown in figure 17.

In this way, we can achieve the total pieces produced by a line in a shift. This calculation will be helpful for the production efficiency calculation for both I-line and U-line.

Station Number	Description	Average cycle time for 30 trials in seconds	Total pieces produced in a shift
1P	Gear wheel pressing with deceleration plate, fitting retainer ring and washer to the wheel shaft.	18.548	1250
2P	Pressing seal, membrane Nitto with Gearbox along with grease.	18.556	
3P	Pushing Gear wheel into Gearbox. Pressing Handle assembly with Gearbox.	18.548	
M81	Riveting & diameter check.	9.967	
4P	Fitting Brush holder in Gearbox with mastic sealing. Cementation of Brush holder. Inserting Armature into Gearbox	18.670	
5P	Fitting stator assembly in the Gearbox.	19.603	
5P(a)	Screwing Stator assembly with M5 X 12 screw & magnetization.		
6P	Gearbox cover sub-assembly.	18.584	
7P	Brush holder cementation. Gear Box greasing .	19.60	
	Gluing machine		
8P	Pasting Gearbox cover with Gearbox and Screwing of Gearbox cover with Gearbox with M3.5 X 10 screws.	12.259	
9P	Final Screwing of Gearbox with M3.5 X 10 screws.	13.511	
ZP	Testing of the motor.	18.512	
ZP(a)	Movement of the motor inside the noise and vibration chamber through the conveyor.		
M6	Motor noise and vibration checking chamber. If the checked motor is "OK" then sticking adhesive label. If the motor is "NOT OK" it is sent for repair.	19.68	
M6(a)	Movement of the motor from chamber to final testing through the conveyor.		
11P	Final testing of the motor. Sticking adhesive label. Placing the completed motor assembly in the bin that will be sent to the warehouse.	18.474	

Figure 17: Cycle time for I-shaped line (Appendix 4: Sheet 3)^[XYZ]

From figure 17, it is understood that the I-shaped assembly can produce 1250 pieces in a shift. From the figure, the bottleneck time is found as 19.678 from station M6 & M 6(a).

Total production time	I	24600
Bottleneck time	II	19.678
Total pieces produced in a shift	I/II	1250

Table 1: Total units produced in a shift for I shaped line (Appendix 4: Sheet 4)^[XYZ]

Total units produced in a shift for the I-shaped line layout is shown in table 1. From the table, it is clearly visible that a total of 1250 pieces is produced in a shift with a production time of 410 minutes. This is achieved by dividing total production time with bottleneck time.

3.4.4 Calculation of production efficiency

Every industry must calculate production efficiency since it is very essential for industrial growth. The performance of an assembly line can be found using the values of the everyday production line efficiency. Production efficiency is used to calculate the efficiency of a production line and to calculate individual operator efficiency. Line efficiency is essentially the ratio of Fully Productive Time to Planned Production. In practice, however, line efficiency is calculated as the product of its three contributing factors: availability, performance, and quality. Individual operator efficiency is the ratio of total minutes produced to total hours worked. The calculation of individual operator efficiency is shown in table 2^[23].

$$\text{Production efficiency} = AE \times PE \times QE$$

Where AE is availability efficiency, PE is performance efficiency, and QE is quality efficiency. The hypothetical shift data for calculation of production efficiency in the I-line layout is shown in Figure 18. (Note: reject pieces contains both repairable and irreparable part. The irreparable part is 10% of total reject pieces).

Item	Data
Total production time	480 minutes
Downtime	30 minutes
Ideal run rate	3.414 pieces per minute
Total pieces	1250 pieces
Reject pieces	125 pieces
Good pieces	=[total pieces - reject pieces] 1125
Equipment uptime	450
Planned production time	=[shift length - breaks] =440 minutes
Operation time	=[Planned production time - downtime] =[440-30] =410 minutes

Figure 18: Shift data for production efficiency calculation I-line (Appendix 4: Sheet 8)^[XYZ]

The ideal run rate value of 3.414 pieces per minute is achieved by dividing the customer demand which is 1400 pieces by planned production time which is 410 minutes.

There are two methods to calculate production efficiency, the first method is the calculation based on the influence of the environment such as different downtimes in a company. The calculation by the first method is as follows. The performance efficiency is the product of operational efficiency (OE) and rate efficiency (RE),

$$\text{Performance efficiency} = OE \times RE$$

Equation 7: Performance efficiency based on Utilization

hence the production efficiency can be rewritten as,

$$\text{Production efficiency} = AE \times (OE \times RE) \times QE$$

Equation 8: Production efficiency based on Utilization [24]

Where $AE = \frac{\text{Equipment uptime}}{\text{Total production time}}$

Equation 9: Availability efficiency based on Utilization

$$OE = \frac{\text{Operation time}}{\text{Equipment uptime}}$$

Equation 10: Operational efficiency

$$RE = \frac{\text{theo.time required to produce 1 piece} \times \text{total pieces produced}}{\text{planned production time}}$$

Equation 11: Rate efficiency

The influence of the environment on production efficiency can be shown more commonly by considering utilization (U). This measure indicates the part of the total time that is requested by the capacity of the machine. The above production efficiency equation shows the product of Availability efficiency AE and operational efficiency OE which can be expressed in terms of total production time (t_p), and planned production time (t_t) [24].

$$AE \times OE = \frac{\text{Operation time}}{\text{Total production time}}$$

$$AE \times OE = t_p/t_t = (t_e/t_t) \times (t_p/t_e) = U \times A$$

Equation 12: Availability efficiency and Operational efficiency [24]

Where A is Availability, t_e is equipment uptime and U is utilization. They can be written in terms of Operation time (t_p), equipment uptime(t_e)that is difference in time required for operation and equipment downtime, Total production time (t_t)as follows ^[24],

$$A = t_p / t_e$$

Equation 13: Availability

$$U = t_e / t_t$$

Equation 14: Utilization

Substituting values of equation (12) in equation (8), we get

$$\text{Production efficiency} = (t_p / t_t) \times RE \times QE = A \times U \times RE \times QE^{[24]}$$

The dependency of production efficiency over U is determined by Availability efficiency and operational efficiency. from the equations of AE and OE it can be expressed as,

Substituting the value of $t_e = [t_p + (1 - U) t_t]$ in equation (13) and (14), then we get the following equations.

$$AE = \frac{t_p + (1-U) t_t}{t_t} = 1 - (1-A) \cdot U^{[24]}$$

$$OE = \frac{t_p}{t_p + (1-U) t_t} = \frac{U \cdot A}{1-U \times (1-A)} = \frac{A}{AE} \times U^{[24]}$$

This proves that operational efficiency and availability efficiency are both dependent on each other when it comes to utilization. This method has not been used since the calculation used in the company since its efficiency depends on the ideal run rate rather than utilization. Another method of calculation is based on total prices produced. The second method is as follows.

$$\text{Availability (A)} = \frac{\text{Total production time} - \text{downtime}}{\text{Total production time}}$$

$$= \frac{480 - 30}{480}$$

$$= \mathbf{0.937}$$

$$\text{Quality efficiency} = \frac{(\text{total pieces} - \text{Reject pieces})}{\text{total pieces}}$$

$$= \frac{1250 - 125}{1250}$$

$$= \mathbf{0.90}$$

$$\text{Performance efficiency} = \frac{\frac{\text{Total pieces produced}}{\text{Operating time}}}{\text{Ideal run rate}}$$

$$= \frac{\frac{1250}{410}}{3.414}$$

$$= \mathbf{0.893}$$

$$\text{Efficiency} = \frac{\text{Total production time} - \text{downtime}}{\text{Total production time}} \times \frac{\frac{\text{Total pieces produced}}{\text{Operating time}}}{\text{Ideal run rate}} \times \frac{(\text{total pieces} - \text{Reject pieces})}{\text{total pieces}}$$

$$= 0.937 \times 0.90 \times 0.893$$

$$= \mathbf{0.753 (75.3\%)}$$

The second method of calculation has been followed in the company XYZ rather than the first method because the production efficiency does not depend on utilization U (that is the line downtime is the same for all shifts) rather it depends on the ideal run rate and quality of pieces produced by the company.

A comparison has been done for different cases. Case 1 is the current I-line production efficiency output with different rejection pieces. From figure 19, for case 1 that produces 1250 pieces per shift, it is clear that the assembly produced an efficiency of 80.3% for rejection pieces of 50. It makes clear that just the reduction in reject pieces has very less effect on overall efficiency. Where case 2 shows the production of total pieces of 1350 per shift for different reject pieces. From the figure, it is understandable that the increase in total output has a dramatic effect on production efficiency. If the rejection pieces have been reduced to 80, case 2 can achieve a world-class efficiency of 85%.

Cases	Reject pieces	Pieces produced	AE	QE	PE	Efficiency
Case 1	125	1250	0.937	0.9	0.893	0.753
	90	1250	0.937	0.928	0.893	0.776
	50	1250	0.937	0.96	0.893	0.803
Case 2	125	1350	0.937	0.907	0.964	0.820
	90	1350	0.937	0.933	0.964	0.843
	50	1350	0.937	0.963	0.964	0.870
Case 3	100	1250	0.937	0.92	0.893	0.770
	100	1300	0.937	0.923	0.9287	0.803
	100	1370	0.937	0.927	0.9787	0.850
Case 4	50	1250	0.937	0.96	0.893	0.803
	50	1300	0.937	0.962	0.9287	0.837
	50	1360	0.937	0.963	0.971	0.876

Figure 19: Comparison of different cases of production efficiency (Appendix 4: Sheet 11)

Case 3 indicates the assembly line with the production of different outputs but with the same reject pieces of 100. For reject pieces of 100, case 3 could achieve world-class efficiency when it can produce an output of 1370 pieces. Case 4 indicates the assembly line with the production of different outputs but with the same reject pieces of 50. For reject pieces of 50, case 4 could achieve world-class efficiency if it could produce the output of more than 1350 pieces. From the comparison, we can understand that change in reject pieces and output has its own effect on production efficiency. Individual operator efficiency is as follows.

Individual operator efficiency

For individual operator efficiency, the workstations 1P, 8P, 9P are neglected since they have very little cycle time. The workstations M81 and ZP are also neglected since it's a machine workstation and cycle time cannot be changed unless a new machine is ordered by the company. Individual operator efficiency is calculated by dividing the total minutes required to produce the units produced according to the takt time (time required to produce total units) by total working hours for an operator in minutes which is total hours worked ^[23].

$$\text{Individual operator efficiency} = A/B \times 100$$

Equation 15: Individual operator efficiency

Where A is total minutes required to produce units according to takt time.

B is total working hours for an operator in a shift multiplied by 60

The calculation of individual operator efficiency is as follows.

Operator efficiency calculation for Workstation 3P

- Total working time in a shift in seconds = 24600 seconds
- Average cycle time of the workstation 3P = 18.547 seconds
- Number of pieces produced at station 3P according to its average cycle time = $24600/18.547 = 1326$ pieces
- Standard takt time = 17.57 seconds
- Total mins req to produce according to takt time (A) = $\frac{1326 \times 17.57}{60} = 388.29$ minutes
- Total time attended in a shift (B) = 410 minutes
- Operator efficiency = $\frac{388.29}{410} \times 100 = 94.72\%$

Table 2 indicates individual operator efficiency for different workstations inside the I-shaped line layout.

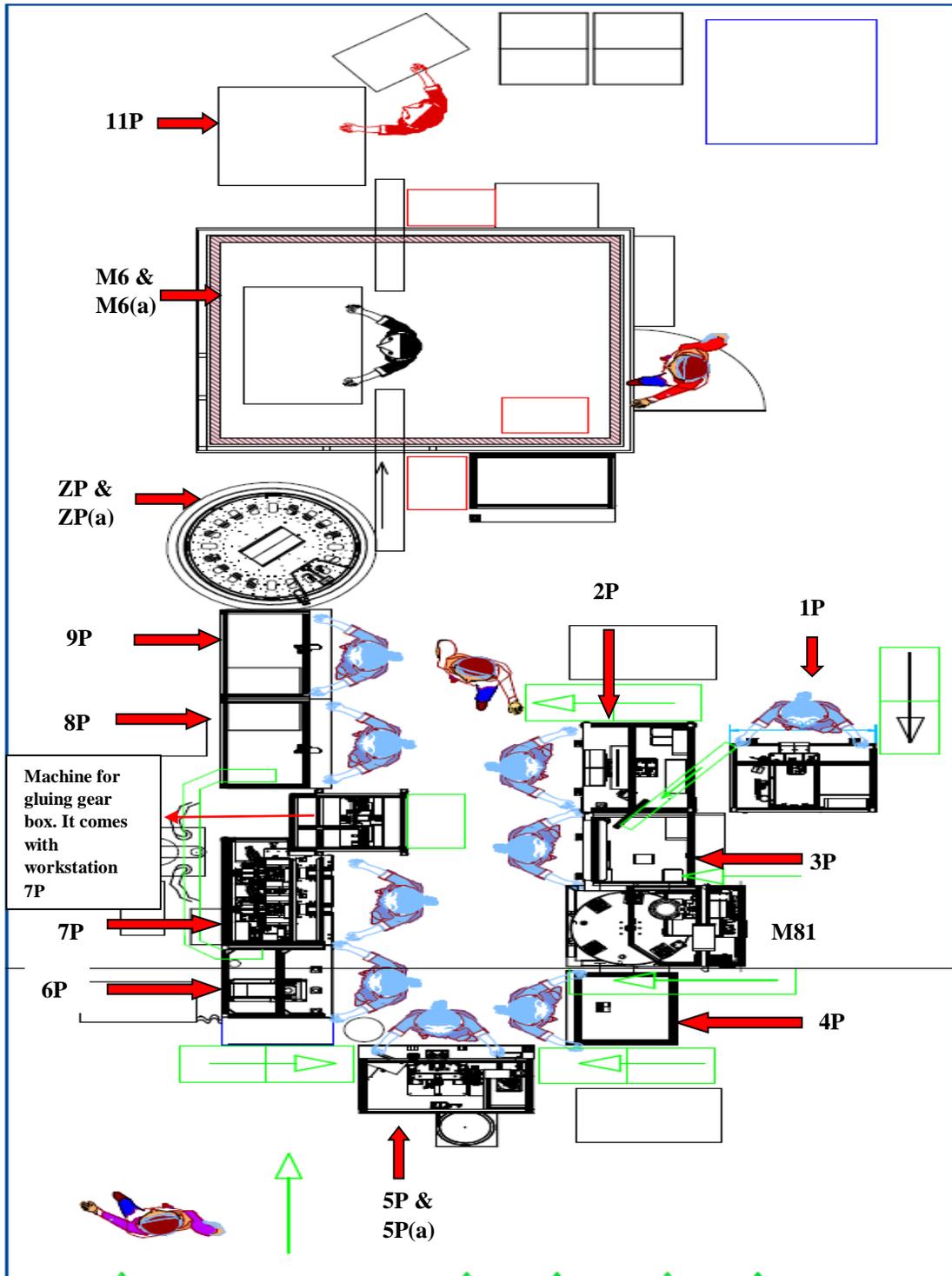
Workstation	Average cycle time I-line	Pieces produced according to the cycle time	I-line operator efficiency (%)
2P	18.556	1326	94.69
3P	18.547	1326	94.72
4P	18.67	1318	94.1
5P	19.603	1255	89.63
6P	18.58	1324	94.54
M6	19.677	1250	89.3
11P	18.4741	1332	95.10

Table 2: Individual operator efficiency for I-line (Appendix 4: Sheet 10)^[XYZ]

3.5 U-shaped assembly line layout and its calculations

The U-shaped line layout is chosen to replace the I-shaped line layout. This is due to the benefit of single-piece flow in U-shaped line layout. The U-line is proposed, designed and implemented after I-line start creating problems inside the assembly due to the increased customer demand. Only the workstation 1P is deformed from the U shape due to the problem of the wastefulness of waiting till the work is completed in station 3P and walking for providing material to workstation 3P when placed in a position like the I-line. The U-shaped floor layout of assembly line C1 is shown in figure 20. A new small conveyor is introduced in workstation 1P, connecting it with workstation 3P for delivering the partly assembled part. The standard operating procedures are the same for the U-line assembly layout.

(Note: In I-line, in workstation 1P, 2P, 4P and 6P. the operators working in the respective workstation are sitting and operators working in the remaining workstation are standing. But in U-line, every operator working in the station is standing operation. This is due to the fact of removing unevenness within the line layout. Additionally, the workstations are height adjustable according to the height of the operator. In this way, the ergonomics of an operator is not affected. Also, this was personally recommended by the director of the company).



- Bins for NOT OK motor parts
- Bins for fully assembled motor
- ▬ Conveyors
- Bins for Materials and Ok parts
- Indication of respective workstation
- Operator standing in station

Figure 20: U shaped floor layout of assembly line CI^[XYZ]

3.5.1 Takt time

The takt time for company XYZ is same for both I-shape and U-shaped assembly layout which is **17.57** seconds. In order to reach the targeted output, the company must produce each piece at a time of 17.57 seconds.

3.5.2 Calculation of cycle time

Station Number	Description	Average cycle time for 30 trials in seconds	Total units produced in a shift
1P	Gear wheel pressing with deceleration plate, fitting retainer ring and washer to the wheel shaft.	15.30	1323
2P	Pressing seal, membrane Nitto with Gearbox along with grease.	18.56	
3P	Pushing Gear wheel into Gearbox. Pressing Handle assembly with Gearbox.	18.57	
M81	Riveting & diameter check.	9.99	
4P	Fitting Brush holder in Gearbox with mastic sealing. Cementation of Brush holder. Inserting Armature into Gearbox	18.55	
5P	Fitting stator assembly in the Gearbox.	18.52	
5P(a)	Screwing Stator assembly with M5 X 12 screw & magnetization.		
6P	Gearbox cover sub-assembly.	18.59	
7P	Brush holder cementation. Gear Box greasing .	16.18	
	Gluing machine	9	
8P	Pasting Gearbox cover with Gearbox and Screwing of Gearbox cover with Gearbox with M3.5 X 10 screws.	15.61	
9P	Final Screwing of Gearbox with M3.5 X 10 screws.	4.38	
ZP	Testing of the motor.	18.45	
ZP(a)	Movement of the motor inside the noise and vibration chamber through the conveyor.		
M6	Motor noise and vibration checking chamber. If the checked motor is "OK" then sticking adhesive label. If the motor is "NOT OK" it is sent for repair.	17.66	
M6(a)	Movement of the motor from chamber to final testing through the conveyor.		
11P	Final testing of the motor. Sticking adhesive label. Placing the completed motor assembly in the bin that will be sent to the warehouse.	18.47	

Figure 21: Cycle time for U shaped line (Appendix 4: Sheet 6)^[XYZ]

Figure 21 indicates the cycle time for the U-shaped assembly line. From the figure, it is clear that the line produces 1323 pieces in a shift. The values of these cycle time are after implementing continuous improvement activity. This is due to the fact that the continuous improvement activity is performed while designing the U-line. Table 3 represents the

calculation for the total number of units produced in a shift. From the table, we can conclude that a total of 1323 pieces is produced in a shift.

TOTAL PRODUCTION TIME	24600
BOTTLENECK TIME	18.59
TIME TAKEN TO PRODUCE ONE UNIT	1323

Table 3: Total units produced in a shift for U-line (Appendix 4: Sheet 5)^[XYZ]

3.5.4 Calculation of Production efficiency

The theoretical shift data for the efficiency calculation of the U-shaped assembly line is shown in figure 22. The efficiency calculation depending on utilization is not used rather easier method is used since the efficiency depends on production rate. The efficiency calculation for rejection pieces of 125 is calculated first and then compared with other rejection values such as 100, 70, and 50 pieces. The results obtained from different cases are compared.

Item	Data
Shift length or total time	480 minutes
Lunch break + Downtime	40 + 30 minutes
Ideal run rate	3.414 pieces per minute
Total pieces	1323 pieces
Reject pieces	125 pieces
Good pieces	= [total pieces - reject pieces] 1198
Planned production time	= [shift length - breaks] = 440 minutes
Operating time	= [Planned production time - downtime] = 410 minutes

Figure 22: Shift data for production efficiency calculation U-line (Appendix 4: Sheet 9)^[XYZ]

$$\begin{aligned}
 \text{Availability (AE)} &= \frac{\text{Total production time} - \text{downtime}}{\text{Total production time}} \\
 &= \frac{480 - 30}{480} \\
 &= \mathbf{0.937}
 \end{aligned}$$

$$\text{Quality efficiency (QE)} = \frac{(\text{total pieces} - \text{Reject pieces})}{\text{total pieces}}$$

$$= \frac{1323 - 125}{1323}$$

$$= \mathbf{0.9055}$$

$$\text{Performance efficiency} = \frac{\frac{\text{Total pieces produced}}{\text{Operating time}}}{\text{Ideal run rate}}$$

$$= \frac{\frac{1323}{410}}{3.414}$$

$$= \mathbf{0.945}$$

$$\text{Efficiency} = \frac{\text{Total production time} - \text{downtime}}{\text{Total production time}} \times \frac{\text{Total pieces produced}}{\text{Operating time}} \times \frac{(\text{total pieces} - \text{Reject pieces})}{\text{total pieces}}$$

$$= 0.937 \times 0.945 \times 0.905$$

$$= \mathbf{0.802 (80.2\%)}$$

The efficiency value is compared for different cases with reduced reject pieces and is shown in table 4. Case 1 is the current U-line assembly with rejection pieces of 125. The following cases produce the same number of pieces but with fewer rejections. The efficiency of a company is considered a world-class level if it has an efficiency value greater than 85%. From table 4, it is clearly understood that in order to achieve world-class efficiency by the company XYZ, the rejection should be reduced to 50 pieces. In other words, the quality must be greatly improved.

Case	1	2	3	4
Reject pieces	125	100	70	50
AE	0.937	0.937	0.937	0.937
PE	0.945	0.945	0.945	0.945
QE	0.90552	0.92441	0.94709	0.96221
Efficiency (%)	80.2	81.8	83.86	85.2

Table 4: Comparison of different cases with lesser rejections (Appendix 4: Sheet 11) ^[XYZ]

The comparison of rejected pieces and production efficiency for different case numbers is shown in figure 23. The graph shows that world-class efficiency is achieved by case 4.

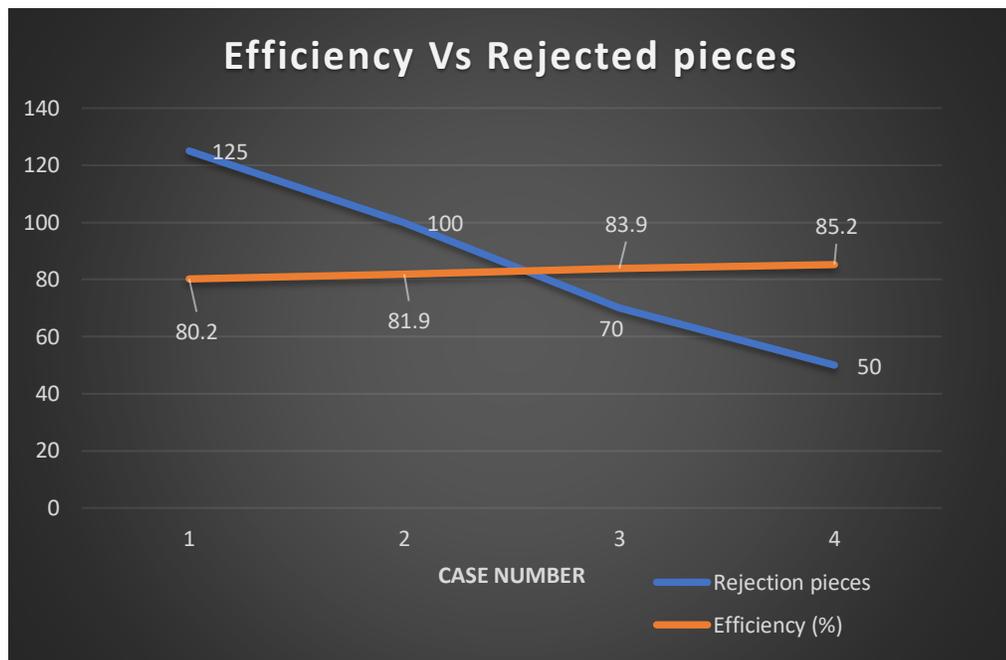


Figure 23: Comparison of Production efficiency Vs Rejected piece (Appendix 4: Sheet 11)^[XYZ]

I-line	U-line
75.3%	80.2%

Table 5: Production efficiency values of I-line and U-line^[XYZ confidential]

From table 5, it is clearly understood that an increment of 4.9percent in the production efficiency is observed after implementing U shaped line layout. Table 5 indicates the efficiency of I-shaped and U-shaped production lines.

Operator efficiency in U- shaped assembly line for station 3P

- Average cycle time of the workstation 3P = 18.57 seconds
- Number of pieces produced at station 3P = $24600/18.57 = 1324.7$ pieces
- Standard takt time = 17.57 seconds
- Total minutes produced = $\frac{1324.7 \times 17.57}{60} = 387.91$ minutes
- Total time attended in a shift = 410 minutes
- Operator efficiency = $\frac{387.91}{410} \times 100 = 94.61\%$

The individual operator efficiency calculation for workstations in the U-shaped assembly line layout is shown in table 6.

Workstation	Average cycle time U line	Pieces produced according to the cycle time	U-line (%)
2P	18.564	1325.2	94.65
3P	18.570	1324.7	94.61
4P	18.554	1325.8	94.69
5P	18.520	1328.3	94.87
6P	18.589	1323.3	94.51
M6	17.659	1393.1	99.49
11P	18.467	1332.1	95.14

Table 6: Individual operator efficiency for U-line(Appendix 4: Sheet 10)^[XYZ]

From table 6, it is clearly understood that the individual operator efficiency at the workstations 5P and M6 in the U-line resulted in better efficiency than I-line. Certain improvements have been implemented in the U-line workstations to get these results.

3.6 Continuous improvement activity

Continuous improvement is sometimes called a change for better or in Japanese term Kaizen^[25]. Kaizen can be implemented only after the identification of different types of waste of time in the assembly line. Kaizen can also be implemented for the places where a work gives more burden to the operator due to extra work imposed or difficulty in performing work other than areas with the waste of time.

Kaizen can be implemented by identifying seven types of waste of time. If one waste of time is identified in workstation, target time shall be set for reducing the time. Different ideas for reducing the time shall be proposed within the time set for target. After approval from the head of the department, the kaizen shall be implemented in the workstation under the help of team members under the supervision of the team leader and manager^[25].

For implementing improvements, the bottleneck stations are first found out. The Cycle time Vs Takt time before implementing improvements is shown in figure 24.

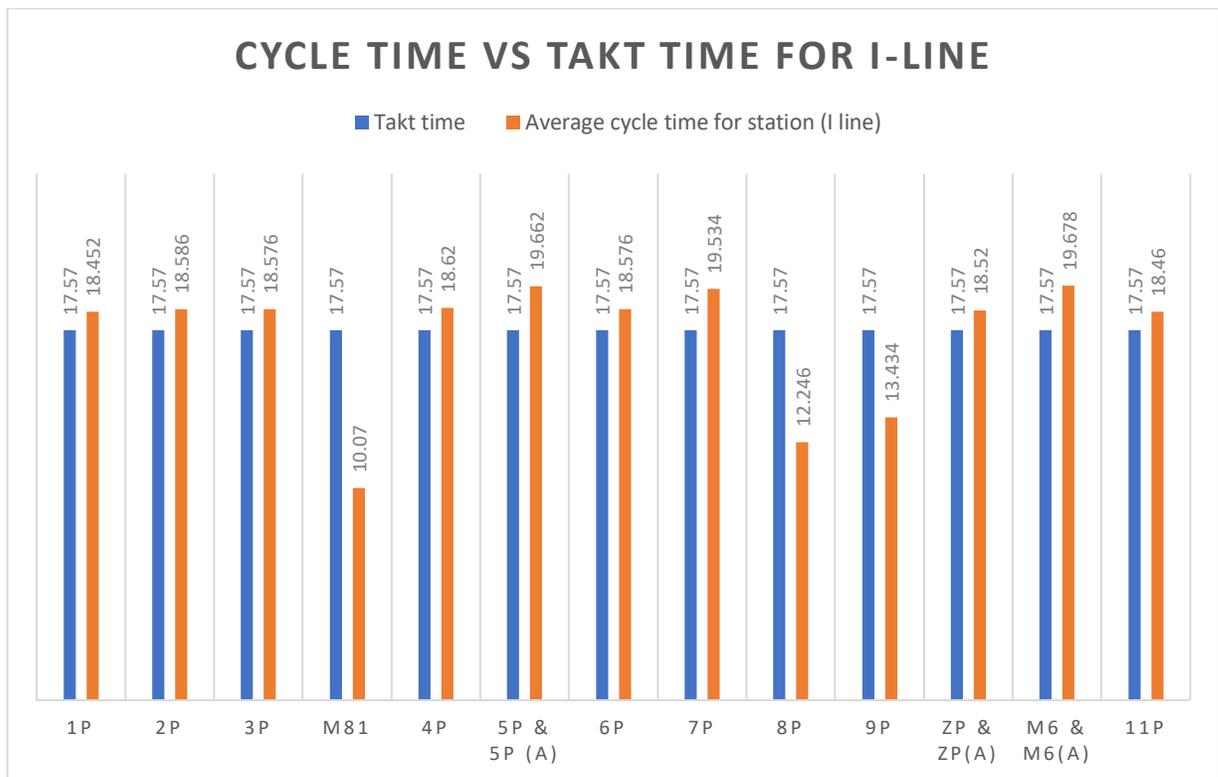


Figure 24: Cycle time Vs Takt time before line improvements (Appendix 4: Sheet 7)^[XYZ]

From figure 24, it is clearly visible that the workstations 5P, 7P, and M6 are the bottleneck stations. In the simplest definition, a bottleneck station is a work stage that gets more work requests than it can process at its maximum throughput capacity. That causes an interruption to the flow of work and delays across the production process. In other words, even if this work stage operates at its maximum capacity, it still can't process all the work items quickly enough to push them to the next stages without causing a delay. So those bottleneck stations are mainly targeted to reduce man-hour which may result in a greater increment in production efficiency^[16].

Improvement in station 1P

In the workstation 1P, the worm wheel is sub-assembled. The sub-assembled is then sent by an operator from station 1P to workstation 3P for fitting the worm wheel into the motor housing. The time taken to complete the process in station 1P is faster than station 3P. So, the operator working at station 1P has been allotted to transfer the sub-assembled part. Sometimes, the operator from 1P must wait till the work is completed in station 3P. This results in a waste of time due to waiting. In order to prevent this waste of time, a conveyor is introduced in station 1P connecting the station 3P. This is shown in figure 25. By introducing the conveyor, the

operator has no need to wait and walk to station 3P as well. By implementing this improvement, a total of 3 seconds has been reduced.

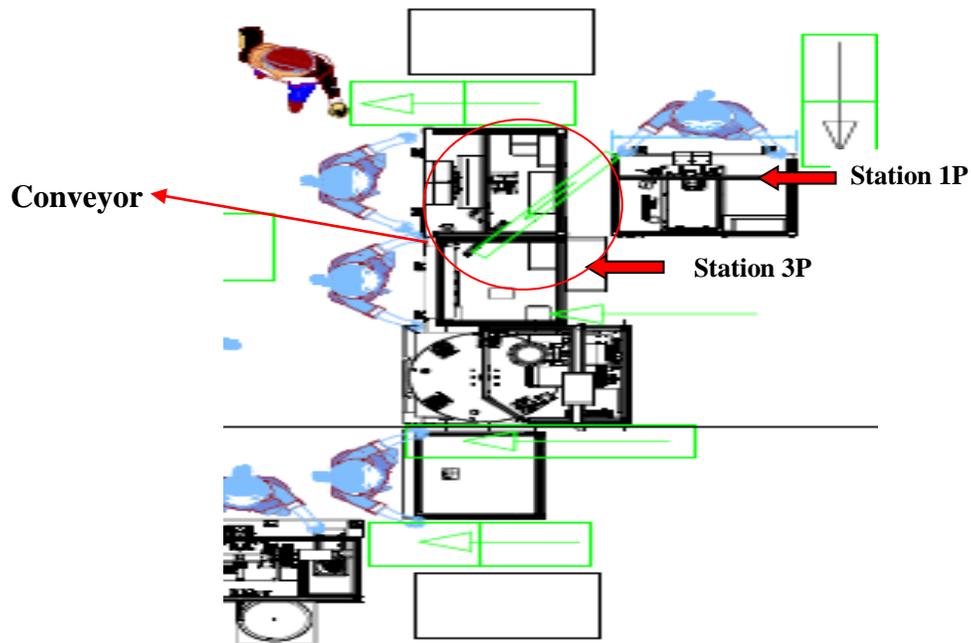


Figure 25: Conveyor used in station 1P [XYZ confidential]

Improvement in station 5P

In U-line, after completion of the motor part sub-assembly in the workstation 5P, the operator finds it difficult to place the sub-assembled part in the space allotted for the next station operator to take that part for further sub-assembly. This is because there is no space to place the sub-assembled part from station 5P as the operator in the station 6P consume more time to complete the job. This makes the operator in 5P to wait for few seconds till he/she gets the space to place it. Also, it is a burden for the 5P operator since he/she should turn a bit and place the sub-assembled part. This results in a waste of time due to waiting. In order to prevent the time waste due to waiting and the burden, a rotating table with pockets to hold the motor is introduced so that the 5P operator need not depend on the 6P operator. The table consists of six pockets to hold six sub-assembled motors. As a result of this implementation, one to two seconds have been reduced successfully. The rotating table with pockets is shown in figure 26.

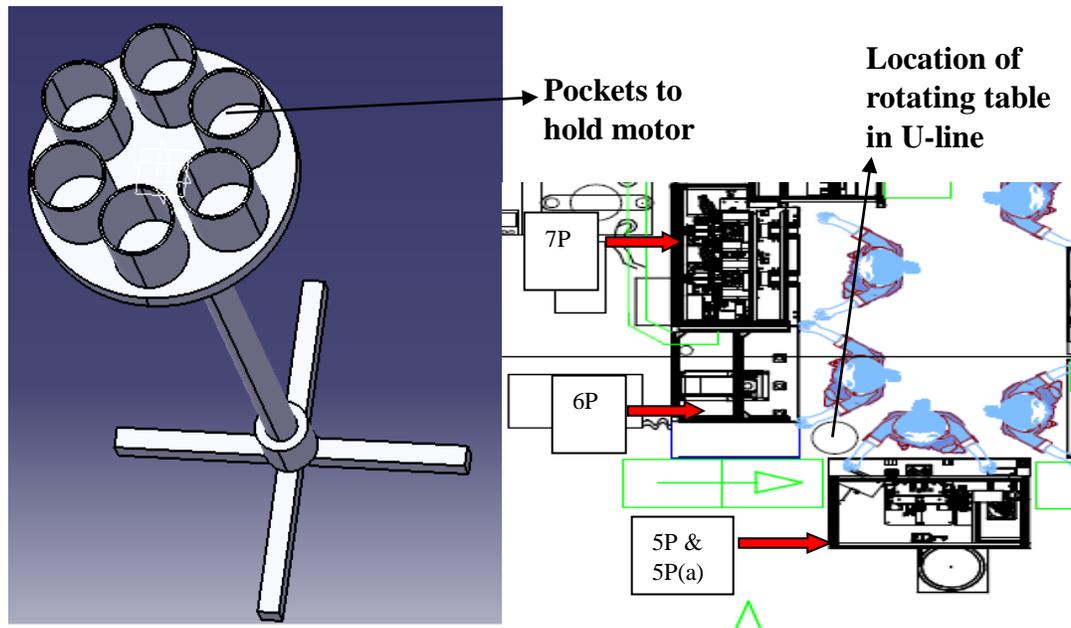


Figure 26: Rotating table with pockets (Appendix 1) [XYZ confidential]

Improvement in station 7P

In the workstation 7P, after the cementation of the brush holder, the assembled part has been sent to the process of greasing and then after that to the process of gluing. For the process of greasing it has been placed in a jig and after it is done, the part is placed in another jig inside the machine for automated gluing. These two processes have been done in different places also greasing is done manually and gluing is done automatically. Provisions have been made inside the gluing machine for automated greasing followed by a gluing process. That is both the process will take place in the same machine thereby resulting in the prevention of waste of time due to motion. By implementing this activity, a total of 3 seconds of working time have been reduced.

Improvement in station 8P & 9P

In the workstation 8P and 9P, the sequence of operation is as follows,

Step 1: Take the sub-assembled part and place it in the fixture. it takes 2 seconds.

Step 2: Place both thumbs in the sensor so that the machine locks the motor in the fixture. It takes about 3 seconds.

Step 3: Take 3 screws and screw the gearbox cover with the gearbox. It takes about 3-4 seconds.

Step 4: Place both thumbs in the sensor so that the machine unlocks the motor in the fixture. It takes about 3 seconds.

Step 5: Take the motor from the fixture and place it in space provided for the next station. It takes about 1-2 seconds

The operations are almost the same for both workstations. In order to reduce man-hour, the operator in the station 8P does the operations of 9P as well. This, of course, includes only the time needed to perform step 3 in station 9P which is 4 seconds since the others are same and it is not necessary to be done again. The previous cycle time of station 8P was 12 seconds. Therefore, the cycle time of station 8P after performing step 3 of station 9P is 15-16 seconds.

The operation of the operator in the station 9P is only checking the whole part and placing it in the station Z. This operation contributes to the time of 4-5 seconds. By implementing this improvement total of 5-6 seconds have been reduced. This operator helps in supplying the material to the workstations.

Improvement in station M6

In station M6, the operator working has to move a certain distance from workplace to take the motor from the conveyor coming from station Z for noise checking and also to place the noise checked motor over the conveyor to send it to the next station. This is due to the shorter length of the conveyor which was 1.5 metres long. This results in a waste of time due to motion. In order to remove the waste of time due to walking, the length of the conveyor on both sides is increased by 0.5 meters so that the worker can take and place the motor from the working position without walking. This is shown in figures 27 and 28. As a result of this improvement, one second is reduced for taking the motor from the conveyor and one more second is reduced for placing the motor in the conveyor. Totally, 2 seconds of working time has been reduced.

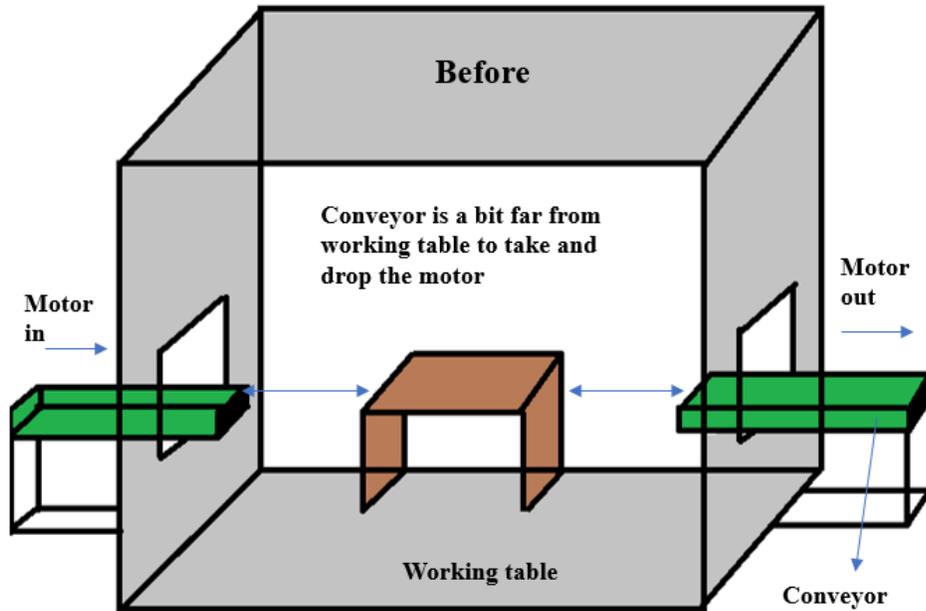


Figure 27: Before kaizen implementation in workstation M6

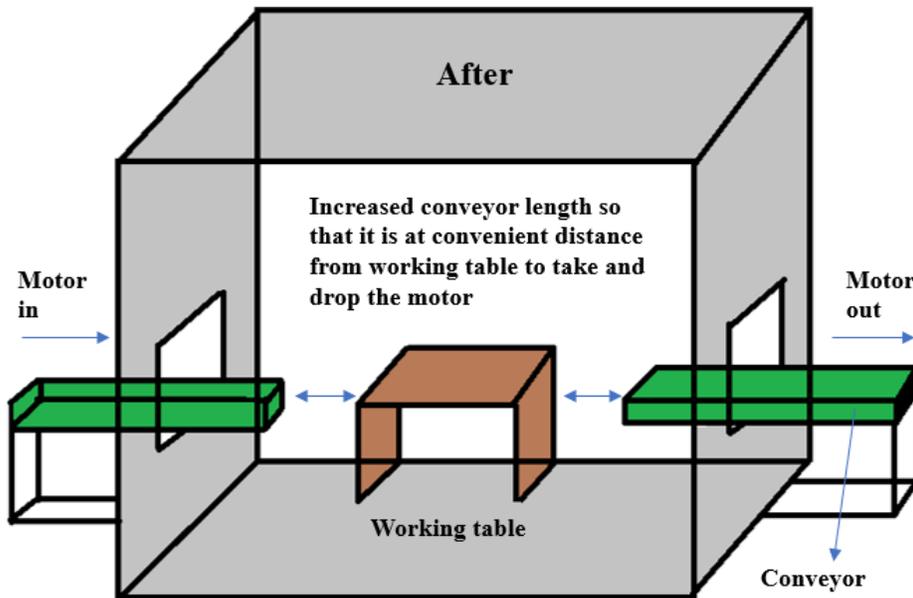


Figure 28: After implementing kaizen in workstation M6^[XYZ confidential]

Through continuous improvement activity, a total of 13-16 seconds has been reduced which resulted in the production of an extra 219 pieces for the whole day from one assembly line. This number may look small, but it has a huge contribution to production efficiency improvement. The company produced a total of extra 1095 pieces per day after implementing a new line layout compared to the old-line layout.

3.7 Comparison of results produced by I-shaped and U-shaped assembly line

3.7.1 Comparison of cycle time

From the calculation part, we receive different values for I-shaped and U-shaped assembly lines. Some stations resulted in good improvements, some stations stayed the same and the graph below shows the comparison of cycle time values of workstations of I and U-shaped layout, also a comparison of average cycle time for both layouts.

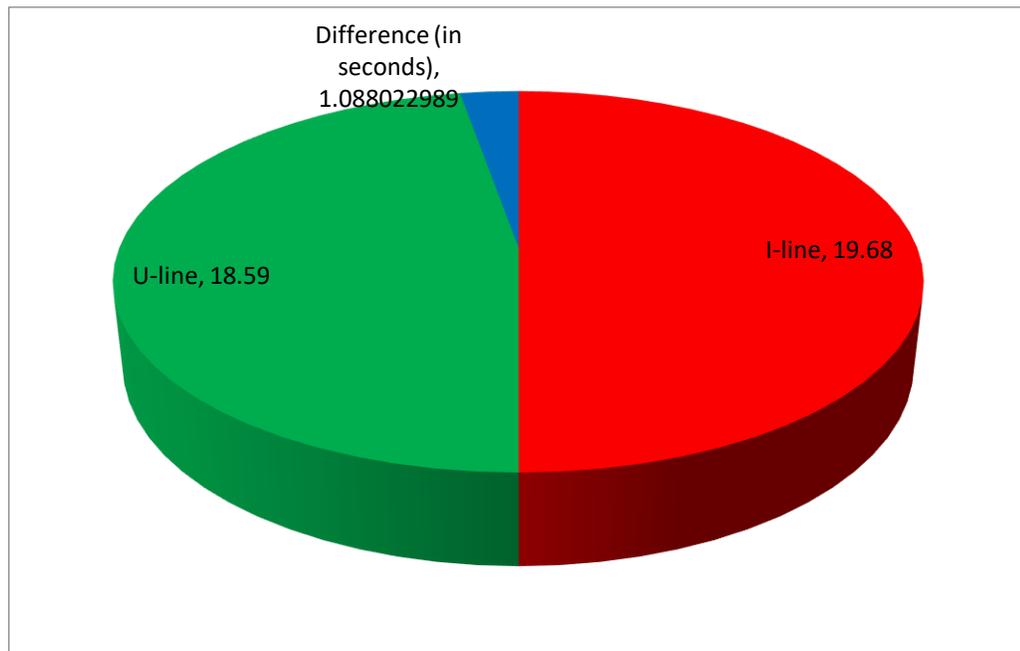


Figure 29: Comparison of Avg CT for whole line (I-line Vs U-line) (Appendix 4: Sheet 7)^[XYZ]

From figure 29, it is clearly visible that a difference of 1.088 seconds has been reduced after implementing the U-line layout. As mentioned before, an improvement in cycle time by even a second brings a lot of benefits to a company. Hence, this is a positive output.

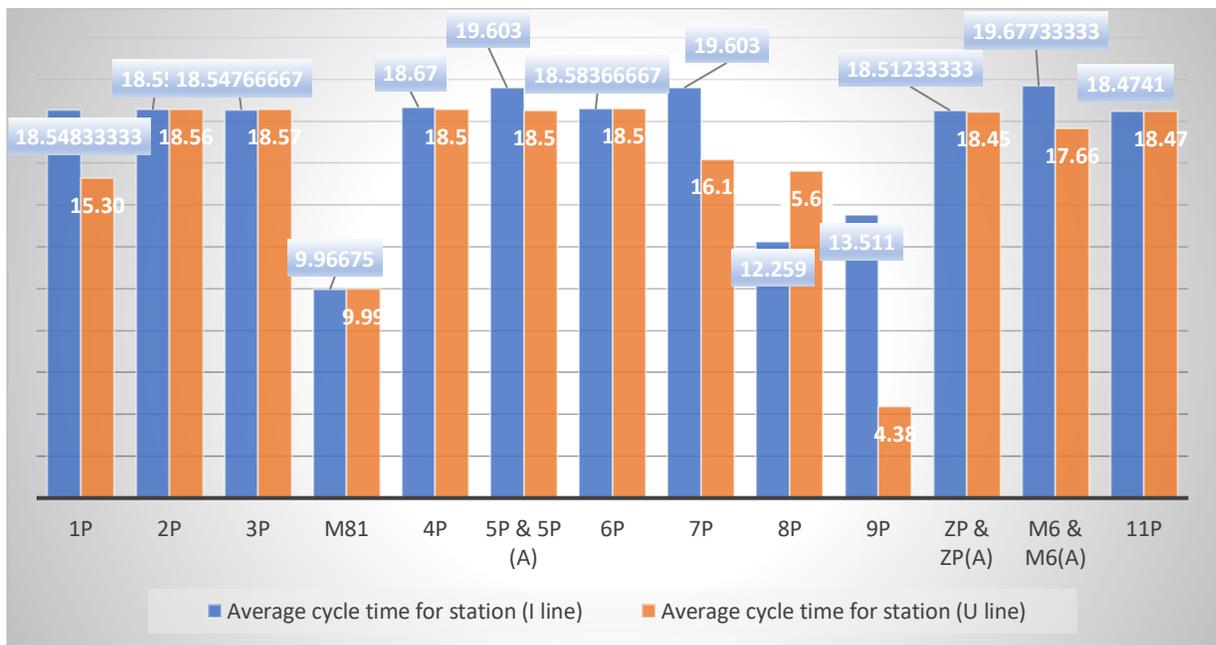


Figure 30: Comparison of Avg CT for workstations in I-line and U-line (Appendix 4: Sheet 7)

From figure 30, we can understand that X-axis denotes workstations and the y-axis denotes time in seconds. In workstations 1P, 5P, 7P, 9P, M6 & M6(a) Implementing U-line layout brought a positive output. There was a negative output in workstation 8P.

3.7.2 Comparison of production efficiency and operator efficiency

Figure 31 shows the comparison of factors (availability, performance, and quality) of production efficiency for the I-line and U-line production layout. From the figure, it is clearly visible that the U-shaped production line layout produced better output in performance by 5.2%, in quality by 0.6% and in overall production efficiency by 4.9%.

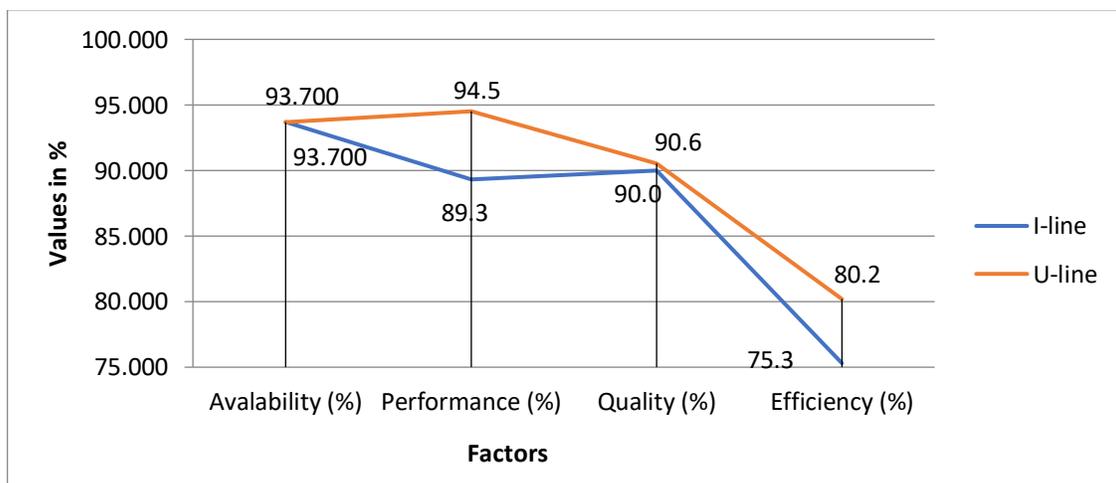


Figure 31: Comparison of production efficiency I and U-line (Appendix 4: Sheet 10)

Figure 32 indicates the comparison of individual operator efficiency for an I-shaped and U-shaped production line. It is visible that U-line produced better results than the I-shaped line. The workstations 5P, 7P, M6 produced better results in U-line than in I-line. 7P is not shown in figure 32 since it already provided better efficiency.

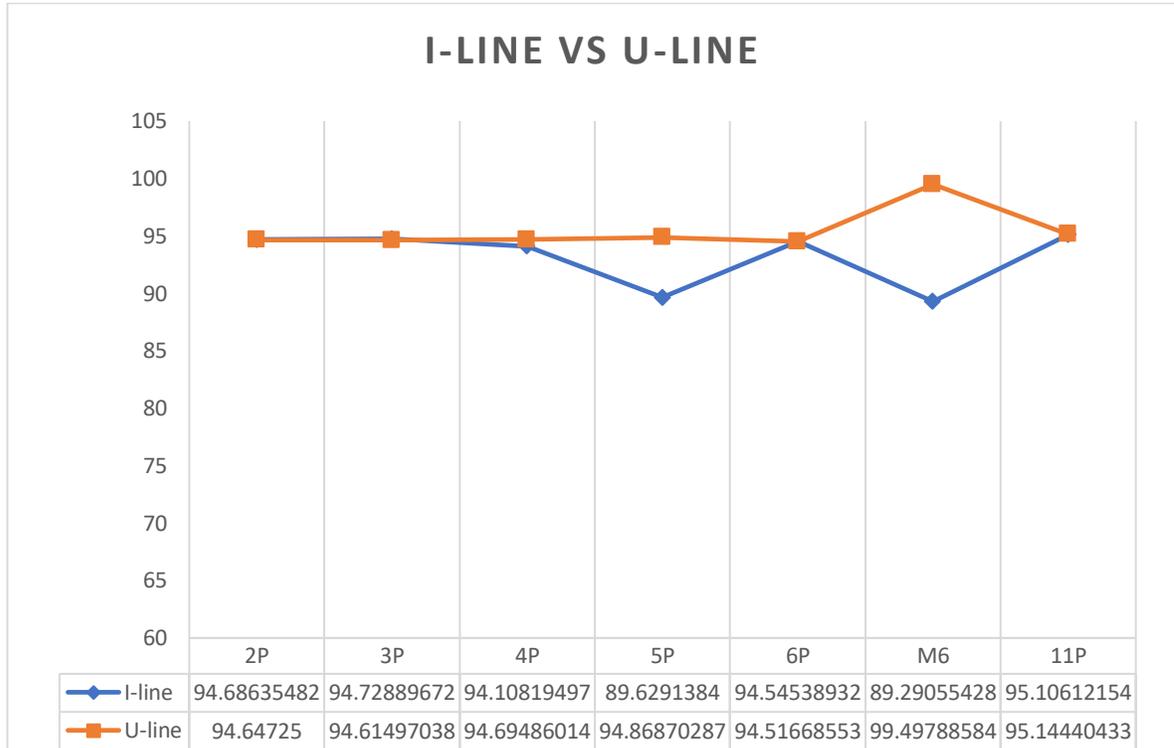


Figure 32: Comparison of operator efficiency for I and U-line (Appendix 4: sheet 10)

4 Conclusion

In this thesis, the literature survey focusing on the types of production line layouts have been successfully done. The current assembly line layout which is of I-shaped have been defined. This is followed by defining and designing of new assembly line layout for the production of motor assembly which is of U-shaped. This layout has also been defined. Through implementing the new layout, the single-piece flow has been achieved. Also, the following objectives have been successfully achieved. Those are as follows,

- The process flow diagram for the production of motor assembly has been studied in detail.
- Every workstation in the motor assembly line has been successfully inquired.
- The customer demand for the company has been analyzed and takt time for the company has been calculated.
- The cycle time of 30 trials for the I-shaped assembly line has been measured by using a stopwatch.
- The factors on which the production efficiency depends upon has been determined and production efficiency for the I-shaped assembly line has been calculated.
- The individual operator efficiency for every workstation for the I-shaped assembly line has been calculated.
- The best suitable layout for replacing the I-shaped line layout has been chosen to be a U-shaped line layout.
- The U-shaped assembly line layout has been designed and implemented.
- The area for improvement is noted by finding wastefulness of time.
- The continuous improvement activity has been implemented in the area of wastefulness.
- The cycle time of 30 trials for the U-shaped assembly line layout has been measured.
- The production efficiency for the whole assembly line and individual operator efficiency for each workstation has been calculated for the U-shaped line layout.
- The output values of the I-shaped line and U-shaped line layout has been compared and projected in the graphical view.

The key features of continuous improvement activity are also to reduce workable issues and improve productivity at the workplace. By implementing a new assembly line layout, the prevention of material traffic in the line, single-piece flow and providing better

ergonomics for the operator working in the stations have also been successfully accomplished. After implementing a new line layout in the motor assembly along with continuous improvement in the workstations, the company obtained a great increment in the production line efficiency which is 4.9 percent.

The benefits of this project were

- The walking distance of the operators moving between the workstation has been greatly reduced.
- Single-piece flow or one-piece flow has been achieved.
- Material traffic in the production line has been reduced after implementing a new line layout.
- The ergonomics of operators in the station have been greatly improved.
- In case of absence of operators or half production required by the company, the line can be balanced by operations performed by an operator working in opposite workstations. This is possible only in the newly implemented production line layout.
- Bottleneck areas have been found which helped in finding the area of wastefulness.
- Time waste due to waiting has been reduced in possible ways.
- Time waste due to inventory has been prevented by following the line balancing technique.
- The production rate of the motor per shift has been increased by 73 pieces per shift and 219 pieces per day.
- The production target has almost been achieved which is 1323 pieces per shift for one Motor assembly line.
- Overall, the output of the new line layout was better and promising which resulted in better production efficiency of over 4.9% when compared to the I-line layout.

References

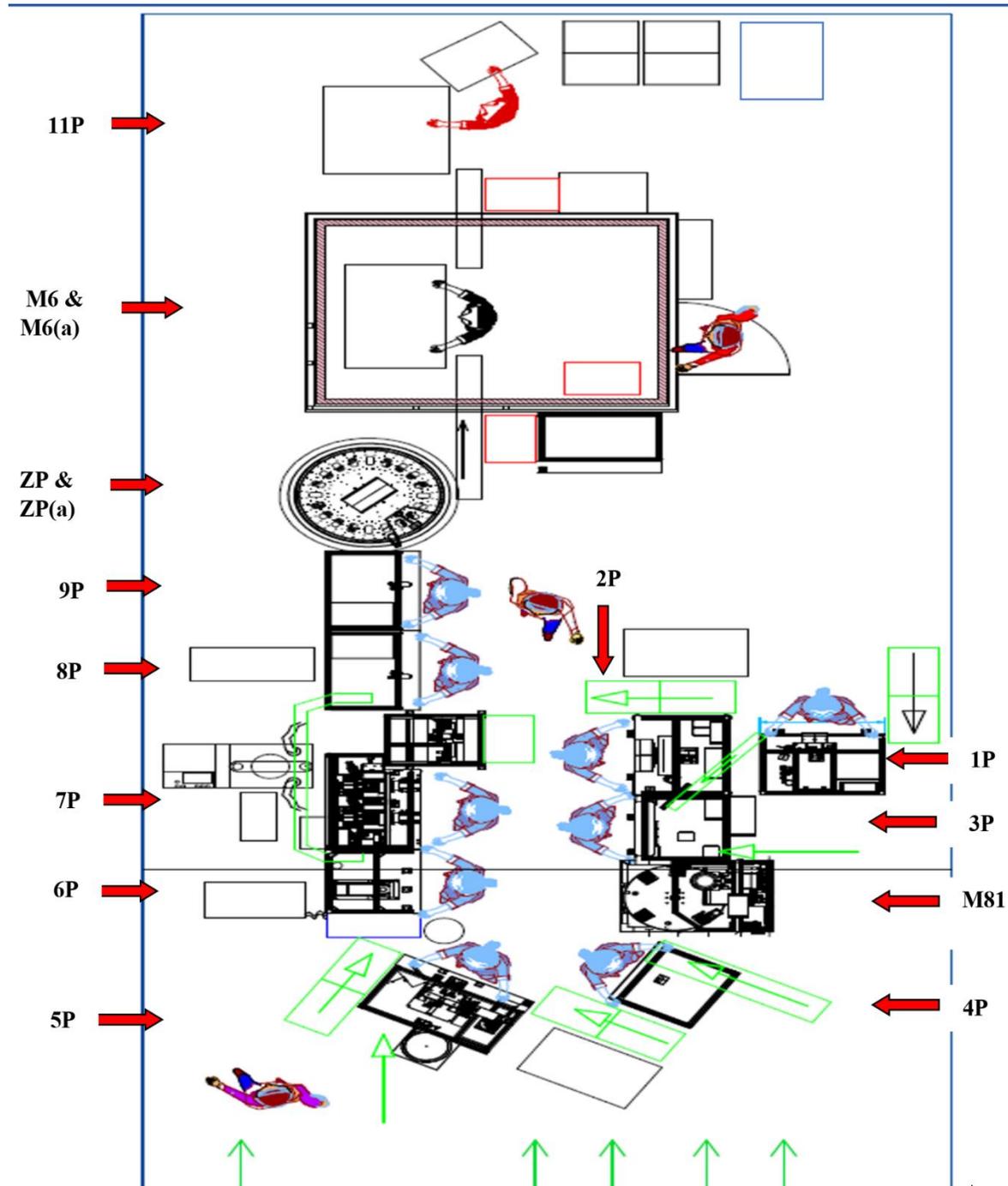
1. Ford & Crowther. *MY LIFE AND WORK. Assembly line*. Page number:80. (1922).[Accessed 04.06.2019]. ISBN 0-405-05088-7. Available at:https://www.goodreads.com/book/show/1122054.My_Life_And_Work
2. Roser, C. *Line Layout Strategies – Part 2: I, U, S and L Lines* / *AllAboutLean.com*. [online] AllAboutLean.com. (15 Nov 2016). [Accessed 04 Jan. 2020]. Available at: <https://www.allaboutlean.com/line-layout-i-s-u-l-lines/>
3. Whiting, B. *Cellular layouts in lean production* / *Study.com*. (2020).[Accessed 04 Jan. 2020]. Available at: <https://study.com/academy/lesson/cellular-layouts-in-lean-production.html>
4. McLean, T. *Factory Layout Examples & How to Choose* / *TXM lean solutions*. (2020). [Accessed 05 Jan. 2020]. Available at: <https://txm.com/factory-layout-examples/>
5. Lean plant layout, *L-shaped layout* / *assemblymag.com*. (1 March 2012). [Accessed 10 April 2019]. Available at: <https://www.assemblymag.com/articles/89823-lean-plant-layout>
6. Miltenburg, G.J., and Wijngaard, J. *The u-line line balancing problem*. *Management Science* / *Sciencedirect.com*, 40 (10), 1378- 1388. (1994). [Accessed 04 Jan 2020]. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0377221797001690>
7. Anthony Inman, R. *Cellular layout* / *referenceforbusiness.com*. (2020). [Accessed 04 Jan 2020]. Available at: <https://www.referenceforbusiness.com/management/Int-Loc/Layout.html>
8. Lean plant layout. *U-shaped line layout*/ *Aspilsan.com*. (2017). [Accessed 28 July 2019]. Available at: <https://www.aspilsan.com/makale.asp?id=12>
9. Dolcemascolo, D. *Achieving one-piece flow* / *Reliableplant.com*. (2020). [Accessed 07 Jan 2020]. Available online: <https://www.reliableplant.com/Read/14703/one-piece-flow>
10. Toyota Management system. *Benefits of one-piece flow* / *Ineak.com*. (22 February 2009). [Accessed 03 Jan 2020]. Available at: <https://www.ineak.com/benefits-of-one-piece-flow/>

11. ASQ. *What is a Flowchart? Process Flow Diagrams & Maps* / ASQ.org. (2019).
[Accessed 16 May 2019, Available at:<https://asq.org/quality-resources/flowchart>
12. Business Dictionary. *What is production efficiency? definition and meaning*. (2019).
[Accessed 09 Nov 2019]. Available at:
<http://www.businessdictionary.com/definition/production-efficiency.html>
13. OEE made easy by Vorne. *Calculate OEE – Definitions, Formulas, and Examples* / OEE. (2019). [Accessed 21 Nov 2019]. Available online:
<https://www.oee.com/calculating-oee.html>
14. Filippo, D.C. Maria A.A. and Mario, T. '*OEE Evaluation of a Paced Assembly Line through Different Calculation and Simulation Methods: A Case Study in the Pharmaceutical Environment*', *International Journal of Engineering Business Management*, Vol.6, No.22, (2014).[Accessed 07 Jan 2020]. Available at:
<https://pdfs.semanticscholar.org/c421/b802d8531f35094cdf69b26d23755b05dbdd.pdf>
15. Maintain X. *How to improve production efficiency in 8 steps*. (2019). [Accessed 10 Nov 2019]. Available at: <https://www.getmaintainx.com/production-efficiency/>
16. Kanbanize. *What is the bottleneck and how to deal with them? Bottleneck definition*. (2019). [Accessed 25 June 2019]. Available at: <https://kanbanize.com/lean-management/pull/what-is-bottleneck/>
17. Michaels, L. *How to achieve assembly-line efficiency* | *Skills you Need*. (2019).
[Accessed 07 Nov 2019]. Available at:
<https://www.skillsyouneed.com/rhubarb/efficiency-in-business.html>
18. Lean Manufacturing Tools. *Types of time waste in the production line*. (2019).
[Accessed 26 July 2019]. Available at: <http://leanmanufacturingtools.org/77/the-seven-wastes-7-mudas/>
19. Manufacturing info. *What is production leveling?* (2020). [Accessed 06 Jan 2020]. Available
at:http://businessknowledgesource.com/manufacturing/what_is_production_leveling_028056.html
20. Toggl. *Takt time Vs Cycle time Vs Lead time*. (2019). [Accessed 07 Nov 2019].
Available at: <https://toggl.com/takt-time-cycle-time-lead-time/>

21. Latest quality. *What is the difference between Takt time Vs Cycle time?* (May 24, 2018). [Accessed on 03 Jan 2020]. Available at: <https://www.latestquality.com/takt-time-vs-cycle-time/>
22. Kanbanize. *What is takt time and how to calculate it?* (2019). [Accessed 20 Nov 2019]. Available at: <https://kanbanize.com/continuous-flow/takt-time/>
23. Sarkar, P. *Production line efficiency and operator efficiency formula.* (January 20 2017), [Accessed 24 June 2019]. Available at: <https://www.onlineclothingstudy.com/2017/01/efficiency-formula-calculate-operator.html>
24. Ron, J.E. Rooda. *OEE and equipment effectiveness E: an evaluation. International Journal of Production Research / Taylor & Francis*, 44 (23), pp.4987-5003. doi:10.1080/00207540600573402. (2006). [Accessed 06 Jan 2020]. Available at: <https://hal.archives-ouvertes.fr/hal-00512884/document>
25. ASQ. *Continuous improvement study, learn about the quality| asq.org.* (2019). [Accessed 25 June 2019, Available at: <https://asq.org/quality-resources/continuous-improvement>

Appendix

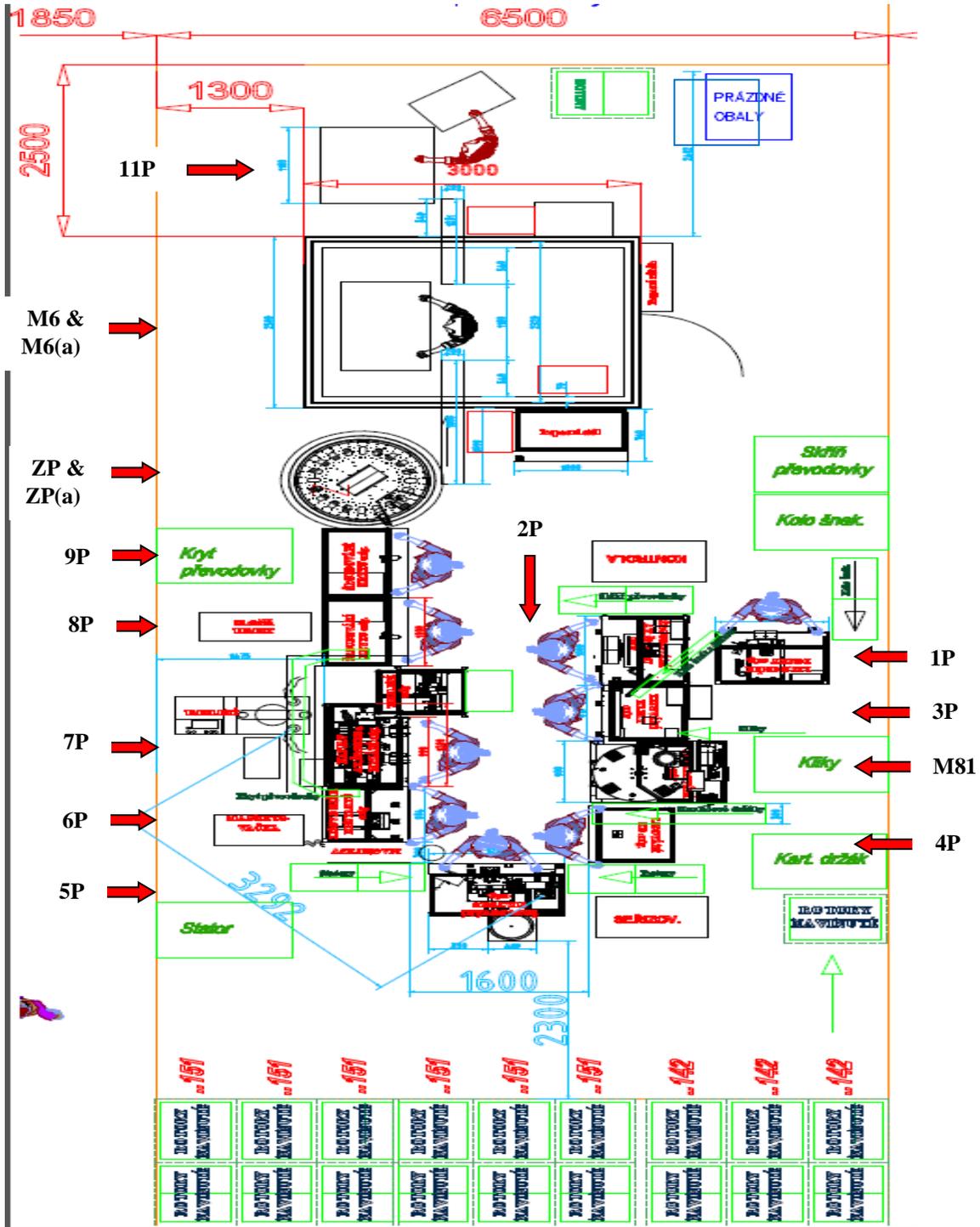
My personal design of U-shaped line layout



- | | | | | | |
|---|---------------------------------|---|--------------------------------------|--|------------------------------|
|  | Bins for NOT OK motor parts |  | Bins for fully assembled motor |  | Conveyors |
|  | Bins for Materials and Ok parts |  | Indication of respective workstation |  | Operator standing in station |

My personal design of U-shaped line layout

U-shaped line layout with dimensions



- Bins for NOT OK motor parts
- Bins for fully assembled motor
- Bins for Materials and Ok parts
- Indication of respective workstation
- Conveyors
- Operator standing in station

U-shaped line layout with dimensions