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Capacity Enhancement through Value Stream Mapping and Line Balancing Technique in Compressor Assembly Line

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Abstract: ***In competitive global market, manufacturers are urged to know the customer needs well in advance to serve the customer. Customer satisfaction and on time delivery of products play a vital role in establishing long and healthy relationship. When demand for a product is growing, manufacturer ought to plan their activity well in advance to ensure product availability to customer. Capacity planning is done considering dynamically varying demand of customers. Manufacturers are also continuously thriving to reduce cost by enhancing machine utilization. But, Capacity loss is unavoidable in any manufacturing facility. And also it is basic necessity that production capacity to be enhanced, with production cost in consideration. The study intends to increase the capacity of an assembly line and in parallel optimize the manpower (productivity improvement). It deals with identifying non value adding activities and handling them to enhance the capacity of an assembly plant to meet forecast demand. These improvements achieved by using the lean tool, "Value stream mapping (VSM)" which helps to segregate value addition and non-value addition activities for each machine or work station and also will help in continual improvement. Current and future state mapping of assembly line will showcase the lean waste involved in process, current issues, line imbalance, possibilities of further improvements, gap between takt and actual cycle time, inventory at each assembly points, WIP machines and lead time at each stations. These individual issues are sorted out by generating kaizens at each station, which involves brain storming and expert opinion, involving all members of team. These improvements will spread over the entire process flow chain as small pockets. These many numbers of small pockets of improvements is harvested by using another lean tool, "Line balancing". Line balancing will improve the overall line efficiency and hence capacity enhancement & man power optimization is achieved. The benefits of value stream mapping followed by line balancing technique had yielded capacity enhancement by 86%, manpower reduction by 28%, productivity improvement by from 1.24 to 1.70 units per person per day, through put time reduced from 325.6 to 259.5 mins, line efficiency improved from 79.7% to 97.9% and VA ratio improved from 33 to 37%.***

Keywords: ***Capacity enhancement, Line balancing, Value stream mapping***

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I. INTRODUCTION

Manufacturers are constantly working towards satisfying the customer need. They work vigorously to serve customer better than best. It is mandatory for any organization to move from customer satisfaction to customer delight for surveying in the market for long time. This customer delight can be achieved by innovation in the product, best in class quality and serving the customer well in advance before need. This project study deals with serving the customer well in advance by capacity enhancement of a production line. This will enhance the adherence percentage of service level (SLA) to the customer. Adhering to the SLA will build confidence of brand to the customer. And also in case if the SLA period is decreased, then it is possible to delight the customer as well. This work is assisted by the support of lean tools.

Lean tools are supporting the manufacturers by helping them in eliminating the waste. Hence it is useful in attaining maximum efficiency for a manufacturer in the manufacturing process. Manufacturers are using various lean tools to improve the efficiency of their business. Among these various lean tools, value stream mapping holds good enough in showcasing the current scenario and future roadmap of an organization. Value stream mapping tool will help manufacturer to analysis the current scenario and designs the future state of a product or line which is selected at various intervals of time period. During this transaction from current state to future state the VSM helps in adding value to a product or process by eliminating the lean wastes. In Toyota it is named as Material and information flow mapping. This tool is supporting the manufacturer in increasing the value added process time by eliminating non value added process time and decreasing the essential non value added process time. Application of this value stream mapping is not only restricted to manufacturing alone, it also in supply chain, service industries, healthcare, logistics and so on.

Success of value stream mapping depends on the involvement of people for identifying the waste in system, proposing proper solution, implementing of kaizen and sustenance of it. It is necessary to form a core team which should have to be led by a person who has prior experience in the VSM. Kaizen generation (waste identification) is a key role. Process kaizen will be identified based on elimination of unwanted transport in assembly line, reduction of excess inventory, elimination of unwanted motion, reduction of operator waiting for machine & resources, elimination of over production and over processing and reduction defects made in the process.

In addition to above kaizen generation mura, muri and Muda elimination is also a part of kaizen generation. Identified kaizens in each area are being bundled together as a many number of small projects and then it is being it is consolidated as kaizen burst. For implementing the identified kaizen it is being allocated to the team members to take a lead. It is the responsibility of VSM team leader for successful implementation of kaizens. Kaizen implementation is made effective by vigorous review and support in periodic basis.

After such improvements in the value stream mapping, the value addition will be held in as small pockets spread over in the entire process chain. By implementing value stream mapping it is possible to improve the value in process chain but real tangible benefits cannot be fetched as such. It will start to hide inside the process chain and reflects as loss while calculating line efficiency. For obtaining the tangible results the overall line efficiency needs to be improved. In order to harvest such pockets of improvements and improvising the overall line efficiency there is need for another lean tool. Line balancing is one of such lean tool which enhances the line efficiency by eliminating the imbalance in the line. Line balancing is a logical problem solving approach where it can be done by heuristic methodology, Linear programming methodology or dynamic programming methodology. Heuristic methodology is suitable for processes where the process split is possible (i.e., parallel assembly process). Heuristic methodology is followed by making the precedence chart for the entire process and simple or complex type of grouping of activity is performed. Linear programming methodology is much more suitable for process industries where there is continuous flow of process (series of activity) will happen without any parallel activities. Dynamic programming methodology is more suitable for process where there will be process addition in the process chain based on the customer need.

Line balancing technique is varying according to the number of variants of product flowing in the assembly line. Either it can be a single variant of product, multi variant or mixed model variant. According to such flow of variant of machines in an assembly line, line balancing can be further classified as single model assembly line balancing (SMALB), Multi model assembly line balancing (MuMALB) and Mixed model assembly line balancing (MMALB). SMALB is suitable for area where only one variant of product is being made. It is comparatively easier to balance the line in SMALB when compared to others. MuMALB is the one in which more than one product is produced. Between the products there will be more similarities and timing will be only small variations. In MMALB there will various models of products are produced in single assembly line. In such cases, there will be more variation between the products and other manufacturing parameter. It is the more complicated type in solving line balancing.

Line balancing of an assembly process will be assisted with a set of rule. Some of these rules will be of largest candidate rule (LCR), Kilbridge & Wester's method (KWM) and rank positional weight method. In addition to these rules many other rules can be customized and added in combination as well. Precedence will be give prime priority in grouping the activity in a line balancing technique. Then in case of LCR technique, the process which holds largest lead time is grouped first and then it will be followed by process which holds many numbers of processes. LCR technique is the most often used among others. In KWM method the process groupings will be allocated based on precedence stage in which it is being to be located. RPW method will provide importance to the core process of the organization. According to the organization, there will factor for each process. It is then multiplied with process timing to provide the overall weight age of the process. Such weights are stacked in descending order to obtain the rank positional weight for grouping of process. The result of value stream mapping combined with line balancing technique will provide an overall reduction of the production cost.

This study was conducted in assembly line of a compressor making company. In this study a successful attempt is made by applying value stream mapping tool for capacity enhancement of assembly lines. This assembly line is called small screw air compressor assembly line which is intended for medium and heavy industrial pneumatic requirements. Each assembly line handles about 50+ variants. Even though assembly variants have different configuration, assembly process and tools are almost same. Other assembly line parameters like total operating cycle time (TOCT), cycle time of assembly station, takt time etc.., are considered for highest runner model.

II. LITERATURE REVIEW

Lean manufacturing have made its foot print from large scale industry to medium scale industry to small scale industry. In an offset printing industry major delay in serving a customer is due to part shortage. A complete flow was analyzed to find the waste hidden in the system and used lean tools like pareto analysis, five-why analysis, source inspection, etc.., to eliminate the waste in process. This has resulted in the elimination of production loss due to shortages [1]. To serve the changing customer and technology feature of product, manufacturers need to develop their lean capabilities. Study conducted with 15 manufacturing countries in India, analyzed using analytic hierarchy process (AHP) and found the major enablers which supported lean production system [2]. Lean manufacturing involves waste elimination which will fetch continuous improvement and it is a never ending process. Lean implementation in discrete manufacturing industry involves more challenges. Study have used value stream mapping, 5S, kaizen, Kanban, visual control and process poka-yoka to improve the lean achievement potential score. This score is represented using a radar diagram [3]. Edward Deming's PDCA (Plan – Do – Check –Act) cycle concept used along with VSM concept in a helical rolling process industry [4]. VSM helps to identify and reduce losses, errors, non value addition time, lead time, etc.., for improving the value to customer product. Another key driving factor of an organization is overall equipment efficiency (OEE). There was a strong correlation between VSM and OEE. Hence study conducted for improving VSM which in turn improved OEE to greater extend [5].

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Implementing lean practices is a challenging task in discrete industry due to several perceived barriers. But this was eliminated by study conducted through VSM and improved production lead time and inventory levels [6]. Lean manufacturing (LM) starts with the plotting of value stream maps. Simulation models were developed using the Queuing Event Simulation Tool to demonstrate the improvements. Result of the study is flexible enough to meet the increasing demand without any additional resources [7]. Lean production paradigm is a graphic technique developed to redesign production systems. Study was conducted in six industrial companies and concluded proper communication of end result of VSM (future state mapping) is necessary for obtaining maximum efficiency from VSM team [8]. Industry 4.0 offers a new pathway for improvement by complete digitalization which will enhance the efficiency of production line. This digitalization will have information which was an analyzed to find the waste in system and for optimizing the process [9]. Cycle time reduction is a key driver in a manufacturing sector for on time delivery of the product to customer. Process were sorted out into value added (VA) and non value added (NVA) activities. Lean tools were used to reduce the non value added activity time [10]. Lean-Kaizen is a continuous process of elimination of wastes. Current state map was plotted, takt time calculated and bottlenecks identified. Future state map guided to find the gap in system. "5-why" method employed for identifying root causes of gap and Kaizen events were proposed as solutions. Poka-yoke and brainstorming lean tools used to reduce inventory level, lead time and cycle time [11]. Industry 4.0 and lean manufacturing aim to enhance productivity and flexibility [12]. Just in time, Kaizen, automation, TPM and VSM lean methods were analyzed to find the higher impact for an improvement and found TMP and JIT have highest significance [13]. Constraint programming (CP) is applied for the simple assembly line balancing problem (SALBP). This have improved the line efficiency and also supported to balance the line without any bottleneck [14]. Robust formulation is used to handle changes in the operation times. Several lower bounds, dominance rules and an enumeration procedure are proposed. Study concluded that protecting an assembly line against moderate levels of uncertainty is achieved at an expense of small quantities of additional stations [15]. In robotic assembly lines, task times depend on the robots assigned to each station. Robotic Assembly Line Balancing Problem (RALBP) consists of assigning a set of tasks and a robot type to each station with precedence constraints. The heuristic solution is an iterative set of instances. Study has developed methods and algorithms computational experiments to improve the assembly line efficiency [16]. Stronger correlation found between precedence constraints and the station limits for SMALB. Linear relaxation of integer program using impulse variables produces solutions of better quality. Study has improved the effectiveness on the U-shaped assembly line balancing problem with precedence constraints [17]. Line balancing and process sequencing are two important challenges in designing mixed-model assembly lines. Study have used mixed integer linear programming mathematical model for a moving conveyor assembly line. Objective is to minimize the length, number, investment of workstations and task duplications as well. Have made a hybrid genetic algorithm model and simulated annealing is also conducted [18]. Problem consists of assigning workers to work station. Study proposed a solution using computer experiment with real and simulated data [19]. Productivity is a key parameter for all manufacturing industries. Productivity enhanced by identifying and eliminating non value added activities. Using lean concepts like process flow chart, Gantt chart and process time study, value stream mapping was developed. Work place standardization supported lean transformation. It resulted in making process smoother, reduced lead time and increased productivity. Overall processing time reduced by about 24% [20].

III. PROBLEM SCENARIO

Currently the organization is undergoing a business transformation and is aiming to expand more into global frontiers. The vision of organization is to scale up to the second leading position by 2027 from its current 8th position. In this direction the organization is expanding into new global arenas and looking ahead for rapid expansion. It is seen that global market demand excellence in product and making available product just in to serve customer demand of multiple product. Due to such stepping into new unknown market, exact demand forecast is difficult and there will be more fluctuation in customer demand for product. In order to survive in such competitive global market, it is necessary to serve a quality product in a just in time. This is due to organization is dealing with multiple product variants manufactured in single assembly line and demand of the specific variant is varying. This demand of compressor manufacturing plant to be flexible enough to handle supply chain dynamics and be equipped accordingly. Currently compressor assembly line is capacity is about 21 machines per day. But due such dynamically changing environment, there is a daily demand of product will rise to 39 machines per day. i.e.., production capacity to be enhanced by 86%.

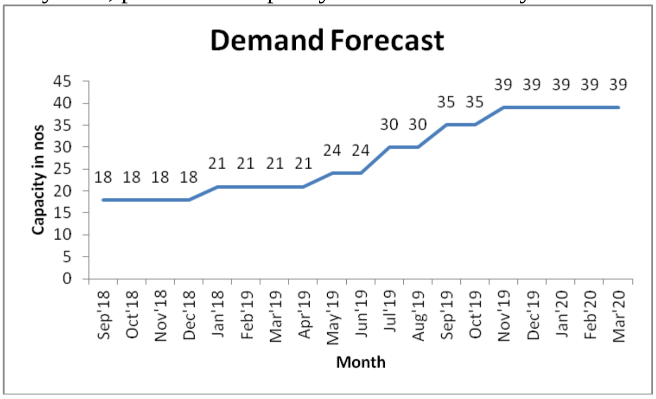

Fig. 1. Daily demand forecast

In addition to acquiring new market by the organization, it is also planned to set up manufacturing plant in the overseas market. In such cases the manufacturing plant located in India needs to be replicated there in overseas. Overseas plant will be likely to be located in the America and European continent. In such locations the selling price of machine can be doubled but cost of production approximately increases by 8 times when compared to India.

With the context it is required to increase the capacity by 86% of assembly line but equivalent manpower cannot be added as such. Hence it is mandatory to increase the capacity of an assembly line with minimal manpower increase as low as possible. For achieving this both improvising the value of process chain and efficiency of assembly line needs to be done simultaneously

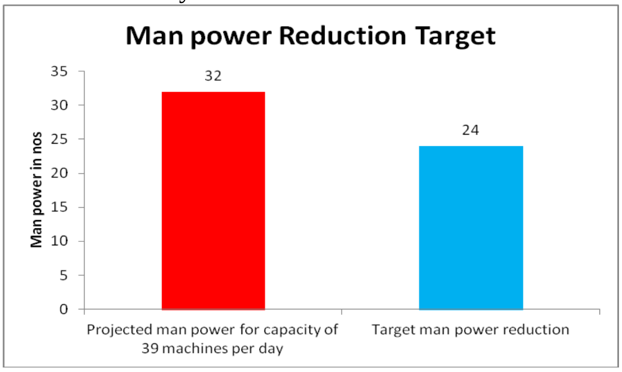

Fig. 2. **Manpower reduction target**

IV. OBJECTIVE

Based on problem scenario of the organization the objective of the project work is defined and business targets are set as below. The objectives are:

1. To increase the line capacity per day from 21 to 39 machines per day.
2. Projected man power requirement for above capacity will be 32 manpower. Target set as 25% reduction, which can be achieved by elimination of 8 man powers.

V. METHODOLOGY

Lean tools are adopted for improvising the assembly line capacity and efficiency. Below are lean tools,

A. Value stream mapping – Elimination of waste
B. Line balancing – Improving the line efficiency

A. Value stream mapping

Value Stream Mapping (VSM) is one of best lean manufacturing tool in which current state is mapped with future state that highlights hidden wastes inside chain of process / services. The gap between the current and future state is achieved by identifying and implementing the kaizens to eliminate waste hidden in the system. In addition to value stream mapping, line balancing tool when used will add much more value to the system. In general, VSM project will fetch big improvement in any particular process in a small pockets spread over entire zone. But real benefits can be obtained only if such pockets of improvements are harvested properly. In this context line balancing is another best lean tool for harvesting such small pockets of improvements. Hence in addition to value stream mapping, line balancing tool will help balance the cycle time in each assembly station, thus eliminating the lean waste to improve value of process / service and improving the assembly line efficiency as well. Successful implementation of Value Stream Mapping project lies with methodology which we are adopting to proceed. First stage of value stream mapping is selection of a product family or service. It is necessary that selected product family is providing prime financial support for organization or it will provide prime support in near future. And also it should have enough potential for next level improvement. After selection of product family, it is necessary to select proper cross functional team for execution of improvements as required by organization. It is necessary that lead of value stream mapping project should have prior experience with such project execution and should able to teach other members. After forming cross functional teams, there should be physical walk-through in the product flow. It will be carried out without any data collection and only process flow observation. After familiarization of process, a real walk through should happen to collect the data such as time taken for each process, value addition, no. of operators in work station, inventory, work in progress, down time, potential for improvement, etc.., After collection of necessary data by team, it will be followed by plotting of current state mapping in a standard value stream map format.

Then at each process steps wherever it is possible kaizens are introduced and implemented. This can be enhanced by noticing the voice of all team members. Then the kaizen at each process steps or stations are consolidated into kaizen blast. Then it is necessary to brainstorm among CFT to arrive solutions for kaizen identified and plan for action. It is the responsibility of team lead and top management to conduct the review periodically. Implementation of such kaizens will bring pockets of improvements which are spread over entire chain of process. It will be followed by line balancing technique to harvest such small pockets of improvements. This process will result in improvising the line efficiency. Hence after improvement it is necessary to monitor and standardize the actions which are implemented. This entire cycle will then be repeated over period of time for having continual improvements in the products or process

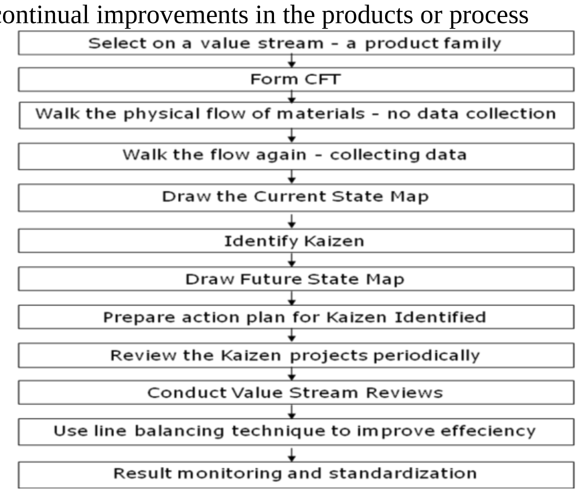

Figure: 3 VSM flow chart

B. Value stream mapping

Line balancing is a designing of an assembly line with smooth product flow where each operators completing the task well within defined takt time. This in turn will satisfy the customer demand as well. Line Balancing consists of task assigning to all station, with optimizing cycle time, takt time and line efficiency. It helps in achieving the equal level of work load in every work station. Assembly line balancing can be performed with below consideration,

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1. Based on project management
2. Based on assembly line variants
3. Based on objective function

For achieving high production volume and low production cost, it is necessary to over ride the traditional methodology and replace it with scientific approach. This can be accomplished by using heuristic method which is about drawing a precedence chart in a way that indicates all the process are included, flexibility of transferring the process laterally before or after to arrive a grouping of activity which will provide an optimum solution. Then it is necessary to fix the structure of it by knowing the number of variants of product made in the single line. In this case it is single model assembly line balancing technique. For the purpose of grouping of activity into set of bundles, it is necessary to allocate rules. These set of proposed rules will be acting as constrains in defining the activity groups. The rules can be of largest candidate rule, Kilbridge & Wester's method and rank positional weight method. In this largest candidate rule the process which is consuming more time will be allocated first rather than others. And also the next constrain which is defined will be of the process which have most followers will be allocated first. These two constrains will build the grouping of activities at best optimal level for the purpose of assembly line balancing technique. These mentioned three techniques of heuristic methodology of single model assembly line balancing using largest candidate rule is selected for the project study.

VI. METHODOLOGY

A. Line Balance chart

Line balance chart consists of cycle time content of each assembly station along with the target takt time. It is necessary to have cycle time lower than the takt requirement and cycle time of each assembly stations should possess very minor variation to have line balance. Bottleneck station will be created if cycle time of any assembly station exceeds takt time. In such scenario debottlenecking of an assembly station needs to be done to avoid line imbalance. Organization consists of a screw compressor assembly lines namely small screw air compressor assembly line. This assembly line is making screw compressor of direct driven type ranging of power capacity from 11KW to 45KW. It is meant for pneumatic requirement in medium and large scale industries. Assembly line is designed with single piece flow of assembled machine from one station to another. It starts with picking of raw material from supermarket stores, assembly, testing inspection and ends with packing stage. This assembly line consists of 9 main assembly station and 2 sub assembly station. Takt time for this assembly line is 24mins and daily demand is about 21 machines per day. This assembly consists of 17 operators and they are distributed as shown below.

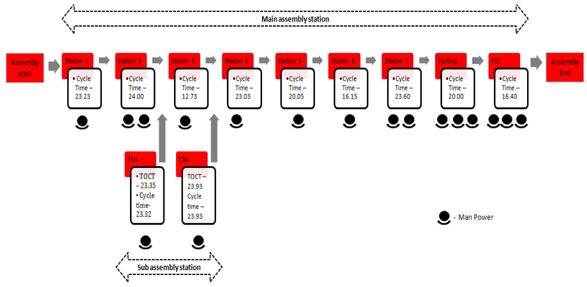

Figure: 4 Schematic view of assembly layout

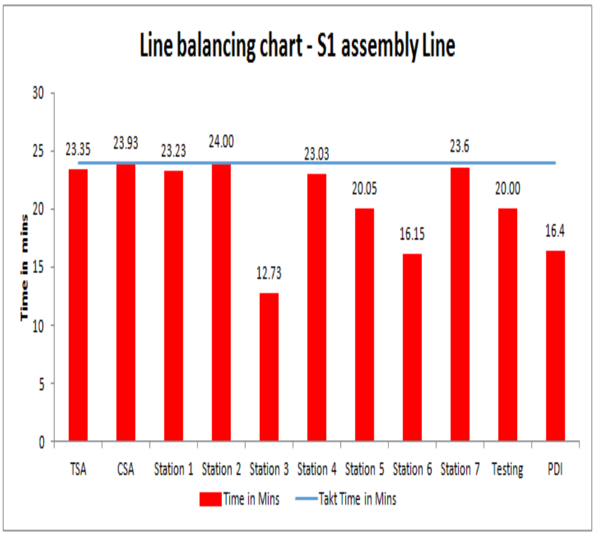

Figure: 5 Assembly line balance chart

B. Activity mapping of assembly station

Compressor assembly line have fasteners tightening process, weighted parts handling process, electrical wiring process, inspection process, operator bending activity, parts fitment process, sticker pasting process, jib crane usage process and cleaning activity. These activities are combined at each stage to convert raw material into finished goods. Fasteners tightening activity mainly consists of joining of two parts by fastening method; it may be of bolts, nut or fittings. It will be accomplished by using manual spanners, ratchet tools or pneumatic tool. Weighted parts handling process and operator bending activity is fully manual process where operator fatigue will be more. For electrical wiring and jib crane usage process usage it needs more operator skill. Whereas inspection process, cleaning activity and sticker pasting process are time consuming process. Hence in an assembly processes, operator needs to equipped with all above process.

Assembly line consists of assembly station as mentioned in below chart, in which different activity in each assembly station. Operator in each assembly station needs to be equipped well to perform all activity. And also there will time loss in the assembly process when they are switching from one type of activity to other.

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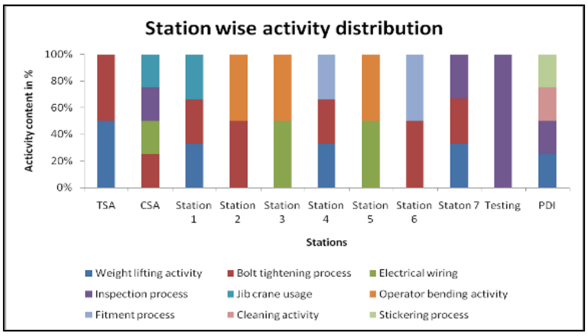

Figure: 6 Station wise activity distribution

C. Value stream mapping

Value stream mapping for a product family is the flow of information from customer to plan for arranging raw materials to plan & execute the production flow and finally physical flow of goods back to customer. It is a chain of link process starts with customer and ends with customer. There will information flow and material flow as well. It includes all the stake holders involved in the adding value to product. Value stream mapping chart will showcase the hidden waste in the system. From this it is easier to take action for elimination of waste in system. VSM chart will consists of various work activity in terms of symbols rather than a sentences. Value stream mapping chart plotted in the perspective of customer value rather than a manufacturer point of view.

Value stream mapping symbols

Value stream mapping is a flow chart incorporated with symbols to showcase the action and flow. Listed below are few Value stream mapping symbols. It is not mandatory to use only specified standard symbols but in turn any specific symbols can be used according to the respective relevant areas. Below symbols are most commonly used ones.

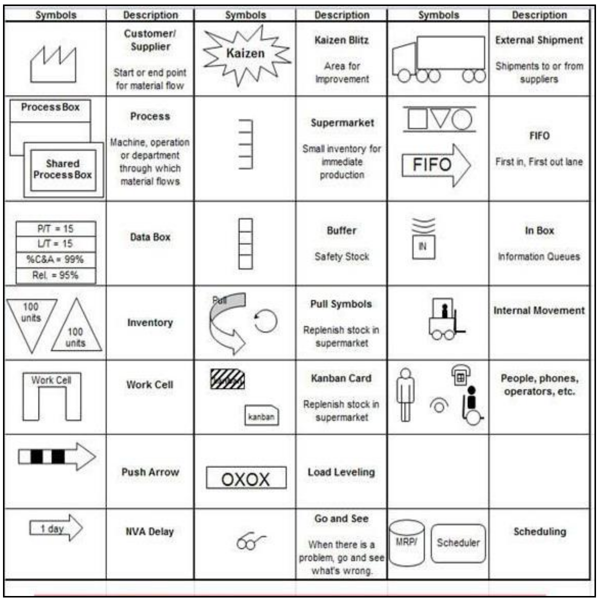

Figure: 7 VSM Symbols

Metrics for value stream mapping

Terminologies and metrics of a value stream mapping are listed below.

Table: 1 VSM Metrics

Terminologies	Description
Available time	It is net total planned available time per shift. It can be expressed as Available time = (Total work time per shift) – (Planned loss time per shift)
Cycle time	It is time taken for completing the task to be performed in the station
Takt Time	Takt time is the rythm rate of any manufacturing plant. Takt time = (Customer demand) / (Available time)
Total operating cycle time (TOCT)	It is the total time required to perform the operation to convert raw material into finished goods TOCT = Sum of all cycle time in each station
Line balance chart	It is a chart which explains about bottleneck in the system. It is a bar chart plot against the target takt line
Bottleneck station	It is a station where cycle time is exceeding the takt time. Bottleneck station decides the no. of outputs from the assembly line
Value addition ratio (VA %)	It is the ratio of value addition time to the total time taken in the station. VA % = ((Sum of value addition time) / (Total time)) * 100%

D. Current state value stream mapping

Current state value stream mapping provides information about the current product flow and the bottlenecks in the system. It is connect from the customer to planning team in terms of information flow and back to customer as product in terms of material flow.

E. Kaizen identification in current state value stream mapping

Continual improvement is the key principle for any organization to improve day by day for surviving in this competitive global world. It is the team activity in the value stream mapping project where entire team will be engaged in kaizen identification. The identified kaizens are plotted in the each assembly station as kaizen burst. The kaizens are generated from the areas or theme like elimination of non value added activity, outsourcing, semi automation of process, operator movement reduction, elimination of over processing and production, elimination of operator fatigue, inventory reduction, reduction of transport, elimination of operator waiting, reduction of reworks, inspection time reduction or elimination, improvising work station ergonomics, etc..,

F. Future state value stream mapping

Future state mapping is the flowchart map of future requirements of the organization. It projects the requirements of the future plan in a symbolic form. It is a state was assembly line is balanced condition without any bottleneck and fulfills the organization target requirements.

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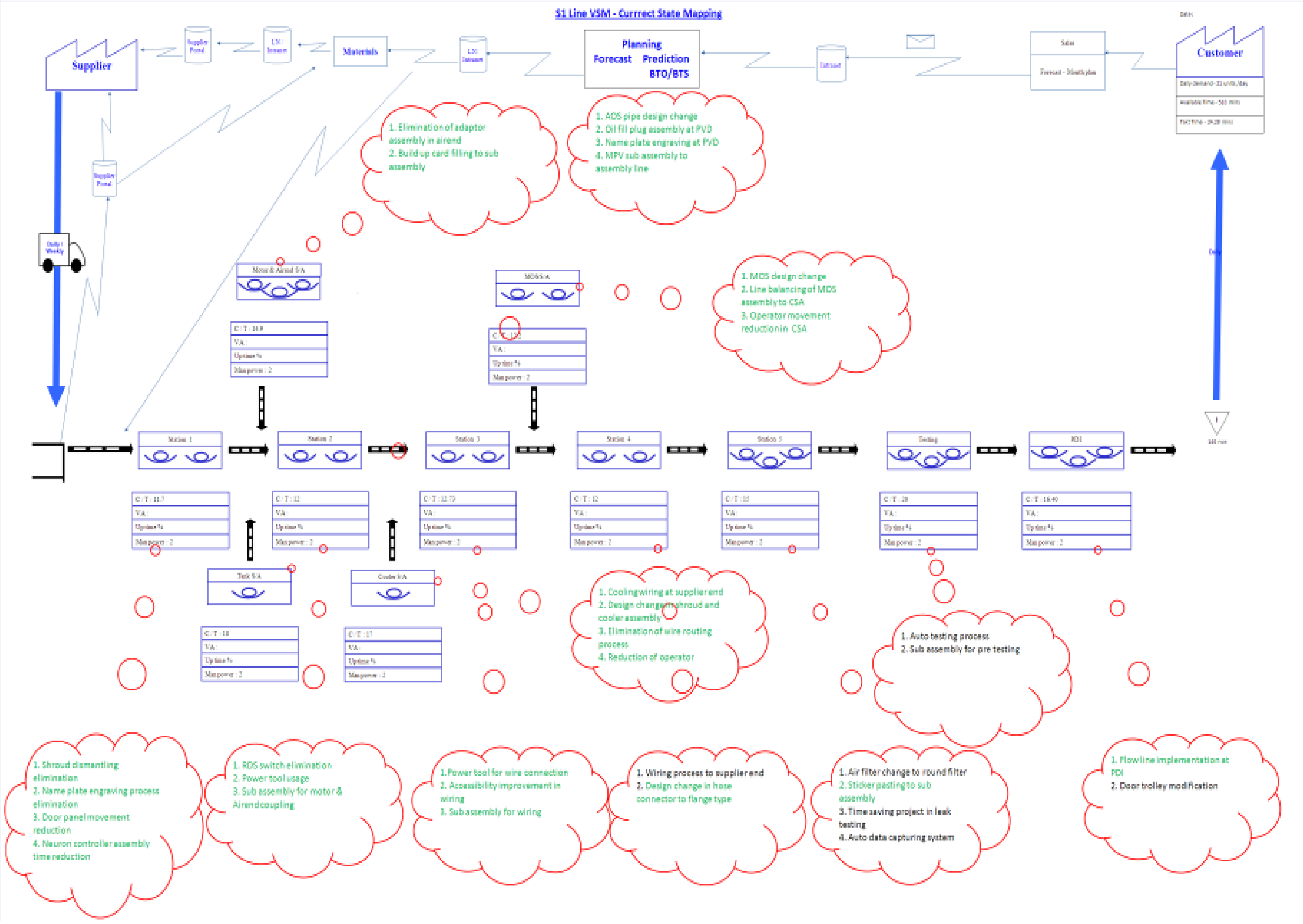
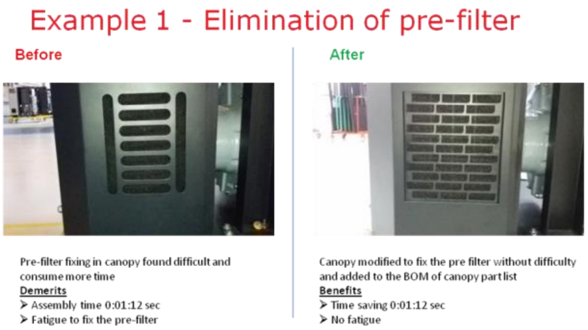


Figure: 8 Current stream mapping with kaizen blast

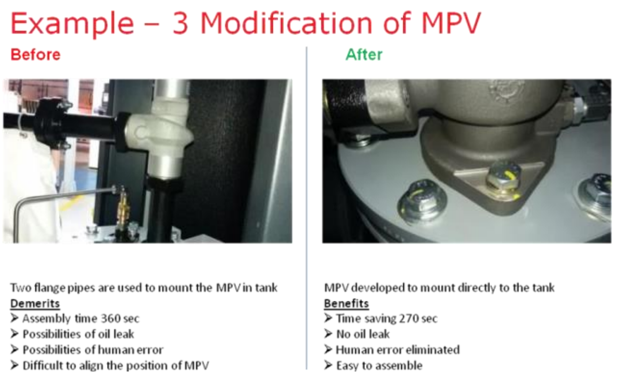
G. Kaizen Implementation

Example 1:

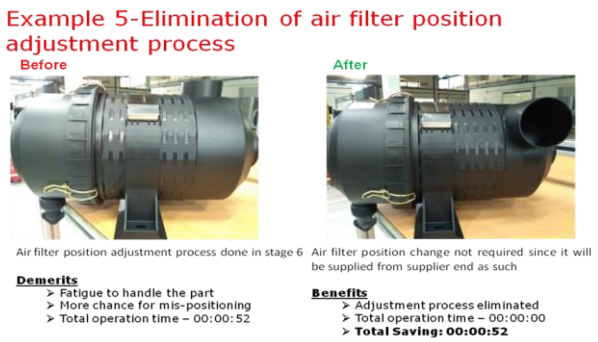


Example 2:

Example 3:



Example 4:



Example 5:

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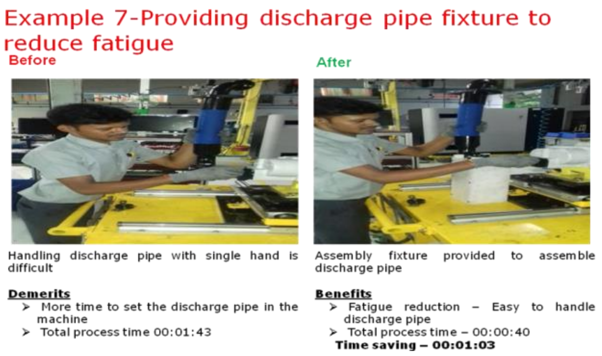

H. Task wise process timing after kaizen implementation

Total process for conversion of raw material to finished goods is taken into consideration for assembly line balancing. The boundary is selected which starts from picking of raw material for super market, assembly process, testing and inspection of assembled product.

Table: 2 Assembly line activity with precedence

S. No.	Assembly Description	Cycle time in Mins	Precedence
1	Material feeding	11.50	-
2	Sub assembly of tank	6.2	1
3	SBB Assembly	5.2	1
4	Motor wiring	6.7	1
5	Intake valve assembly	4.6	1
6	Motor air end sub assembly	22.7	4,5
7	Cooler sub assembly	5.9	1
8	Cooler shroud loading in canopy	5.0	6,7
9	MOS sub assembly	6.3	1
10	MPV Sub assembly	4.5	17
11	Canopy dismantling	6.5	1
12	AVM assembly	5.0	11
13	Control panel assembly	5.9	11
14	Controller assembly	3.4	11
15	Name plate fixing	2.2	11
16	Motor and airend loading	10.9	6,12
17	Tank loading	3.2	2,3,16
18	Discharge pipe coupling	3.8	16,17
19	Motor and airend fixing in canopy	4.4	18
20	Solenoid valve wiring	6.3	18
21	Main motor wiring	5.0	13,16
22	Pressure sensor assembly	8.2	11, 13
23	Gland assembly	3.2	13
24	Control panel wiring	6.7	14,23
25	Wire routing	4.7	24
26	Moisture separator assembly	5.3	9,27
27	Hose assembly	5.5	8
28	Air filter assembly	6.6	27
29	Bundy tube assembly	4.9	28
30	Roof sheet assembly	3.6	31
31	Leak testing	4.1	29
32	Pre PDI	3.8	31
33	Testing	45.0	31
34	PDI preparation	11.4	33
35	PDI inspection	11.5	34
36	Door assembly	11.3	35
	Total time in mins	259.5	

I. Precedence diagram

It is a heuristic approach of assembly line balancing methodology. Below chart indicates the precedence diagram of process with task time for each process.

Line balancing chart is constructed with two rules,

1. Precedence rule
2. Longest candidate rule

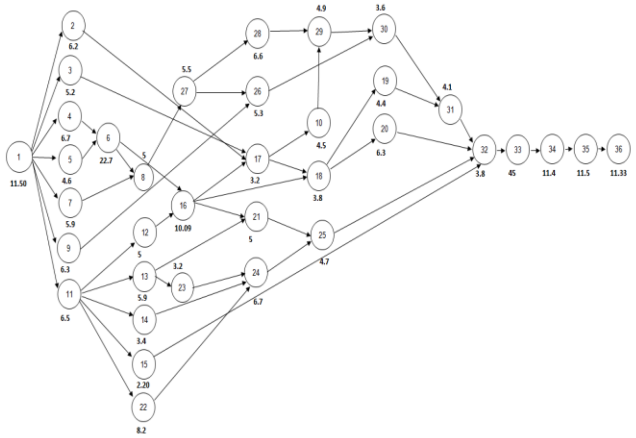

Figure: 9 Precedence chart with cycle time

J. Result and Discussion

Value stream mapping had resulted in the elimination of non value added activities in assembly process and line balancing technique had resulted in improvising the efficiency of assembly line. Combinations of both have resulted below benefits to the organization.

Line balance chart after balancing:

With takt time as 11.5 mins reference, cycle time of each assembly station is plotted to obtain line balance chart as shown in below chart.

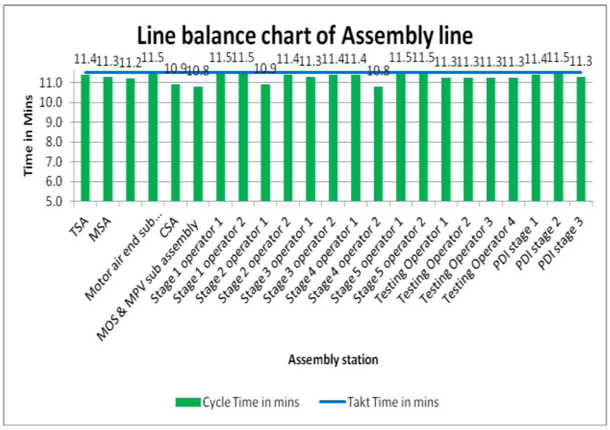

Figure: 10 Line balance chart of assembly line

Capacity enhancement:

Production capacity improved by 86%

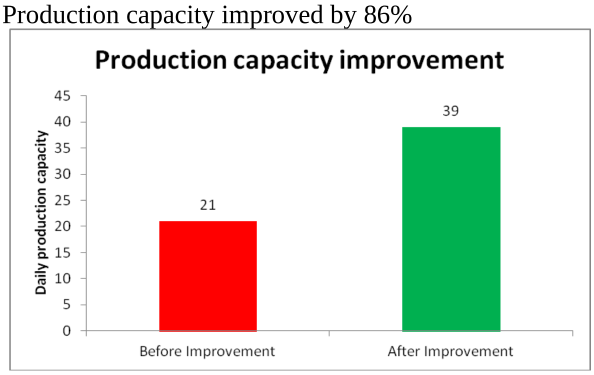

Figure: 11 Production capacity improvements

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Man power reduction:

Projected man power will be 32 for daily capacity of 39 machines. It had been reduced to 23 man power. Man power reduction of about 28%

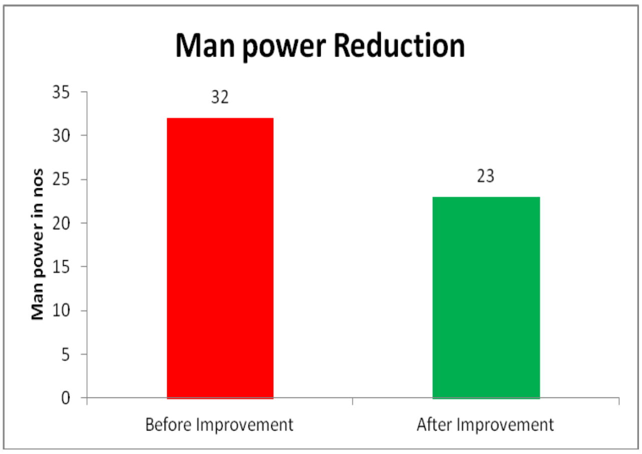

Figure: 12 Man power reductions

VA ratio improvement:

By eliminating waste in the process, VA ratio improved from 33% to 37%

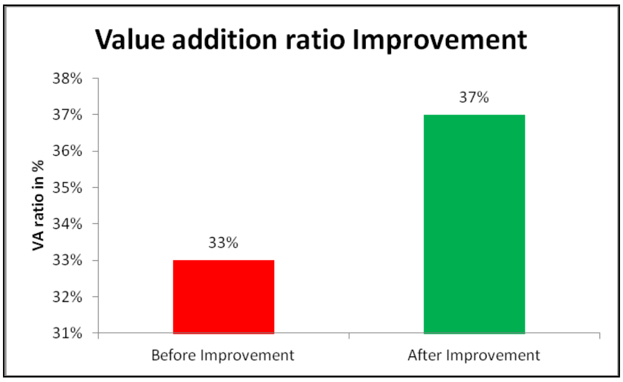

Figure: 13 Value addition ratio improvements

Line efficiency improvement:

Assembly line efficiency improved from 79.7% to 97.9% due to line balancing technique...

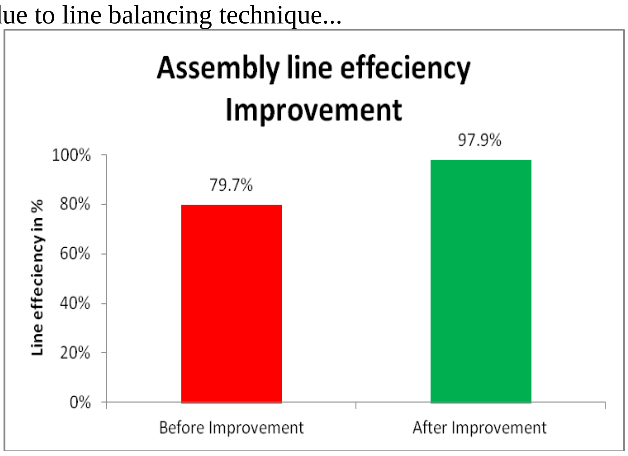

Figure: 14 Line efficiency improvements

Through put time reduction:

Through put time reduction from 325.6 mins to 259.6 mins by time saving kaizen implementation.

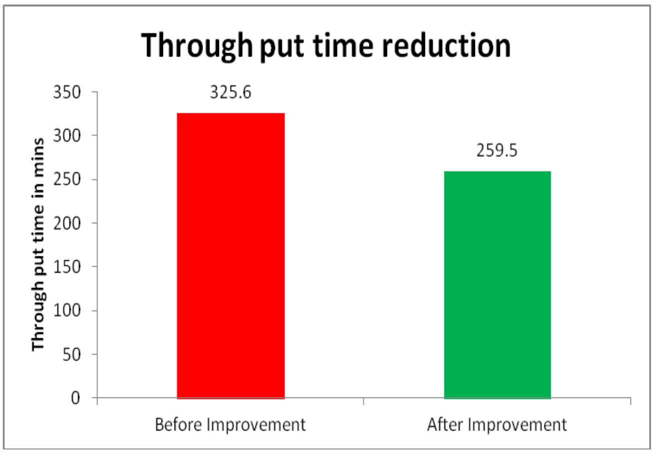

Figure: 15 Through put time reduction

Productivity improvement:

Productivity improved from 1.24 to 1.70 units per person per day.

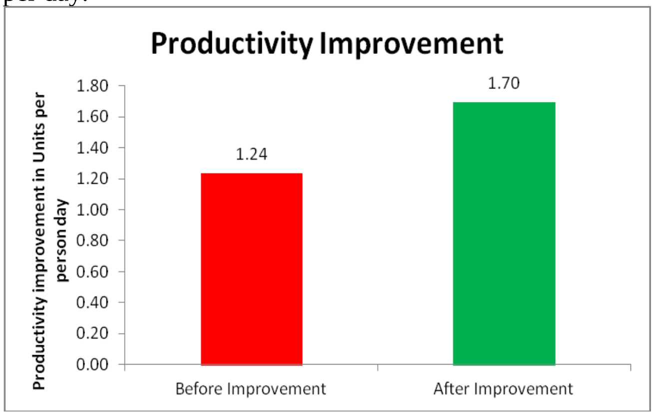

Figure: 16 Productivity improvements

Other Benefits:

Other intangible benefits includes inventory reduction, morale improvement by operators engagement in the project work, space utilization reduction, deskilling of operator and operator unwanted movement reduction

VII. CONCLUSION

This study used value stream mapping tool for integrating two assembly lines for capacity and flexibility improvement. The result of value stream mapping classified into 3 phases. The first phase is about integrating the assembly line using lean technique focusing on assembly line and resource saving. The second phase is about increasing the production capacity by reducing the cycle time using value stream mapping tool. VSM was used in identifying and eliminating the lean waste which was build inside the assembly process. Non value added activities identified by VSM are further addressed by developing various kaizens. Kaizens are developed by teams in shop floor. These brainstorming kaizens validated by cross functional team (CFT) and plotted as a kaizen blast. Action plan made to implement the identified kaizens.

Third phase is the line balancing technique which increases the efficiency of assembly line by eliminating process waiting hidden in the system. Overall results of the study had improved the flexibility of assembly line by making any product variant in integrated assembly line at same flow rate and also the capacity enhanced to 45 machines per day without any man power addition.

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