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Production Rate Improvement on Monoblock Pump through Implementation of Lean Tools (Deming Cycle)

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Abstract

The global economic competitiveness has demanded the manufacturing companies to sustain and remain profitable in the competitive market by increasing the productivity. Implemen- tation of lean tools has remained as an efficient way to improve productivity. This study focuses on improving the productivity of

0.5 HP Monoblock pump manufactured by Mahendra Pumps, one of the leading pump manufacturing industry in Coimbatore through implementation of lean tools. The workflow used is the Deming Plan-Do-Check-Act (PDCA) approach which provides opportunities for continuous evaluation and improvement. In each phase of this cycle, lean activities along with lean tools like time study, value stream mapping integrated with Arena Simulation, and performance analysis were carried out. The time study is done on the selected production systems to identify the bottleneck stations. Then, the bottleneck stations are taken into elemental level by the Arena Simulation which provides the material and information flow of current state of system in dynamic nature. The kaizen suggestion is derived from the task analysis which differentiates the value adding time and non-value adding time. Arena simulation was used to create the future state map based on the suggestion to ensure the increase in production rate. The improved production rate is evaluated by performance analysis and the results obtained were documented using standardized work combination table.

Index Terms—Lean tools, Deming cycle, Productivity improve- ment, Arena simulation, Monoblock pump

I. INTRODUCTION

The only way a business or enterprise can grow and increase its profitability is by enhancing productivity in all aspects- sales, finance, production, engineering, cost, maintenance, and management. Productivity is the value of outputs (goods or services) produced divided by input resources (wages cost of equipment) used, commonly associated with labor effective- ness in the industry. The production rate is the ratio of the total number of goods produced and the time spent on them. By increasing the production rate, productivity enhancement can also be achieved. To increase the production rate, the production cycle time, which is the time required to produce a single unit, has to be reduced [1]. Toyota first initiated the approach of lean. Lean production originates from the Japanese manufacturing method known as TPS- Toyota pro- duction system. It concentrates on depreciating waste in a man- ufacturing system without compromising productivity. Wastes are classified into seven types, i.e., Motion, Time, Investment, over-processing, overproduction, Waiting and defects. VSM is

a map of a process flow for better visualization. VSM is a mapping tool used to map a productive process or an entire product’s supply chain. It maps not only material flows but also the information flows that signal and control production. Moreover, a value stream is a collection of all actions (value- added as well as non-value-added) that are required to bring a product through the main flows, starting with raw material and ending with the finished product to the reached customer. The ultimate goal of VSM is to identify all types of waste in the value stream and take steps to eliminate the wastes. It is of two kinds, i.e., Current Value Stream Mapping and Future Value Stream Mapping [2]. The purpose of the time study is to improve the effectiveness and productivity of the work system. The time study is the systematic study of work systems to develop the preferred system, determining the time required by a qualified and properly trained person working at a normal pace to do a specific task or operation and assisting in training the worker in the preferred method [3].Kaizen is a Japanese term that means continuous improvement, derived from the word ‘Kai’ means continuous and ‘Zen’ means improvement. The kaizen philosophy consists of constant improvement, problem-solving, upgrading the standards and process-oriented thinking [4]. Arena simulation is a measuring tool to identify how changes to the process or variables will affect the entire process. The usage of traditional lean visual management tools such as Value Stream Mapping exposes the waste to be eliminated and prevented from recurring, making the workplace more efficient. VSM provides only a first visual aid in comprehending the process. But arena simulation will provide dynamic behavior of production processes in a detailed way [5].Lean manufacturing is a process of maximizing the value of the product by eliminating the waste and it pro- vides the continuous improvement of process & equipment by eliminating the non-value-added activity- transportation, inventory, motion waiting, overproduction, over-processing and defects [6]. Productivity is improved by reducing different kinds of wastes. In any organization, process efficiency and lead time reduction are improved by lean. Task analysis is preferred to identity the waste activity. The whole tasks are of three categories: Value- added task, non-value-added task, and pure waste [7]. The lean production methods and instruments are not equally applicable to large and small enterprises. Difficulties in the implementation of lean for small and medium enterprises are: lean methods are not well-known by the firm and hard for the small firm to hire qualified staff. Some suitable lean methods for the small enterprises are 5S, First-in-First-Out, Benchmarking, Kaizen, Just-in-Time delivery, Pull- principle and Kanban, Visual management in production, Set- up time reduction to reduce waste, Value Stream Mapping, Poka Yoke and standardization, and Low-cost Automation [8]. Continuous Improvement or Kaizen emerges from Japanese industries. This technique improves the manufacturing process in terms of cost, quality, and productivity. Kaizen suggests starting more with modest than reinventing from scratch. The implication of Kaizen leaves a highly flexible, efficient and productive factory floor alongside an entire lean supply chain. Kaizen recommends an experimental plan and it starts with a test plan [9]. The major factors for the successful implementa- tion of Kaizen are good communication between management and the employees, clear corporate strategy, presence of a kaizen champion personnel, good knowledge management and employee’s empowerment [10]. Kaizen encompasses a number of techniques, tools and methodologies, including Total Productive Maintenance (TPM). The pillar of TPM is “Improvements in Process and Equipment”, also known as kobetsu kaizen. For better performance increment in pro- duction, process and equipment, TPM methodology, kobetsu kaizen pillar and visual management, particularly dashboards had a good contribution [11]. Value Stream Mapping is a Lean technique used to illustrate and analyze the logic of the production process by giving a graphical overview of the material and information flow in the manufacturing unit. The main steps of the value stream mapping are (1) Value stream scope, (2) Current State map, (3) Future State map, (4) Implementation Plan and (5) Implementation of the Improved plan [12]. In order to eliminate the waste, the visualized map was created for the entire process and the non-value adding activities were identified. As a result, a new future state of the industry was developed and implemented [13]. To implement lean concepts, we should know the current situation of the industry and it can be done only by value stream mapping. Lean manufacturing technique can be applied in the crankshaft manufacturing industry by selecting value stream mapping used as lean tool. Here the idea is to increase the export sale and the company's quality and cost. The key elements of value stream mapping looking forward to reducing the waste are the customer and their requirements, process steps, process metrics, inventory, supplier with material flow, information and physical flow, and total lead time and takt time. The future state map represents the improved processes and equip- ment [14]. Productivity is a key to determining the success of a company. It is the ratio of output to all the resources used to produce the output. To increase productivity, the measurement of work is a fundamental tool. Work measurement is mainly used to quantify the work content related to a job in terms of the standard time. The outcome of time study is the standard time which is used to: determine the schedules and planning work, determine the standard cost, and determine the machine effectiveness [15]. The actual time and standardized time are measured and compared to identify the inevitable times. As a result, new approaches are established to reduce the non-value adding times [16]. The time study has also been used to design the early stage of automated assembly line by time estimation. The main purpose is to support the decision about the levels of automation in the assembly line. This assembly model and time estimating are tested on examples and a computerized tool is also developed. Several other proposals related to time study are also tested. They are processes of time performance evaluation, time savings, productivity assessment, lines balanc- ing and cost estimating [17]. An extensive literature review has been carried out on various lean tools such as Kaizen, Value stream mapping, Time study and methods to increase the production rate were reviewed.

II. METHODOLOGY

Productivity improvement on 0.5 HP Monoblock pump is achieved by implementing Deming's cycle strategy. The strat- egy consists of four major steps, i.e., PLAN, DO, CHECK and ACT. The relation between four steps and activities resembles Toyota's eight-step process [18]. The workflow chart shows the workflow along with the tools used for improving the production system.

STAGE 1 - SELECTING stage where specific product varieties are chosen for improvement. Based on the Product Quantity Analysis chart, the volume distribution of the vari- eties of products could be obtained and illustrated in the form of a Pareto chart. The product varieties are separated into high and low volume products using the 20:80 rule.

STAGE 2 - ANALYZING stage where the current produc- tion system is observed and analyzed. The standardized time along with the Lead time can be determined in this stage using Time Study Techniques. This mainly consists of handling time, working time, Work transfer time and cycle time.

STAGE 3 - DESIGNING stage where the data collected via Time study is used to construct Current value stream Mapping (CVSM). CVSM shows the present scenario of the production system and could be helpful in reducing the lead time.

STAGE 4 - IMPLEMENTING stage were the unnecessary non-value-added time has to be reduced, which reduces the lead time. Thus, the wastes in the process have been removed and the improved way of working is depicted in the form of Future Value Stream Mapping. The reasons for the time delay in work are identified and resolved using Root- Cause Analysis.

STAGE 5 - EVALUATING stage, where the performance evaluation is done by analyzing the major factors like Produc- tivity, Lead time, Quality. These parameters are the important factors to be considered after the implementation of the improved system. Along with the process, any abnormalities such as bottlenecks and material shortages were analyzed and improved.

STAGE 6 - STANDARDIZATION, where the standardized work with an improved production rate has to be documented for further use. This standardized working condition must be displayed at the workplace for reference.

The value stream mapping helps identify the current flow of the material and information in processes for a family of products, highlighting the opportunities for improvement that will most significantly impact the overall production system [19].

III. DEMING CYCLE – PRODUCTION RATE IMPROVEMENT

Deming cycle is one of the Kaizen (continuous improve- ment) tools used to solve any Industrial problem with four repetitive steps. By following the Deming cycle, the increase in production rate can be achieved.

A. *Plan phase*

The plan is to establish objectives and processes or counter- measures with expected outcomes based on past performances or future forecasting of work. Specific series of pump that has to be improved in terms of production rate was selected using product quantity analysis. The selected series are TC50+, TC50+ ES, MCH 60, CHV 1 ES, CHV 50 ES, CHV 1HH, MCH 100, METRO 10, SMV16, MAX05. Sections of the existing production system are selected, which is analyzed and improved using the Deming cycle. The selected sections are winding, machining & assembly sections.

The components obtained from the respective sections are stator coil winding subassembly, rotor shaft sub-assembly & Final assembly of the pump. Since these are the sections directly involved in the manufacturing of the components, these Sections are common for all the selected series of pumps, where its production system is subjected to improvement. The standard time and lead time of the existing production system are determined using line observation and time study. Time Study (Winding and Machining Section): Time study is the technique of observing and recording the time taken for every process in the work sequence of the industrial operation. The time measurement sheet is prepared as per the industry needs. It mainly includes: Hand time (HT), Machine time (MT), Work Transfer Time (WHT). The normal time and standard cycle time are determined by using the formula.

Total Time, TT = HT+MT+WHT

Average Time, AT = TT / (No of Observations) Normal Time, NT = AT* Rating Factor

Standard Time, ST = Normal Time (1+ Allowance) Existing production system using Current Value Stream Mapping is found.

B. *Do phase*

The non-value adding time in the existing production system is determined using simulation by Arena. The simulation is done for all three sections, namely: winding, machining, and assembly. The cycle time, work in process, inventory level collected during the line observation and time study are used in the simulation to get the desired output. The unnecessary non-value adding time in the existing production system is eliminated using task analysis. The task analysis is a process of separating the value-adding time and non-value adding time. By referring to the results obtained from the Arena Simulation, the task analysis is done.

Kaizen Activities on Current State: The Kaizen suggestions are given based on the following: Build-ups of inventory, long travel distances, Bottlenecks, Significant variations in cycle time, Stock shortages, High scrap and rework rates, 5s and safety issues. Because these elements were creating delays in the normal production process, the above-mentioned elements are checked for all three sections, and improvement activities are provided to rectify the delay.

Assembly Section

Because of significant variations in cycle time, batch pro- duction is converted into continuous line production and the unnecessary non-value-adding activities are eliminated.

Winding Section

Replacement of plastic clips: The plastic knot like clips could be replaced with metal clips. This replacement would save the time of clamping the coil. The plastic clips need another rod-like equipment to clamp the coil. These metal clips could be handled with ease. This data was noted by observing starting coil winding machine.

Average Time taken for clamping 18 coil stacking (By plastic clip) = 100 sec.

Average Time taken for clamping 18 coil stacking (By metal clips) = 40 sec.

Coil Holders: The coil winding machine has six coil holders. Only three holders are used, which produces three sets of coils. The productivity and efficiency of the machine could be increased by using all six coil holders. This data was noted by observing starting coil ending machine.

Average time for making 6 sets of coil winding (only three coil holders used) = 670 sec.

Average time for making 6 sets of coil winding (all six holders are used) = 335 sec.

Skilled Workers: Both the starting and running coil windings undergo the same procedure. The time taken by the workers varies drastically.

Average time taken by the Running Coil winder (for three sets) = 205 sec.

Average time taken by the Starting coil winder (for three set) = 335 sec.

Since the winding stator subassembly of the pump needs both starting and running coils, the starting coil winder must be replaced with a trained worker or the person must be trained. Thus, the winding stator body subassembly productivity could be improved by concentrating on the starting coil winding process.

Hourly output of Running coil winder = 54 sets. Hourly output of Starting coil winder = 33 sets.

Coil Removal Process: Coil patterns must be adjusted and pushed front. This makes the coil removal process easier. Without adjustment, the removal process would be time- consuming. This data was noted by observing the starting coil winding.

Time taken by the winder (without adjustment) = 160 sec. Time taken by the winder (After Adjustment) = 104 sec.

Coil Insertion: Coil insertion involves two steps, i.e., Manual and Machine Insertion.

Average Manual Insertion Time = 140 sec. Average Machine Insertion Time = 175 sec.

The worker operating the coil insertion machine is highly skilled and the work elements are completed with good speed. The manual insertion worker is less skilled and works at a slow speed. The manual worker works leisurely, whereas the

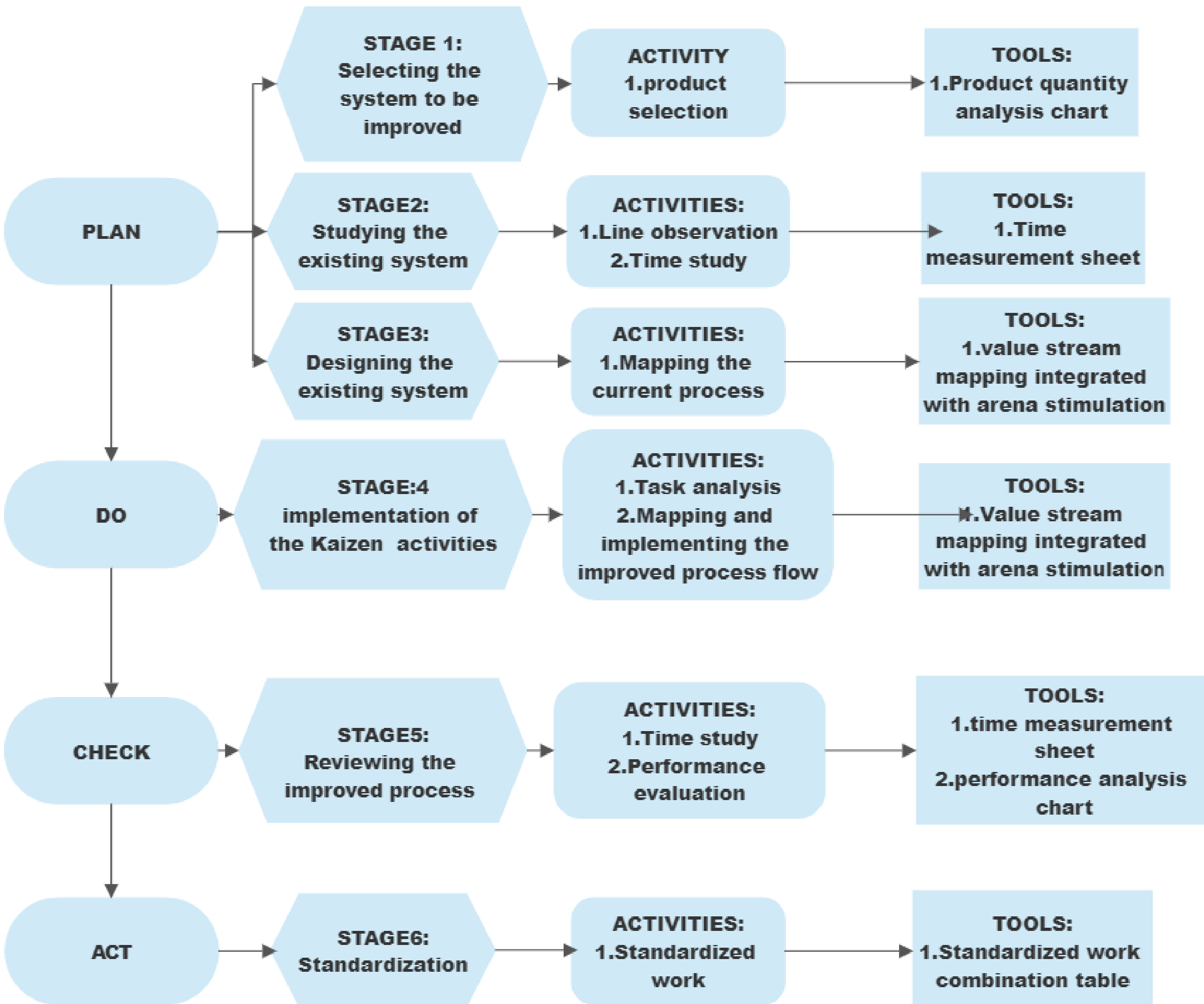

Fig. 1. Workflow Chart.

machine operator faces huge fatigue. It is better to equalize the time taken by both operators.
The work elements – Removing the coil from both starting and running coil must be done by the manual worker.
Average Manual Insertion Time = 170 sec.
Average Machine Insertion Time (with allowance for worker fatigue) = 170 sec.
This uniforms the work with a constant production rate of the inserted pump subassembly. The clips are transferred to the starting and running coil winding machine operators. Sometimes the winding operators had to wait for the clips. It is better to increase the number of clips used and could be used in circulation rather wait without operating.
Transfer time from coil insertion machine table to winding machine operator = 60 sec.
Coil Forming and Electrical Connections:
Average time taken for coil forming = 86 sec.
Average time taken for electrical connections = 67 sec.
Waiting time of the operator working on coil forming (170-86) = 84 sec.
Waiting time of the operator working on electrical connec- tions= 86 sec.
Thus, two workstations have to be allotted for both manual insertion and Machine insertion. There exist two coil insertion machines where only one works and another one is not used.
Time taken for coil insertion process with 1 workstation each = 170 sec.
Time taken for coil insertion process with 2 workstations each = 85 sec.
Hence, there is no waiting time and the production rate is improving drastically.
Coil Winding Baking: Advanced baking machine has to be purchased for fast baking and quick cooling.
Time taken for baking and cooling for the batch of 30 = 5900 sec.
Time taken for a single subassembly = 197 sec.

This is highly time-consuming and increases the waiting time for further processing.
Machining Section
Drill bit wear in Rotor Shaft Drilling: The drill bit has to be changed due to its wear. The drill bit broke due to improper handling of the same at high speed.
Time taken to change the drill bit = 70 sec.
This is unnecessary non-value adding time. The drill bit which broke inside the part would lead to component rejection.
The bottleneck in keyway milling: The key way milling process is carried out after rotor shaft drilling.
Time taken for key way milling process = 140 sec. Time taken for Rotor shaft drilling = 33 sec.
There exists a bottleneck before the milling process. Thus, introducing another milling workstation would reduce this bottleneck and waiting time. The improved state of the pro- duction system is found using Future value stream mapping through Arena simulated model. The improvements made in the production system of the selected pump series are implemented.
The suggestions for the production rate improvement are practically demonstrated with skilled workers. Line observa- tion was done to check the proposed methods and their respec- tive cycle time. The framework of Implementation is depicted in the form of the flow chart below, where the production rate along with restrictions are observed and rectified.
The observations made during implementation are dis- cussed, along with the restrictions faced by the system. Suggestions are made to retain the improved production rate by improving the system. In all three sections, the work elements and the processing time with allowance are much sufficient to finish the work by the skilled worker. The expected production rate could be attained by regular, continuous production. The bottlenecks, Uniform distribution of work (standardizing), un- wanted waiting and

transfer time are considered and improved. In case of any unplanned time delay, the production rate could get reduced. There are certain restrictions that occur seasonally in the industry other than the usual standard work format. These are mentioned below:

Late announcement to the workers by the management regarding the change in the daily plan of production. The initial setting and arrangements made differ from series to series. Thus, late announcements lead to unwanted setting and arranging time which adds an extra 1 hour to the regular production time.

i. Mahendra pumps do not practice pull system. The entire chain of the system starts with the planning and purchase department – machining – winding – Assembly – Testing. The system lacks proper time scheduling, which comes from top to low order, i.e., testing to planning and purchase department. This planning is much required to maintain the production rate.

ii. Workers are not assigned with a fixed work. Each and every worker must be assigned and fixed to a single job. This gives the workers experience in the specific work, which could improve their skill rate (highly skilled).

iii. Delay in machining and transporting vendor com- ponents from unit 5 of Mahendra pumps. This disturbs the assembly line and reduces the production rate. Proper Gantt chart and work allocation should be inculcated in unit 5 machining section.

iv. Frequent stoppage in all the sections due to raw material delay such as casing from machining, capacitors, winding coils. Stocks must be maintained to produce at a constant rate.

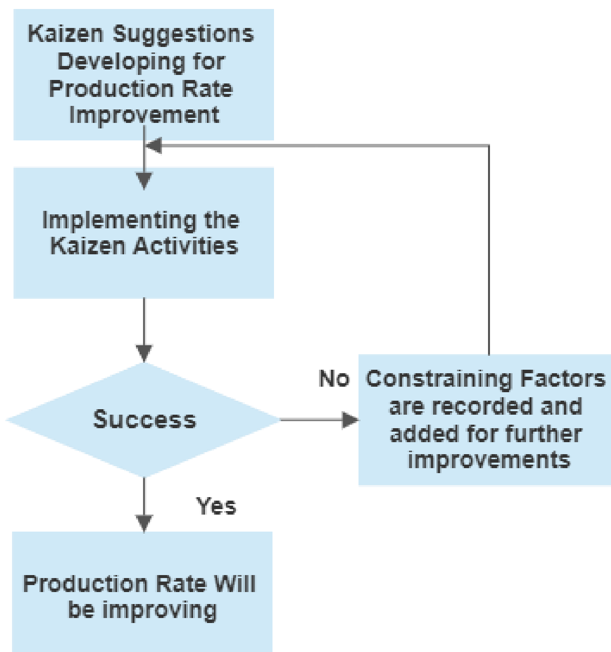

Fig.2. Framework for implementation

C. Check phase

The improved process of the selected pump series is re- viewed using performance analysis. The performance evaluation is done between the current and future state simulated model for all three sections. It is clearly depicted that by eliminating the waste in a production system will increase the production rate.

TABLE I
Performing analysis for winding section- Arena Simulated Model

PERFORMANCE ANALYSIS OF WINDING SECTION		
ELEMENTS	CURRENT STATE MODEL	FUTURE STATE MODEL
Value adding time (min/product)	9.17	9.18
Handling time (min/product)	9.58	4.28
Transfer time (min/product)	3.34	2.23
Total non-value adding time (min/product)	12.95	6.50
Total time (min/product)	22.12	19.03
Total available time per day (hours)	7.5	7.5
Simulated output (product/hour)	45	78
Actual output per day	270-300	270-300
Simulated output per day	337	585

TABLE II
Performing analysis for machining section- Arena Simulated Model II

PERFORMANCE ANALYSIS OF MACHINING SECTION		
ELEMENTS	CURRENT STATE MODEL	FUTURE STATE MODEL
Value adding time (min/product)	4.6	276
Handling time (min/product)	1.17	1.17
Wait time (min/product)	9.57	4.55
Transfer time (min/product)	0.14	0.14
Total non-value adding time (min/product)	12.27	5.99
Total time (min/product)	15.60	10.58
Total available time per day (hours)	7.5	7.5
Simulated output (product/hour)	47	80

Actual output per day	300-350	300-350
Simulated output per day	352	600

TABLE III

Performing analysis for assembly section- Arena Simulated Model

PERFORMANCE ANALYSIS OF ASSEMBLY SECTION		
ELEMENTS	CURRENT STATE MODEL	FUTURE STATE MODEL
Value adding time (min/product)	14.68	9.65
Handling time (min/product)	-	-
Wait time (min/product)	0.41	0.55
Total non-value adding time (min/product)	0.41	0.55
Total time (min/product)	15.09	6.68
Total available time per day (hours)	7.5	7.5
Simulated output (product /hour)	6-7	25
Actual output per day	50	50
Simulated output per day	50	50

By implementing the suggestion provided for the assembly section, the time taken for producing 50 CHV series pumps reduces from seven hours to two hours with the necessary allowance provided. It can be observed from all the three tables, the main performance indicators transfer time, wait time, handling time, value-adding time and simulated output were improved.

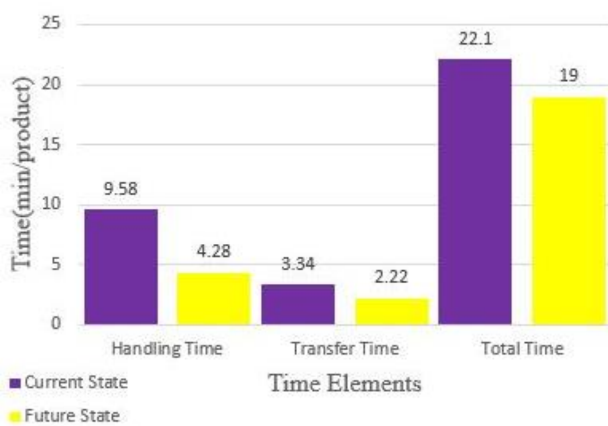

Fig.3. Performance Chart – Winding Section

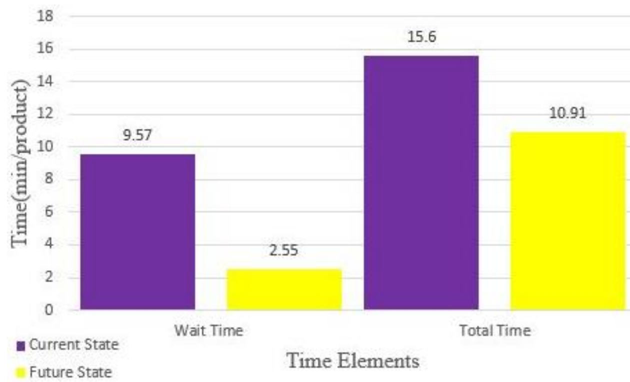

Fig.4. Performance Chart – Machining Section

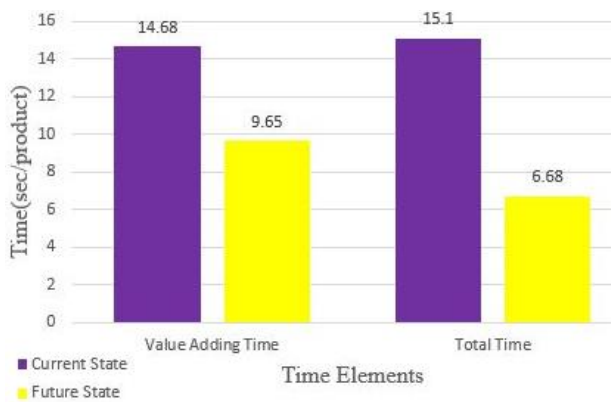

Fig.5. Performance Chart – Assembly Section

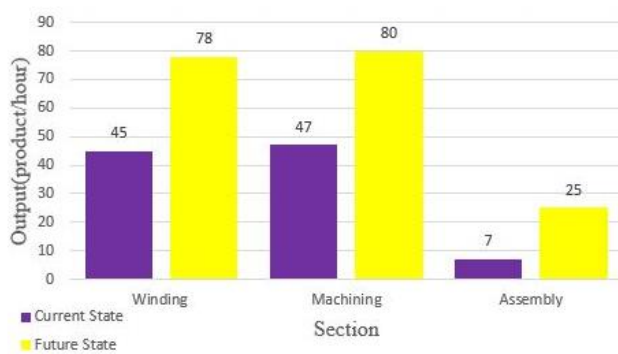

Fig.6. Simulated output chart for all section

D. Act phase

The improved conditions are standardized through documentation. In this act phase, the detailed workflow along with the improvements and results are documented with relevant data. The documentation was done using the standardized work combination table, one of the lean tools used to demonstrate the combination of manual work time, walk time, and machine processing time for each operation in a production sequence. Based on the standardized work combination sheet, the workers are taught the improved way of working by the management.

IV. CONCLUSION

To meet the demand, Demings' cycle is used to increase the production rate. Product quantity analysis made in TC50+ and CHV series pumps by using time study and arena simulation, the bottleneck stations and non-value adding activities were identified. The suggestion was checked with arena simulation before implementing. The production rate after implementing the lean tools is increased by: 73.33% in Winding Section, 70.21% in Machining Section, 316.66% in Assembly Section. While implementing the suggestions, certain constraints such as raw materials shortage, delay in vendor components and lack of proper time scheduling were faced. These constraints are taken care for further improvements in the industry.

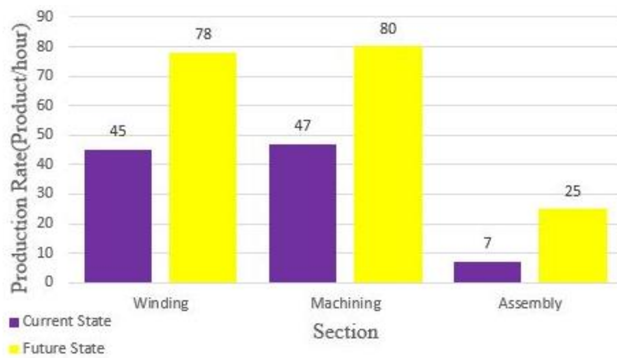

Fig.7. Production rate of current and future state for all the sections.

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