

# Two-sided assembly line balancing of refrigeration assembly lines

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## Abstract

The application of lean manufacturing on pre-assembly and final assembly activities lines is attempted. Value stream mapping and a two-sided assembly line balancing genetic algorithm are applied. A case study in a household appliance company was considered for reaching the best flow solutions in the refrigerators assembly line.

## Keywords

Assembly line balancing, Value stream mapping, Lean applications

## Introduction

Accomplishing excellence, global competition, and catching up with the rapid technological changes and advance in manufacturing and information technology, are forcing manufacturers to optimize all possible manufacturing processes and operations for the purpose of delivering high quality products in a short period of time. The results of compressing time are greater productivity, shorter delivery times and lower costs.

The pursuit of this optimization has intensified the demand for higher product development speed, manufacturing flexibility, waste elimination, better process control, efficient manpower utilization to gain competitive advantages (Karim et al.2010).

Lean is an integrated system of principles, practices, tools and techniques that are focused on reducing waste, synchronizing workflows, and managing production flows (de koning and de Mast 2006). The implementation of lean, as adopted by the authors, is not only a method of reducing or eliminating waste but also a framework for enhancing efficiency and thus maximizing improvements (Hasle et al. 2012).

Currently assembly lines are fundamental to smooth the production system. An assembly line is generally used for mass production. Assembly line balancing may be defined as the process of assigning tasks to the work stations in such a manner that all workstations have approximately equal amount of work assigned to them (Avikal et al. 2012). Assembly lines are studied under several operational perspectives seeking its flexibility (Calvo 2007).

This paper focuses on the analysis and use of lean manufacturing in the context of its application on pre-assembly activities and in the final assembly line. This objective is fulfilled through the presentation of a case study in a refrigeration company.

## **Literature Review**

Lean principles come from the Japanese manufacturing industry. The term was first coined by Krafcik in a Fall 1988 article, "Triumph of the Lean Production System," published in the Sloan Management Review. Krafcik's research was continued by the International Motor Vehicle Program at MIT, which produced the international best-seller book co-authored by Womack et al. called *The Machine That Changed the World* (1990). Hank and Nicholas (2002) state the fact that Lean manufacturing has evolved from the Toyota production system. Lean manufacturing is a way of thinking; a culture where all employees continuously look for ways to improve the process with the philosophy of eliminating all non-value added activities. Shah and Ward (2007) reviewed the literature on lean definitions and concluded their review with a simple definition that summarizes some of the most important characteristics of work systems that can be described as lean. They define lean as: "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability" Stone (2012) recalled that Womack and Jones defined waste "as any human activity which absorbs resources but creates no value". Value defined as "a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer. However, as Hopp and Spearman (2004) pointed out in the lean literature, treating lean primarily as the reduction or elimination of waste is but one side of the coin. The other side is that lean is also a framework for enhancing efficiency and thus maximizing improvements. This side of lean leads Hopp and Spearman to argue that lean in positive terms is better defined as "best buffer production" rather than "low waste" or even "low buffer production". This is important because there may be many sources to buffering and variability, not necessarily characterized as "waste". Assembly lines are fundamental to get smoothing of production systems (Alvarez et al.2009). The assembly line balancing problem is used to optimally balance the assembly work among the stations with respect to preset objectives. The two-sided assembly line is a line where tasks on the same product item can be performed in parallel at both sides of the line (Kim et al.2009).Bartholdi (1993) was the first to address the two-sided assembly line balancing problem (TALBP) with the objective of minimizing the number of stations by applying a simple assignment tool. Kim et al. (2009) proved that TALBP provides shorter line length, reduced throughput time, lower cost of tools and fixtures, and less material handling which is analogous with the objectives of the application of lean manufacturing. Lluís (2011) recalled the fact that in manufacturing plants, the assembly areas usually maintain a store of components to be assembled in the finished products. The products are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time. These assembly areas are associated with considerable investment costs. Therefore the configuration of an assembly line is of critical importance for implementing a cost efficient production system (Taha 2011).Methodologies to optimize design, balancing and scheduling of production systems have been widely explored by means of both analytical and heuristic procedures.

Another easily applied industrial tool that is used in the lean approach is the value stream mapping (VSM). Hines and Rich (1997) applied the seven VSM tools for waste elimination in TPS. Domingo et al. (2007) used VSM as a visualization tool used to identify where waste occurs and eliminate it by developing a handling system. Lasa et al. (2008) proved that VSM is an original and practical method to design and create efficient and flexible productive environments. VSM can support dynamic modeling for the changing process and resources. VSM can also enable leanness in an organization (Xie and Peng 2012).

This paper is focused on the implementation of the value stream mapping tool as an improvement technique and the analysis of a two-sided assembly line in a refrigerators factory which is one of the largest public sector manufacturing companies in Egypt. The company is eager to provide the utmost degree of care and attention to its customers as to become the most prevalent and credible brand in the market. The company is one of the leading adopters of the different quality improvement techniques and is looking forward to enhance its performance through the application of Lean concepts in conjunction with assembly line balancing to fulfill its goals.

From the above, the aim of this paper is to raise the production volume to satisfy the customer demand. This is achieved through implementing some lean tools such as Value Stream Mapping to reduce the level of non-value added activities. Assembly line balancing is also used for the aim of decreasing the cycle time and increasing flow. Using value stream concepts, both current and future states maps of the factory's pre-assembly activities scenarios have been discussed to identify sources of waste between the existing state and the proposed state of the selected organization for improving its competitiveness.

In order to accomplish these objectives, this paper is organized as follows: the first section describes the industrial case study used to illustrate the improvement approach, while the following section depicts a precise description of the research approach. The final section presents the computational results and puts a conclusion on the findings of the research.

### **Industrial Case study**

The research is based on a case study applied in a household appliances company. The company will be referred to by (I) for confidentiality. Company (I) is a member of a group of industrial facilities; which is one of the largest public sector manufacturing companies in Egypt. Company (I) enhanced a leadership position in white goods. The company is eager to provide the utmost degree of care and attention to its customers as to become the most prevalent and credible brand in the market. The company is one of the leading adopters of the different quality improvement techniques and is looking forward to enhance its performance through the application of Lean concepts in conjunction with assembly line balancing to fulfill its goals. However, there are several problem areas in the pre-assembly activities and in the final assembly line itself:

1. There are different types of WIP inside the factory. The most critical, is the one between thermoforming line and pre-assembly line.
2. Long distanced travelled in the production area due to the presence of stored material on the shop-floor.
3. Excessive stations and workers on the final assembly line.

These problems contribute to less productivity and unutilized areas which lead to poor synchronization between workplaces.

### Research Approach

For the purpose of planning enhancement, a framework for an efficient analysis procedure was designed as follows: Data is gathered about the production lines. Make and/or buy parts are determined. Outline process charts, Material flow charts and process flow diagram were developed; wastes in the pre-assembly processes were detected and tabulated. Material flow through manufacturing operations and the shop-floor configuration are shown in figures 1 and 2.

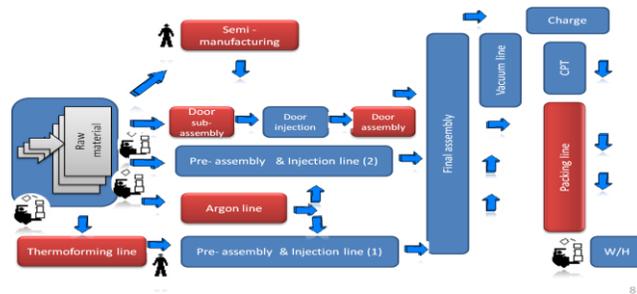


Figure 1- Material Flow

The assembly line under study includes 92 elements in 73 stations. Station 7 was considered the reason of the existence of bottleneck as it has the largest work time 35 sec. A precedence analysis of the line is conducted while a sample of the data collected for stations time and idle time are shown in Table 1. The table shows each station activities and whether it is value adding or non value adding activity, number of workers in every station and the measured cycle time. Station 7 appears to be a bottleneck workstation with maximum load and no idle time.

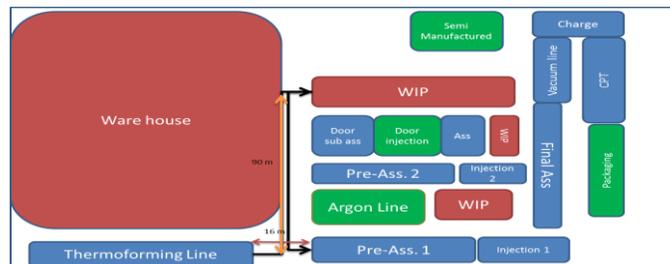


Figure 2- Shop-floor configuration

Table1 - Current Assembly Line Stations

	Station	face/ back	No. of workers	Station time (sec)	Value add. (sec)	Non value added (sec)	waiting (sec)
1	Feed the line with injected refrigerators	Face	3	13	0	13	22
2	Clean plastic cabinet	Face	1	19	0	19	16
3	Fit freezer fan + Fixing by 2 screws	Face	1	25	25	0	10
4	Fitting freezer back (Foam + Plastic)	Face	1	29	29	0	6
5	Fit freezer thermostat harness + fix by 2 screws	Face	1	23	23	0	12
6	Fitting damper + Fixing by screws + Fit air duct	Face	1	27	27	0	8
7	Fixing air duct + Meat drawer rollers	Face	1	35	35	0	0
8	Bulb switch + damper cover	Face	1	22	22	0	13

### Pre-Assembly Activities Improvements

There are different types of WIP inside the factory area. The most critical, is the one between the thermoforming line and pre-assembly line. It occupies more than 800 m<sup>2</sup> which is more than 6% of the total refrigerator factory area. Analyzing the causes revealed that this is due to the lost time in changeover in the thermoforming line, as it takes more than 2 hours for changing over from one model to another in thermoforming cabinet line and more than 3 hours in thermoforming door line. This changeover takes place every two shifts, so there must be a safety stock to compensate this lost time. This WIP causes transportation waste; as thermoformed parts travel about 90 meters to the storage area and back to pre-injection line which is only 16 meters away from the thermoforming line; these results in material handling unjustified cost, in addition to possible damage to parts during transportation (Figure 2). All of these wastes will certainly cause delay and increase in the lead time. The need for eliminating wastes encountered in the pre-assembly activities stressed upon the use of the VSM as an approach for improving the production system.

A current state value stream map (figure 4) is constructed to analyze and design the flow of materials and information required to bring a product to a consumer. The production process runs as demonstrated:

Extrusion-Thermoforming-Argon assembly-Pre injection-Injection }  
 Door bending-Door injection-Door assembly } Final Assembly  
 Damper assembly-Air Duct Assembly Fan Motor }

The company runs one shift per day; there is a total of 8 hours (or 480 minutes) in a shift, 45 minutes for breaks, then:

$$\text{Available Time to Work} = 480 - 45 = 435 \text{ minutes}$$

Customer demand is 800 units a day, the Takt time is calculated:

$$\text{Takt time} = \frac{(480 - 45) \text{ mins} \times 60 \text{ sec}}{800 \text{ unit per day}} = 32 \text{ sec/unit}$$

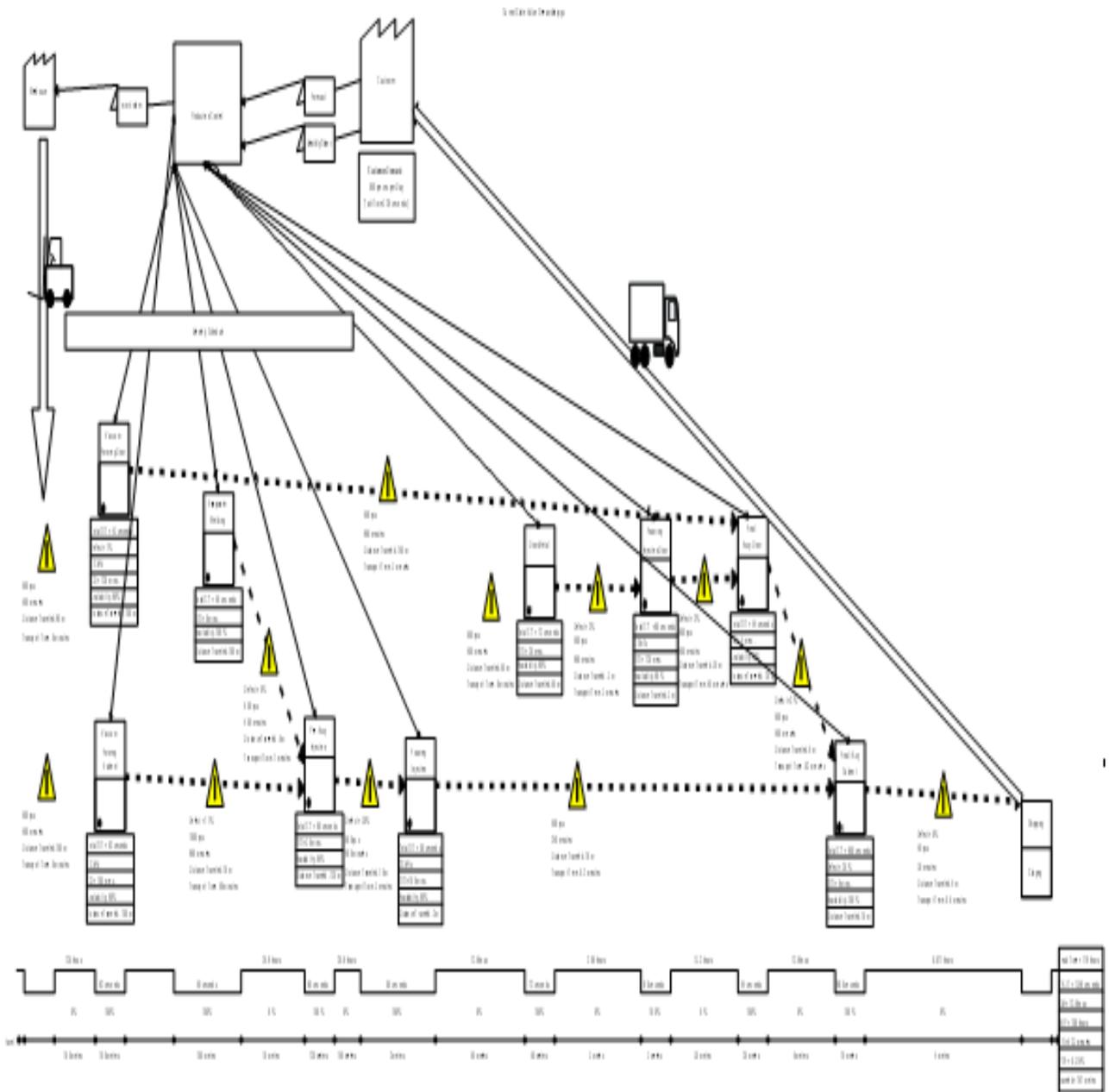


Figure 3- Current state value stream map

### The Future State VSM

The future state map (Figure 3) depicting the possible modifications incorporated in the manufacturing processes of refrigerator parts is shown in the figure. After the analysis of wastes existing in the manufacturing processes, the most objective action was the implementation of Quick Change Over (QCO) in the following production lines; thermoforming door, thermoforming cabinet foaming injection line (see current state value stream map).

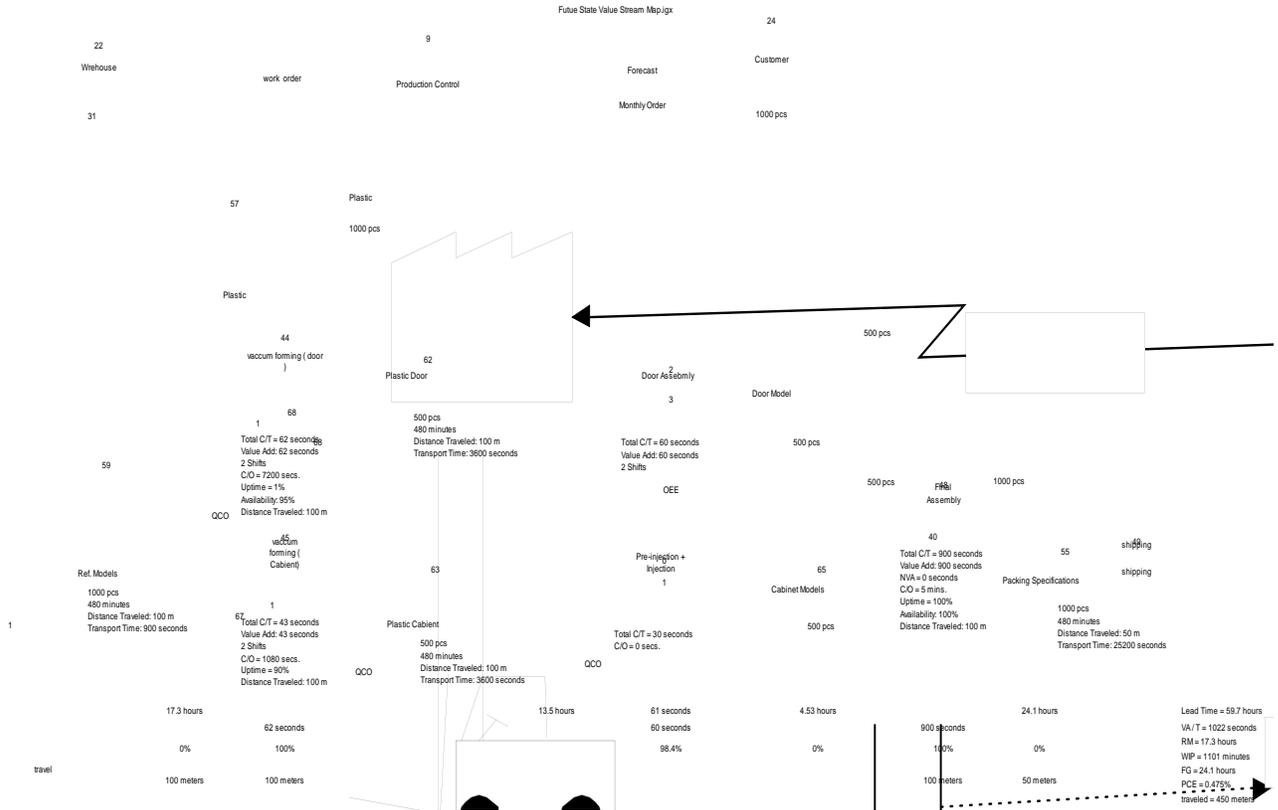


Figure 4- Future State VSM

### The Assembly Line Balancing Problem

Refrigerators’ assembly is not a simple process. It encounters a huge number of tasks on both the front and back sides of the product. The precedence graph for the investigated assembly line is given in Figure 5. The numbers inside the nodes of the graph correspond to the tasks. In our industrial case study the number of workstations in the line is 73 stations. Station 7 was considered the reason of the existence of bottleneck as it has the largest work time 35 sec which exceeds the Takt time. Other problems existed in stations 22 and 31 as their cycle times were 33 sec.

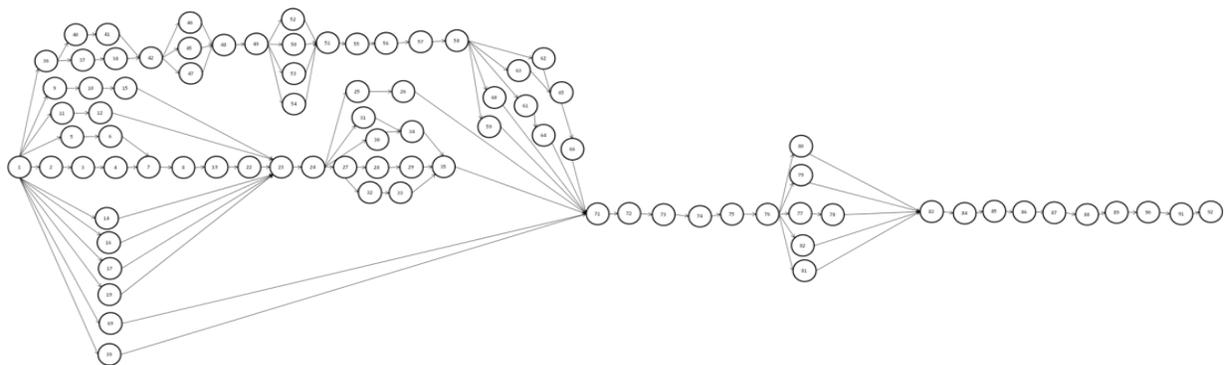


Figure 5- Precedence diagram of the final assembly line

After studying different algorithms, a genetic algorithm is chosen to be the tool used to generate alternative solutions. The algorithm was used to generate 4 different proposals. The 4 proposals are compared to attain the optimum solution taking into consideration the following factors:

- Production Rate (output)
- Number of workers
- Efficiency
- Smoothing index
- Total working time

## Results and Conclusions

### VSM Results

VSM analysis was performed to the thermoforming processes, since they are the most critical operations in the shop area. Inventories are represented in days. This is due to the fact that to calculate the total production lead time in a VSM, the inventory is considered as “the number of days a part waits before it gets processed”. Hence, based on the daily demand, the inventory is converted into number of days by dividing the available inventory by per day requirement. Other improvements in several performance measures as a result of conducting the VSM and the application of Quick Change Over (QCO) in the following production lines; thermoforming door, thermoforming cabinet foaming injection line are as follows:

- Reduction of work-in-process inventory from 95.1hrs to 18.35hrs.
- Lead time has decreased from 107hrs to 59.7hrs as a result of applying which is a result of reduction in inventory.
- Total distance travelled has been reduced from 757meters to 450 meters
- Reduction in time consumed in change over from 500minutes to 143 minutes

### Assembly Line balancing Results

The results of the rebalanced assembly line are given in Table 2. Before balancing the assembly line, cycle time of the line was 35 seconds. After balancing the line by using the GA to 32, 32, 29 and 29 seconds respectively which mean that the cycle time is reduced by 8.6% and 17.14%, respectively. Moreover, the workload is more smoothed balance delay was reduced by 18%, 19.21 %, 21.16%, and 17.24% respectively. Smoothing indices also were reduced which minimized the variation between activities.

*Table 2- Summary of the suggested proposals*

	Current	Proposal 1	Proposal 2	Proposal 3	Proposal 4
Cycle Time (sec)	35	32	32	29	29
Efficiency	60.12%	79.06%	79%	81.28%	82.76%
Balance delay	39.88%	20.94%	21%	18.72%	17.24%
Smoothing Index	15.05742433	7.860563691	5.656854249	6.646696	6.1864956
No. of Stations	73	50	52	56	55
Workers	82	61	61	65	64
Total Working Time (sec)	2555	1600	1664	1624	1595
Total Idle time (sec)	1019	352	344	304	275
Production Rate	103 unit/hr	113 unit/hr	113 unit/hr	124 unit/hr	124 unit/hr

Other conclusions can be made concerning the number of mated stations and the number of workers in each proposal. In proposals 1 and 2, the total number of stations became 50 and 52 stations consequently, 37 of which are mated stations. This decreased the number of workers from 82 to 61 workers. In proposals 3 and 4 addition, the total number of stations became 56 and 55 stations consequently, (40 mated stations) instead of 73, which decreases number of workers from 82 to 64 workers.

The application of assembly line balancing had several implications. There were 73 work stations in the assembly process, this number was reduced considerably in the four proposals, this reduction resulted in higher line efficiency and a smoother process which was one of the main objectives of this research study. The work assignments were also optimized and number of workers decreased. According to the results a proper way to allocate human force to each station referring to their skill became clear. The considerable increase in production rate due to the application of the balancing algorithm; complies with the company' objective of increasing throughput. The availability of four different scenarios facilitates the decision of which assignment to use based on the desire of the company to allocate its resources.

## **Conclusion and Recommendations**

This research deals with integrating different lean tools with balancing a two-sided assembly line GA to reduce WIP, lead time and the total distance travelled in the production area of a manufacturing enterprise. Through the application of this integration, smoothing of the assembly process took place for the objective of optimizing the number of work stations and the human force. Consequently, increasing the efficiency of the assembly line and the production rate occurred. Based on the practical application conducted, it was proved that assembly line balancing and VSM are effective lean manufacturing techniques, which could be deployed in manufacturing areas for enabling improvement. Therefore, offering opportunities for competitiveness. It is desired for this improvement to be dynamic and ongoing. More advances can take place through a continuous improvement strategy framework and the application of more lean measure such as lean rate and dock to dock calculations.

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