# Improving Flexibility by Implementing Multi Product Assembly Line in Screw Air Compressor Assembly Line

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## Abstract

The contemporaneous competitive global economy, it's a formidable requisite to meet the dynamic customer needs and demands which are often region specific. It is all about the ability to adapt rapidly to handle changing customer demands. Agile manufacturing helps in swiftly adjusting the existing manufacturing process to the dynamic customer needs both in terms of new features built into the product and technological change with a special focus on cost. Current study involves integrating two assembly lines that were manufacturing air compressors of different capacities into one single assembly line. The newly integrated line ought to be capable of handling product variants. Each variant has its own product features with possibilities for human error. Industry 4.0 – an enabler to develop an integrated quality embedded process will ensure the prevention of human error. In the aforementioned line integration process, lean tools such as Value stream mapping (VSM) an effective lean tool that helps to identify the value added and non-value-added activities; Eliminate – Combine - Rearrange - Simplify (ECRS) an approach that helps to optimize the process and Line balancing a production strategy to meet the optimal production rate were inculcated to eliminate the shortcomings. The study evaluated the current state and future state of the processes through VSM, thereby obtaining an insight about the ever-evolving market demand, TAKT time, cycle time and nine wastes involved in the processes that determined the scope for improvement. Introduction of a Supervisory Control and Data Acquisition (SCADA) application helped in manufacturing the multi-variants in a single line, acted as an advanced poke yoke system to reduce human error that also enlisted data to improve the processes. Kaizen implements were generated with a brainstorming session with members from Cross Functional Teams (CFT). After line integration and implementing kaizens and incorporating line balancing, it was observed that the line capacity enhanced by 9.25 %, with a cycle time reduction by 29.94%, besides improvement in the line- agility from 68 % to 100% and optimizing the need by two manpower.

## Keywords
Lean Manufacturing; Line Balancing; Industry 4.0; ECRS and Value Stream Mapping.

## 1. Introduction
Manufacturing organizations are trying to become the choice of all their customers by providing the products on time with better than the best quality and with optimum cost to ensure the long-term relationship with the customers. This project deals with capacity enhancement by integrating two different assembly lines to meet the fluctuating customer demands with flexibility in line design. Manufacturers are actively working to meet the needs of customers; they operate actively to represent their customers with better than the best quality and cost of their products (Fritzsche 2018). The lean tools would support to achieve this (Kumar et al, 2020). Lean tools aid manufacturers by allowing them to reduce waste (Laksono et al. 2019). Therefore, it is useful for a manufacturer to reach the optimum productivity of production. Industries adopt numerous aids like VSM, 5S, Poka -yoke, SMED etc. to enhance their company's performance and value (Boysen, 2008). Value stream mapping is a good tool to highlight an organization's current

scenario and potential roadmap among these various lean tools (Dinesh et al, 2019). The VSM can support the manufacturer in evaluating the present situation and planning the succeeding presence of a product. It helps to add value to a product or a process by removal of lean waste during this transition from present state to succeeding state. By removing non-value-added activity time and reducing the required non-value-added activity time, it helps the manufacturer to increase the value-added process time, it leads to the value addition to the product (Rother and John 2003). The use of VSM is besides being limited to output alone, it also helps in the supply chain, service, healthcare and logistics sectors etc.

This research was performed from one of the production cells of a compressor manufacturing sector. An effective attempt is made in this study by applying a value stream mapping tool to combine two production cells. Most of the process of both assembly lines products is same. But there is a difference in product configuration ranges. There are 450+ variants in total. And the Total Operating Cycle time (TOCT) and Takt time also different between two lines.

## 2. Literature review

Balancing Workload and Workforce Capacity in Lean Management: Application to Multi-Model Assembly Lines, emphasize on the concept that to develop a multi-model assembly line (Fortuny-Santos 2020). They also discover the underlying relationship between the cycle times of desired and actuals to that of the workload and capacity. Mixed assembly line balancing method in scenarios with different mix of products" states the preferences over a multi model line which helps to meet the ever-evolving customer demands without facing challenges in handling variants (Gustavo et al, 2016). Applying Value Stream Mapping in manufacturing states that VSM has shown tangible results in increasing the visibility of the value stream and the output of producers, regardless of the inadequate usage seen in some work (Romero and Arce, 2017). The lean practice is one of the best strategies used worldwide by manufacturers to improve their productivity. Lean practice is considered to result in the elimination of waste and the management of critical process related to production (Kumar et al, 2020). The benefactors of agile manufacturing in the field of automobile which provide insights on the management which is customer-centric (Fritzsche 2018). Value stream mapping (VSM) allows each process or work station to identify the kind of activity based on the work measurement researches which not only provides the improvement assistance in the process framed but also helps in the mapping of the as is state and the future state of the designated line by displaying the times of mura and muda that are involved as hurdles to improve the overall cycle time and to check on the overhead and inventory costs (Dinesh et al, 2019). The most common objectives in line balancing are the minimization of the number of workstations and maximisation of production performance (Saravanan et al, 2018). The technique minimises bottleneck operations and arrange the workload between work stations to maximise line efficiency and reduce the waiting time (Mengistu 2019). Discrete event simulation helps to identify the bottleneck, gives insight to improve the efficiency of the system without any physical changes in the system. It helps to minimize the experimental trials, reduce the lead time to execute the solutions by eliminating the iterations (Krishnan et al. 2018). Implementation of Industry 4.0 indulges in the integration or bridge wing the gap of digitalisation with the industrialisation that later is being improved as continuous progressive nature (Rother and John 2003). It also impulses on capturing data in the real time matrices (Dutta et al, 2020). The value stream mapping is developed by generation of future state by attenuation of current state with 5W1H pattern thus helps to improve the efficacy (Laksono et al. 2019). It is necessary to single out the problems while doing ALB (Assembly Line Balancing) since there is a huge capital investment in the process of achieving efficiency (Boysen, 2008). It is necessary to implement all necessary kaizen and manual improvement technique to achieve highest efficiency with regards to facilities (Gruber and Todd, 2002, Gustavo et al, 2016, Fortuny-Santos 2020, Romero and Arce, 2017). It is important to rank the priority at which the bottle neck is eliminated which is a proven lean principal technique that has enhanced the overall efficiency (Kumar et al, 2016). The quality with quantity is most effective prospects to meet customer's demand (Krishnan et al, 2018). The industry 4.0 must be processed using the 10-step principle or the USA principle in automation for which the assembly process must achieve its maximum efficiency through manual process thereon proceeds for automation. The lean implementation in any industry must fulfil the lean concepts of kaizen and the kaizen will help in reducing the concept of achieving maximum potential in assembly line by reducing the assembly wastes (Dadashnejad, 2019). Assembly lines are usually balanced based on the simple assembly line balancing problem (SALBP) but due to various restrictions therefore more generalized problem solving method is to be adopted for better efficiency (GALBP) (Becker and Scholl 2006). Kaizen must be always consolidated with multiple references in order to ensure the sustainability of work area (Wiljeana 2011).

## 3. Problem identification

In this study, the contemplation of multi-model mix line is quintessential for various reasons. The two different lines that are considered for multi-model mix line already accounts for models with varied assembly prospects, i.e., the is a facet in dimension, methods of assembly which in turn affects the cycle time and also the ergonomics of the operators (Becker and Scholl 2006). The major defiance that hurdles to opt on multi-model mix is the diverse models which ascend to twenty-two numbers. There is also a rudimentary issue faced with the current assembly lines which are accounted to be two in numbers. Line A, which accounts to 15 variants already is branched out to two different product groups as A, B, C, D and E which embraces 1,1,1, 6 and 6 variants respectively. On the other hand, the Assembly line B, which accounts for 7 variants on whole not only varies by its nature of assembly but also has a major unit foot print change thereby resulting to drastic changes in weight. The range of foot print varies up till 2.5 times and the weight more than 5 times. Adding up to this issue is the demand curve of the units assembled in these two existing assembly lines 1&2. In the case of Line A there is a soaring demand in the market for which the capacity of the line to serve the global demand for the variants is inadequate. Line B with a lesser number of variants struggles which an improper demand pattern there by reckons for excessive resources in terms of humans, facilities and layouts. This imbalance in the Line A and B attenuated to reduction in overall efficiency of the segment assembly considerably. In the perspective of an ever-evolving OEM company these losses will account for the hit in their dividends in terms of finance, but also the standards at which it operates. Figure 1 and Figure 2 illustrates the effective utilization of both the test lines that are to be subjected to the experiments. The trend graph clearly indicates the imbalance between the assembly line where Line A is over utilized and Line B is underutilized.

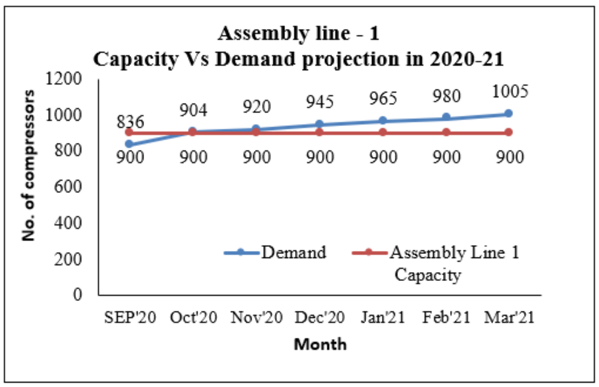


Figure 1. Line A – Capacity Vs Demand

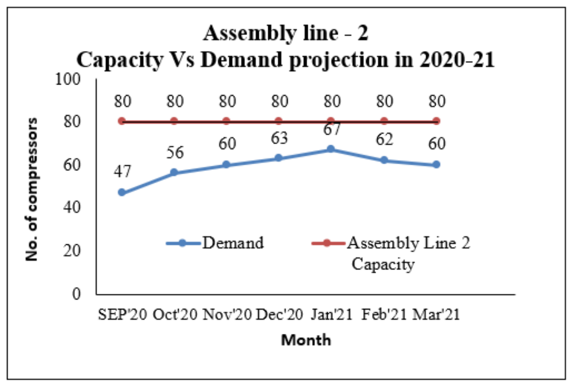


Figure 2. Line B– Capacity Vs Demand

## 4. Objective

Learning from the above trend graph we have decided the objective of the research is to implement the multi model mix line which comprises of 22 major variants. Amongst those variants they are further branched out into number of smaller variants based on customers' requirement and technical requirements. Apart from the primary motive, there are few other determinants which would contribute in its own way to achieve the prime motive of multi model mix line to its best possible efficiency.

- Ameliorating the capacity utilization by upgrading flexibility close to 100% between two observed lines.
- Revamping the capacity of assembly line from 980 machines per month to 1072 per month.
- Optimizing the man power requirement in order to dwindle the total production cost.
- To enforce the lean systems and acquaint Industry 4.0 as a part of assembly line process to invoke better flexibility and to improve the overall effectiveness of the syste.

## 5. Methodology

### 5.1. Line Balancing

Line-balancing strategy is mainly preferred in order to check the docility of the production lines to accept the external and internal differences. There prevail various types of line balancing. Static Balance means extended changes in the capacity for a certain interval of time. It occurs due to hypo-exploitation of work cells, equipment and operators (Krishnan et al, 2018). Dynamic Balance indicates to the intermediate or impulsive disparity in capacity on the basis of the time durations mostly (Dadashnejad, 2019). Dynamic invariance usually occurs due to the variants in the product or in the working time of the products independent of the variations (Fortuny-Santos 2020). Operator utilization or Operator availability is the lion's share attribute when it comes in strategizing the flexibility of the associated with the person's skill set and abilities.

### 5.2. Work Measurement

It is a combination of approaches which deals in enumerating the time average taken by an operator in order to comply certain systematic production tasks at a pre- accounted accomplishment. Study consists of set of recorded timings along with the capability or speed at which the task is carried out at accumulated conditions with desired level of performance (Fortuny-Santos 2020). The video study is an amalgamation of the motion study and time study (Mengistu 2019). On the flip side, the motion study could be defined as the stratagem to derive the best possible technique to handle the operation by the operator irrespective of the criticality of the process (Krishnan et al, 2018). The major advantage of the video is to annihilate the limitations of both the time and motion study which is the time study cannot yield its maximum efficiency when it is adapted to specialized works and in the case of motion study it is highly dependent on the person's perception (Gustavo et al, 2016). Lean strategies are acquired in order for extemporizing the production capacity and efficacy.

### 5.3. Value Stream Mapping

Value Stream Mapping (VSM) is pre-eminent tool which is used in the barrage of lean manufacturing strategies which help the individual in accentuating the wastes that are being hidden in the list of tasks by providing oneself with the as is condition and the to be or desired condition (Kumar et al, 2020). In general, the VSM is utilized to provide major groundbreaking advancements in the line in clusters (Kumar et al, 2018). These are usually ought to be spread over the region. But reaping benefits is possible only if these clusters are properly amassed (Saravanan et al, 2018). There by both these tool in tandem will improve balance in the TOCT of the production line and by doing so it ensures minimize the mura, muri to ameliorate value of the entire line by increasing its efficacy (Romero and Arce, 2017).

### 5.4. ECRS Approach

Eliminate Combine Re-arrange and Simplify (ECRS) approach is one amongst the prevailing approaches to improve the line efficiency thereby increasing the productivity of the line. The Methodology adapted towards the problem identified becomes the epitome of the result. The following methodologies were adapted to approach the problem systematically and resolve the short comings. Layout drafting of the as is condition becomes one amongst the quintessential process in providing us with a holistic picture of the line. The figure 1 flaunts on the existing line which is taken up for the study, thereby giving us a virtual walk through towards the problems or challenges.

### 5.5. TAKT time calculation

It is necessary calculate the TAKT time of the variants that are being enclosed in the band of scope which in turn forms as the data for further technical validations (Dadashnejad, 2019). The table 1 ensures the points of various models that are being released under macro level.

Table 1. Monthly demand requirement

| **Monthly demand requirement** | | |
|---|---|---|
| **Models** | **No. of units per month** | **F3 Equivalent** |
| Product A | 131 | **66** |
| Product B | 286 | **143** |
| Product C | 23 | **23** |
| Product D | 412 | **412** |
| Product E | 152 | **152** |
| Assembly Line 1 | **1005** | **796** |
| Assembly Line 2 (Product F) | **67** | **100** |
| **Total Monthly demand** | **1072** | **896** |

### 5.6. Line balancing against the TAKT

Line balancing is a technique acquired to bemuse balancing operator and machine time to match the production rate to the Takt time (Krishnan et al. 2018).

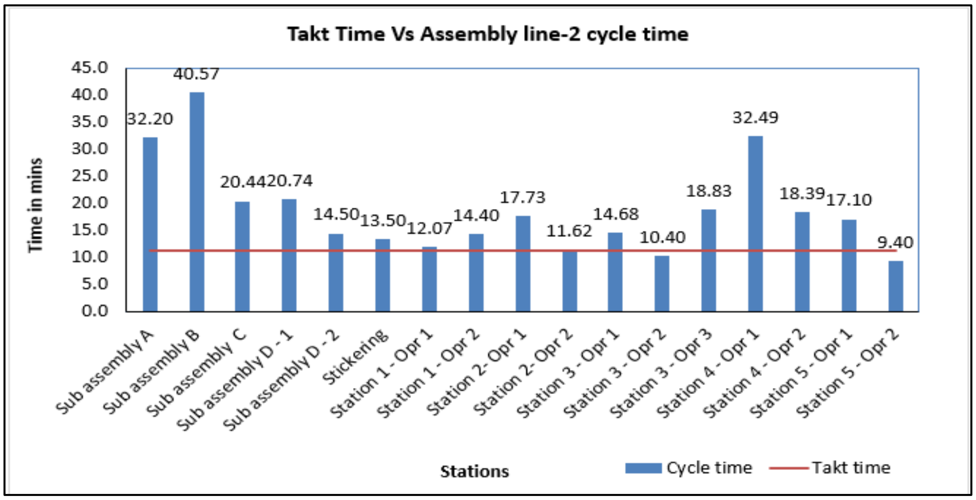


Figure 3. Line balancing bar graph- for integrated assembly line

The aforementioned graph is obtained with respect to the study on the line which is to be integrated (Figure 3). It is pretty evident that many stations show much more variations from the desired time. In order even drill down on where exactly to initiate the brainstorming the mathematical modeling and simulation software ARENA is used and required findings are being noted for improvement on priority basis (Figure 4) (Kumar et al, 2016).

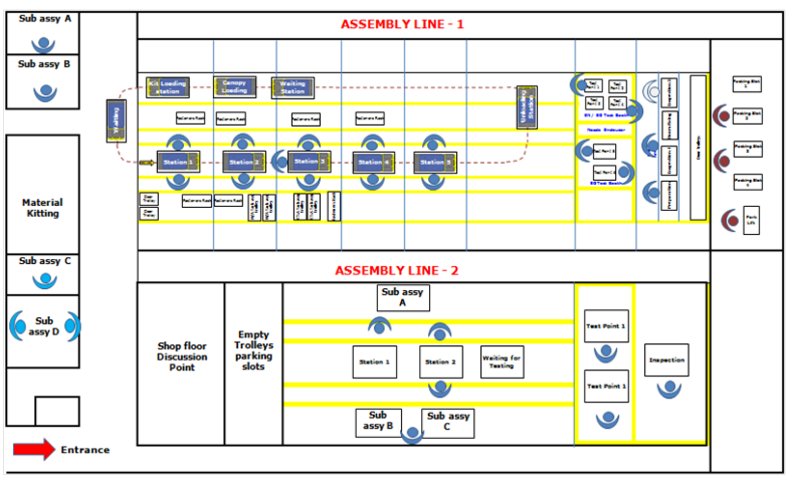


Figure 4. Current layout of Assembly line 1 and 2

### 5.7 ARENA simulation with respect to the line balancing

Based on the simulation of the current assembly line an ARENA simulation is generated and the following are found to be its end inferences (Figure 5 and Figure 6).

| Waiting Time | Average | Half Width |
|---|---|---|
| Batch 5.Queue | 0.00 | 0.00 |
| Canopy dis assy St.Queue | 173.65 | 6.54 |
| Cooler Sub assy St.Queue | 81.2112 | 1.36 |
| Hold till Motor release.Queue | 9.3848 | 4.43 |
| MA and Tank Match.Queue1 | 0.00 | 0.00 |
| MA and Tank Match.Queue2 | 20.5464 | 2.63 |
| Motor Airend assy.Queue | 67.5648 | 2.57 |
| Motor wiring Process.Queue | 0.7102 | 0.30 |
| Station 1 Process.Queue | 0.00 | 0.00 |
| Station 2 Process.Queue | 0.00 | 0.00 |
| Station 3 Process.Queue | 0.00 | 0.00 |
| Station 4 Process.Queue | 0.00 | 0.00 |
| Station 5 Process.Queue | 0.00 | 0.00 |
| Stn 1 MA Tank Match.Queue1 | 123.33 | 9.00 |
| Stn 1 MA Tank Match.Queue2 | 0.00 | 0.00 |
| Stn 2 and cooler batch.Queue | 0.00 | 0.00 |
| Stn 2 and cooler match.Queue1 | 135.47 | 10.54 |
| Stn 2 and cooler match.Queue2 | 0.00 | 0.00 |
| Stn1 MA Tank Batch.Queue | 0.00 | 0.00 |
| Tank Sub assy.Queue | 57.6656 | 1.68 |
| VFD Assembly.Queue | 0.8003 | 1.81 |

Figure 5. Queue or waiting time in stations

| Scheduled Utilization | Average | Half Width |
|---|---|---|
| Benis | 0.8948 | 0.01 |
| Dhilip | 0.1335 | 0.06 |
| Karthik | 0.7830 | 0.01 |
| Kumaravel | 0.6788 | 0.01 |
| Murugesan | 0.5351 | 0.01 |
| Prashanth | 0.7270 | 0.01 |
| Rajendran | 0.7315 | 0.01 |
| Senthil | 0.8948 | 0.01 |
| Venkatesh | 0.7830 | 0.01 |
| Vinodh | 0.7039 | 0.01 |
| Xavier | 0.7270 | 0.01 |

Figure 6. Operator utilization

## 5.8 Value Stream Mapping - Current State

After mapping out an overall data through the above-mentioned processes. A Gemba walk was handled and the current state of the assembly line was observed and mapped in VSM, non-value-added activities and scopes for improvements were identified. By the after sought of kaizen bursts, the disparity in time between the models reduced considerably (Wiljeana 2011).

## 5.9 Kaizen Identification and Categorization

Kaizens are being generated in each assembly station. These kaizens were being consolidated and executed through ECRS approach. Cooling system design modification as like Line-A models –E; Common sub assembly feeding trolley with sub assembly fixture –C; Layout modification to accommodate the Line B Models – R; Tools station modification for easy accessibility for the operator – S; Top plate O ring assembly simplification –S; Customized lifting bracket to simplify the cooler sub assembly loading – S; QR Code implementation for manual part entry elimination – E; Poka Yoke for critical process to eliminate human errors –S; Elimination of pre tightening process by providing torque-controlled battery-operated tools – S. Since multi products assembly in one assembly line will leads to human errors which will impact the customers (Figure 7, Figure 8, and Figure 9). To prevent this Multi skill development for the operators and Poka yoke are planned for CTQ (Critical To Quality) process with the base of Industry 4.0 concept by integrating the man, machine, material and information with a single platform (Dutta et al, 2020).

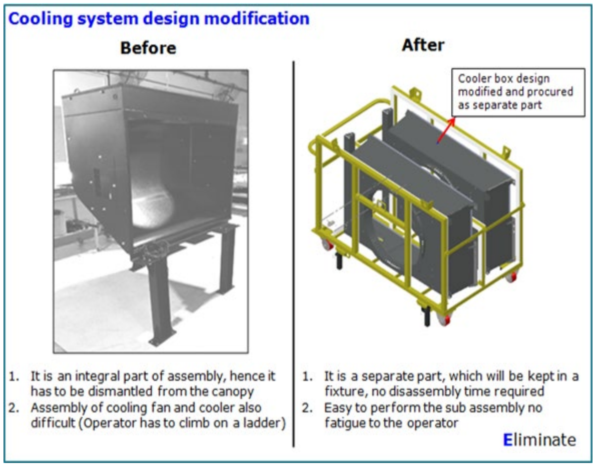


Figure 7. Cooling System modification-Product Design

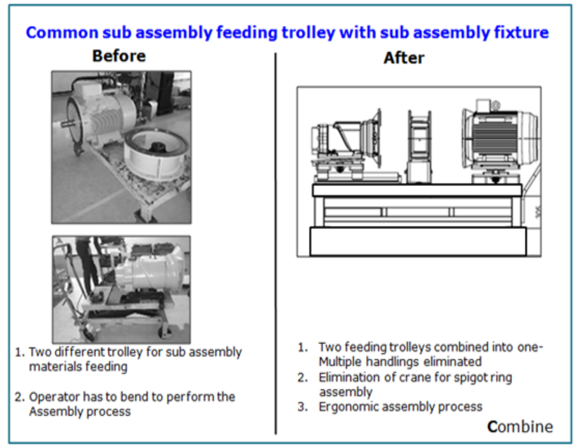


Figure 8. Sub Assembly Fixture Design Modification

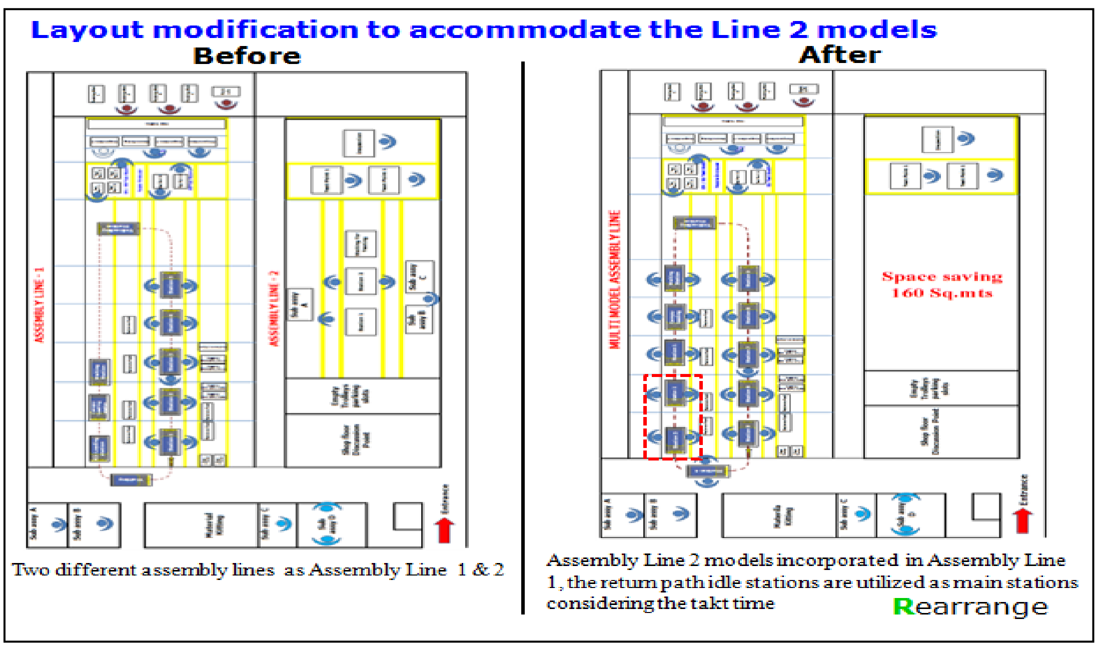


Figure 9. Assembly Layout Modification

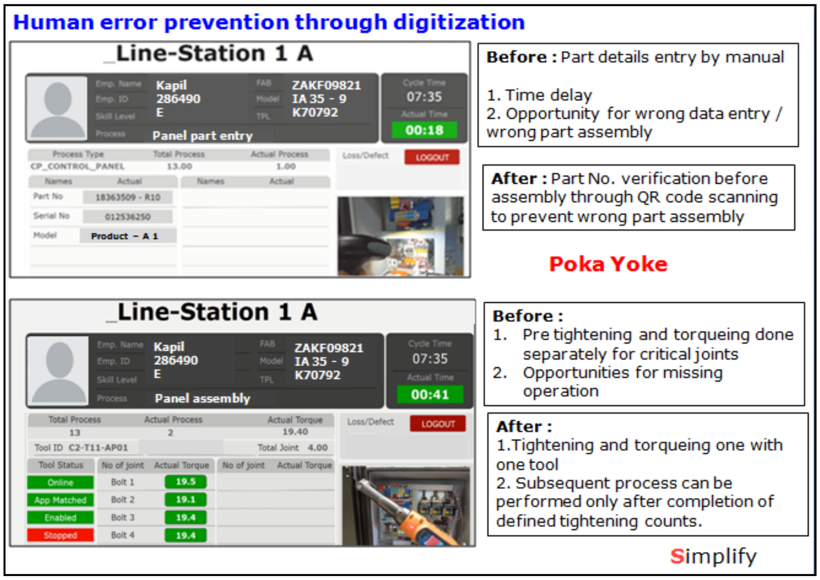


Figure 10. Human Error Prevention with the Aid of SCADA

Table 2. Human error prevention with the aid of SCADA

| Before | | After | |
|---|---|---|---|
| **Process** | **Failure mode** | **Modified Process** | **Benefits** |
| Critical part details writing in history card | Missing of writing<br>Wrong entry<br>Wrong part assembly | Critical part details capturing through QR code and comparing with part details from Bill Of Material | Elimination of wrong details capturing, wrong part assembly |
| Tightening of critical fastening joints using torque wrenches | Missing of tightening | Tightening of critical fastening joints using torque controlled tools with feedback and in-process controls with Poka Yoke | Elimination of less or excess tightening and no rework in subsequent processes |
| Acknowledgement to ensure the manual check points | Acknowledgement after completing all the processes | Digital acknowledgement after completion of each manual process with time stamp | Verification check points ensured at the time of process completion |
| Inspecting each of the assembly process at final inspection | Chances to send the finished product to end customer with defects | All the processes are ensured in sequential manner before leaving the station with inter locking in conveyor system | Zero opportunities on sending the defective product to the customer end |

The Figure 10 and Table 2 gives out the outright view from the in-house developed SCADA application exclusively for the industry.

## 6. Results and discussions

Current study which involved integration two assembly lines that were manufacturing air compressors of different capacities into one single assembly line which did achieve being capable of handling product variants. Through larger band of variants with unique product nature, infusing Industry 4.0, lean stratifications such as Value stream mapping (VSM), Eliminate – Combine - Rearrange - Simplify (ECRS) and Line balancing with kaizen bursts yielded substantially greater benefits. The capacity of the line ramped up from 49 per day to 54 per day accommodating 22 variants of products thereby achieving a multi model single line. Apart from balancing the line, the manpower, capital investment and space were marginally optimized, and improvement in 5S is also reaped as an additional benefit (Figure 11).

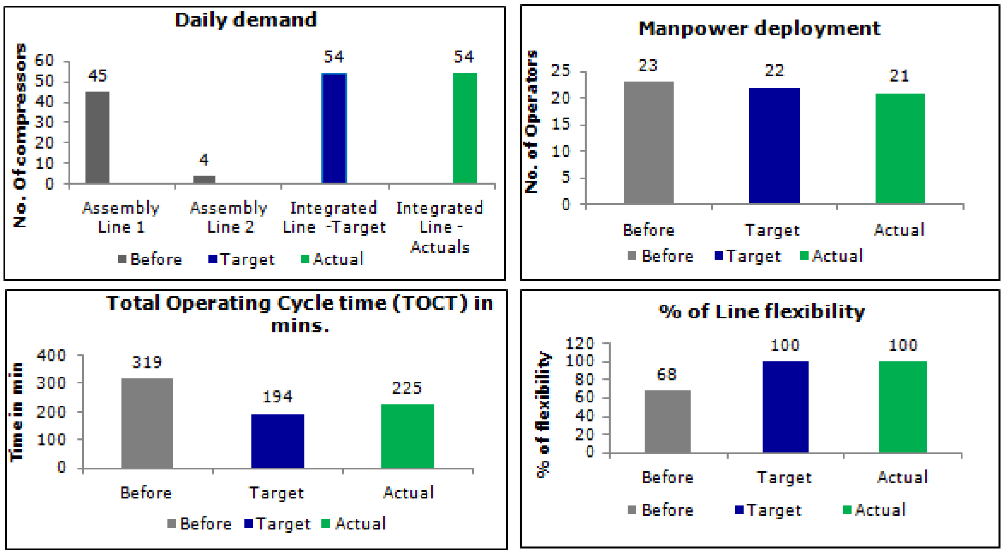


Figure 11. Results Comparison

## 7. Conclusion

The study was initiated with the prime objective of increasing the capacity, improving line agility and flexibility by integrating two assembly lines in to a single assembly line. By using the VSM tool, the current state and future state of the assembly line were adjudged. The current state mapping envisions potential to improve the capacity and flexibility of the line through kaizen bursts. These kaizens along with beneficial inputs from the implementation of SCADA application and ECRS approach, enthralls opportunities for cycle time reduction, capacity improvement and productivity improvement. Elicited from these improvements, the future state mapping was revamped by blending the strategy of Line Balancing, resulting in two additional stations.By the virtue of these additional stations in tandem with the required manpower, it is observed that there is an increase in the line capacity from 45 to 54 units (per shift) along with assembly time reduction by 29.94% including two manpower optimization and 160Sq.mts of space saving. Way forward, by extending the horizon of the captivation of SCADA in the multi-model assembly line, there is an immense prospect to evolve not only the flexibility of the line, but also paving way for accommodating futuristic proto-models with utmost ease of assembly with bare minimum human interventions. Thus, by implementing multi product assembly line through the medium of industry 4.0 and lean tools establishes itself to be a stronger predecessor for Industry 5.0 which would become inevitable in near future.

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