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CONTINUOUS PROCESS IMPROVEMENT ON HEAT EXCHANGER PLANT THROUGH VALUE STREAM MAPPING

K.P. Lusiba[1*] & M. Dewa[2]

[1]Department of Industrial Engineering
Durban University of Technology, South Africa
kydiva.lusiba37@gmail.com

[2]Department of Industrial Engineering
Durban University of Technology, South Africa
mendond@dut.ac.za

ABSTRACT

Lean manufacturing is an optimum approach for the reduction and elimination of waste within an organisation. The case study company is based in South Africa and produces heat exchangers through main processes which include pre-assembly, core building, brazing and final assembly. A plant walkthrough revealed an inefficient portrayed by inventory stacked awaiting final assembly and frequent delays at the brazing furnace as it waited for material from core building. This paper proposes a framework for continuous process improvement through the deployment of value stream mapping. Process analysis was conducted using value stream analysis and it was revealed that operators were not fully utilizing the capacity of the bottleneck workstations. Two instead of one planning points and inefficiency at assembly were identified as root causes of the high work in process level. Furthermore, work in process build-up was caused by the furnace that was run two shifts while the preceding assembly and core building were running three shifts. Recommendations were made for continuous process improvement and a roadmap for reduction of waste was proposed.

*Corresponding author

1. INTRODUCTION

Globalization has brought many advantages to globally operating companies such as a greater choice between different suppliers. The buying company can obtain the optimum product for an optimum price to exploit this opportunity, while the supplier faces intensified competition from other suppliers. As a result, it is crucial for suppliers to be competitive and this can be accomplished through the reduction and elimination of waste within an organisation. A value stream map is one of the best tools used to map the process and reveal the hidden waste in the system. The problem at the case-in-point plant was portrayed by inventory stacked awaiting final assembly and frequent delays at the brazing furnace as it waited for material from core building. This paper focuses on the implementation of value stream mapping for assessing the value and non-value adding activities in the manufacture of car heat exchangers components and proposes continuous process improvement opportunities for the automobile component manufacturer.

2. LITERATURE REVIEW

The seven wastes defined by Japanese Toyota manager Taichi Ohno include waste of inventory (stock on hand); waste of processing; waste of movement; waste of overproduction; waste of time on hand (waiting); waste in transportation; and waste in making parts that are defective [1]. Continuous improvement practice is one of the Lean manufacturing basics that focus on elimination of waste or elimination of non-value adding steps in an organisation. Value-stream mapping is a process of mapping entire materials and information needed for the manufacture of a specific product and how the information flows throughout the production system [2]. Value stream mapping is basically representing the value stream data into a map or diagram, in which the current or future state of the production system is represented. As the term indicates, a current state value stream map (VSM) represents the flow of information and materials in the current process while future state VSM shows the future state, where there is a reduction or elimination of waste from the system.

Value stream mapping is one of the visual tools that is utilized in lean manufacturing for identifying and analyzing all the production activities, from planning to shipment of the products. A VSM map makes it easy to obtain improvement opportunities with high impact on the entire production process [3]. The VSM tool examines the current and future process map layout of the value chain, and this makes it feasible to keep records of the current state and the actual process that will be enhanced. The VSM is a chart that consists of symbols and icons that explains the two different types of flows. The first flow is the information flow from logistics planning, that contains the customer call offs or orders that precede the production process. The second flow is the material flow in production, which is taking into consideration all the production steps that are required to produce good parts, until the part is sent to the customer. Performance measurement is allocated to all manufacturing processes that reveal and display the status of the existing processes and generally including, setup time, cycle time and baseline shift, number of operators in a shift, scrap rate, machine availability, efficiency, and machine downtime. As soon as the performance measurement methodologies are in place and drawn according to the value stream map, it becomes easier to pinpoint opportunities for improvement and prioritising according to the impact they have on cost reduction, increasing flexibility and enhancing quality and productivity. Lastly, a future state is drawn in order to aid with visualising the future process when the opportunities of improvement are implemented [4].

A value stream is a set of defined actions needed to get a specific product through the three critical tasks of management in any organization, and these include management of information, physical transformation and problem solving [5]. VSM is a visual technique used to map the flow of information and material required to manage the activities carried out by manufacturing organizations, suppliers and distributors to send finished goods to customers. VSM aids the identification of value adding and non-value adding activities in a value stream [4]. A succeeding step in VSM is developing a future state map supported by the improvements generated from the current state. The information availability in the VSM assist and confirms the decision of implementing lean techniques and can in addition keep the organizations motivated during the actual implementation phase with the aim of getting the desired outcome.

VSM is referred to as one of the important tools of lean approach and is utilized to identify value-adding and non-value adding (wasteful) activities in the system, but when the VSM tool is not applied correctly, it can complicate the process of waste identification, leading to misunderstandings and assessment errors, and weakening the future continuous improvements initiatives [4]. Process mapping highlights the different steps in the processes and underline where the value is added. Waste can be classified in line with the generally accepted types of waste. Value is the step where the expected outcomes for the customer are defined [6]. Questions that can be asked to define value include; Is this step changing the form or product character? Does this step meet an exact customer specification? If the answer is "yes" then more economic ways to perform this step are explored. Methods time measurement (MTM) is one of the methods that can be used to identify value in the process [7].

3. METHODOLOGY

The case-in-point manufacturer uses lean tools but, however, there are loop holes in the system that leads to poor product quality, high regulatory non-compliance risk, poor process flow and high lead times. A value stream mapping was therefore required to display the material and information flows and assessing the value and non-value adding activities in the manufacture of automotive heat exchanger components. Material supply and the finished goods warehouse were also taken into consideration in order to close the cycle. As representative products, a product of each of the high volume core building lines was chosen and the key figures for the map at core building and assembly include number of operators; part number of representative product; SAP cycle time; observed cycle time during line walk; throughput time; setup time; and number of shifts. Value analysis was then conducted for the core building process, after which an assessment of several continuous improvement initiatives was done to identify which initiatives would reduce inventory costs and waste from the plant. Three proposals were developed as roadmap for reduction of waste to improve the situation in the plant.

4. RESULTS

4.1 Current State Value Stream Map

A waste walk was conducted at the case study company in order to accurately map the current state. Figure 1 shows a value stream map that was developed for the Engine Cooling (EC) plant. Manufactured products are delivered to the customers once a week, excluding the radiators and the low temperature radiators (LTR), because these products are shipped on daily basis. Customer orders are sent to planning department, from which a plan for core building is issued. This is indicated in the VSM with an arrow from planning to core building and second plan is issued for assembly line in which the sequence can vary from the core building sequence. A second arrow on the VSM goes from planning to assembly line. Cores kept behind the furnace/ brazing line are counted daily and this information is used to issue a third plan for brazing. These three production sections that do not work hand in hand when it comes to planning, but all parts start at core building (initial assembly), brazing (pre-heating process to combine the parts together) and last step assembly (final assembly includes crimping & leak testing).

The observation at the assembly line revealed that the operators could not achieve the SAP cycle time at three of the four regarded lines, though there was no occurrence of breakdowns or defective/scrapped parts. Only the operators for the evaporator line were able to achieve the cycle time as shown in Figure 2.

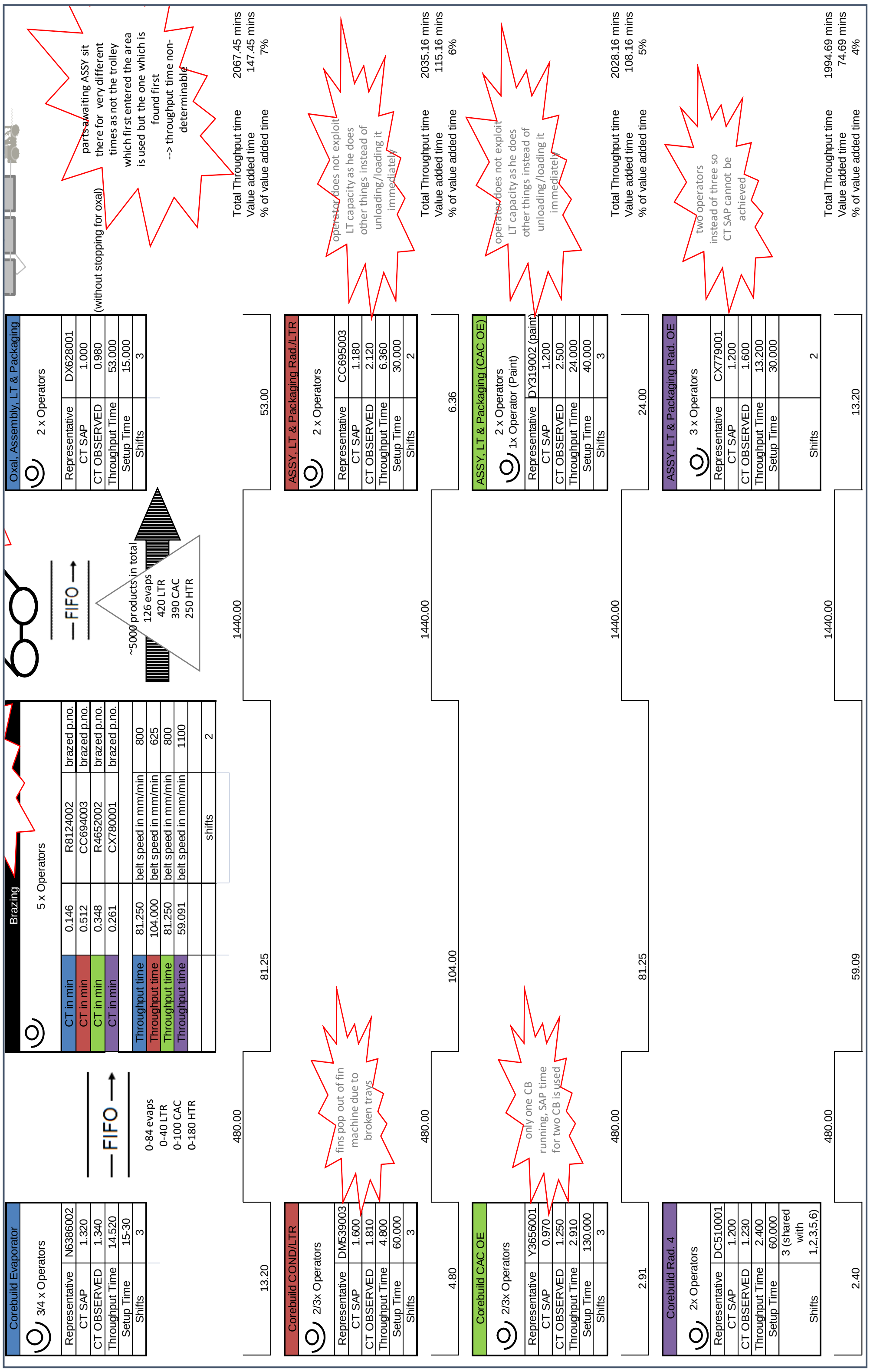

Figure 1: Snapshot of Value stream map for the EC plant

The brazed parts wait for assembly in the FIFO lanes at the assembly line and in the post brazing FIFO lanes next to the furnace. The post brazing FIFO lanes are not used as FIFO lanes and new brazed parts are stored randomly where the operators find some space. Therefore, in the value stream map the symbol for push material transfer and the triangle for inventory is indicated next to the FIFO lane and a Kaizen flash underlines this issue. The numbers of the parts that are selected for the VSM are counted at the point in time when the line walk was done. In addition, it is indicated that there are about 5000 parts in total awaiting assembly. The furnace/brazing throughput and cycle times are taken from the SAP system. There is no Kaizen flash as there was no problem observed. The inventory in the FIFO lanes in front of the furnace inlet was inserted as a range because the products were brazed during the observation. The maximum numbers of products were low because at that point in time when the observation for the specific product was done the furnace was brazing those parts. This does not necessarily have to be the case at every point in time as there are three different brazing families and sometimes products had to wait until their brazing programme is used again.

Oxal, Assembly, Leak Testing, & Packaging	
2 x Operators	
CT Observed	0.980
Throughput Time	53000
Setup Time	15000
Shift	3

Figure 2: Evaporator line cycle times

The VSM shows that the radiator assembly line had a manning shortage since there were two operators working instead of three operators, which would be the ideal situation. The charge air cooler (CAC) and low temperature radiator (LTR) lines had no breakdowns and or manning shortage but the leak testers were not fully utilised to their full capacity, and the leak testing process is the bottleneck of the lines. Instead of immediately unloading and loading, the leak testers, were performing other activities when they finished one product. For instance, the operator at the CAC line would pack the products in the cardboard box for shipping and at the same time the operator of the crimping station would stop working as the First-In-First Out (FIFO) lane in-between crimping and leak testing is full. After more than five minutes the crimping operator would then unload the leak tester that was waiting to be unloaded. Poor utilisation of the bottleneck station results in inability to achieve the SAP cycle time and tose deficiencies were marked with a Kaizen flash.

4.2 Value Analysis

VSM highlighted Kaizen flashes for which detailed value analysis would be undertaken. Value analysis was then conducted by assessing the activities in terms of value-adding, non-value adding essentials and non-value adding waste. Value-adding is a change of form or character of the product and things that the customer is willing to pay for. Non-Value Adding Essentials is waste that cannot be avoided that lean seeks to eliminate. Non-Value Adding Waste is waste that does not add value and can be avoided [8].

It was noted that in some instances, the core building production line could not keep pace with SAP cycle time but the deviations were not as high as at assembly line. The CAC core building line has one core builder instead of two possible core build stations and this led to higher cycle time. TYhe observed cycle time at the condenser/LTR line was found to be higher than the SAP time. One reason is that the trays that were filled with airways from the fin machine were broken fins popped out of the trays and the operator had to collect and insert them manually. These issues had been highlighted as Kaizen flashes in the VSM. A key challenge was determining the duration for which brazed cores wait for assembly since the operators took readily accessible coreswithout following the FIFO rule.

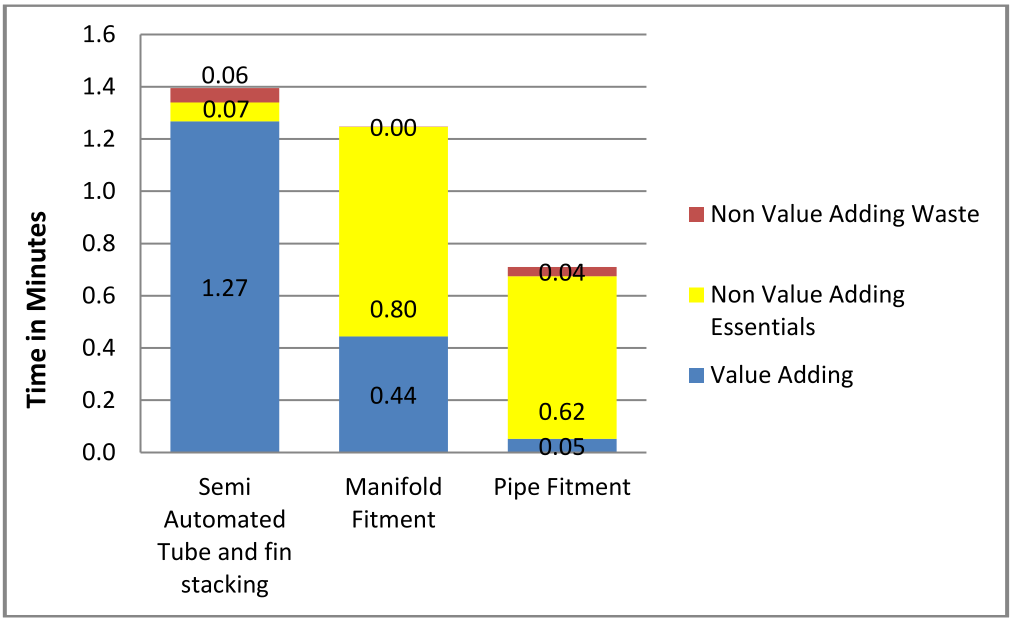

Figure 3: Core Building Value Analysis

Figure 3 displays value analysis per operation on the core build line of evaporators to classify value adding, non-value adding waste and non-value adding essentials.

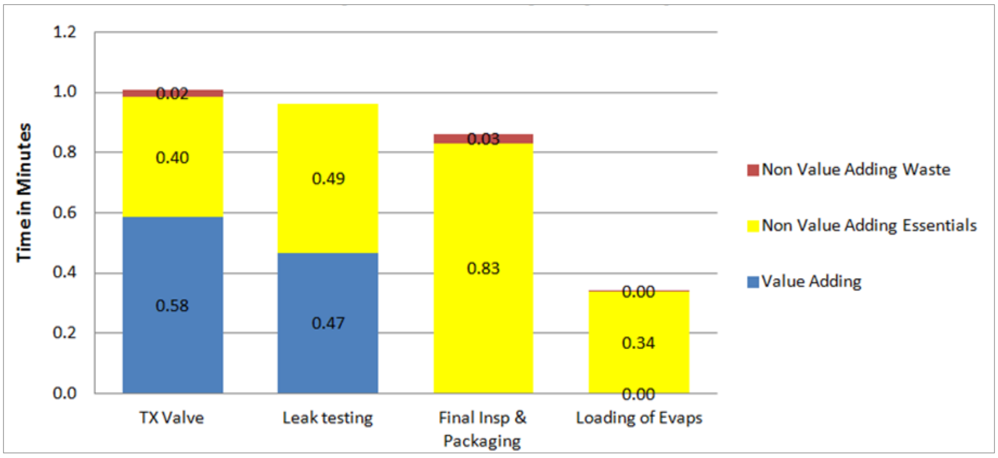

Figure 4: Assembly Value Analysis

Figure 4 displays value analysis per operation on the assembly line of evaporators. It also presents the different elements on the Evap assembly lines and classifies the activities into value adding, non-value adding waste and non-value adding essentials.

4.3 Furnace Downtime

The furnace is a costly station and has high-energy consumption, and thus it is crucial to have a detailed record of its downtime. The furnace is never switched off entirely; nevertheless the furnace consumes more energy when running than in standby mode. Table 1 shows the downtime in minutes for a six month period from January to June. The downtime due to no parts decreased from January to May but then increases slightly in May and June. It is revealed that high maintenance cost that takes up about 13% of the total operating cost, and this could be reduced by good planning.

Table 1: Extract from Furnace Downtime Report July 2016

Furnace Downtime (minutes) Due To Number of Cores					
Jan	Feb	Mar	Apr	May	Jun
2550	1170	260	0	120	190

4.4 Work in Progress Awaiting Assembly

The brazed parts were found in the FIFO lanes next to the furnace, at the lines and at other areas that are supposed to be used for other purposes. Figure 5 shows the cores in the FIFO lanes in the background and even more cores in the area next to them. In addition, the area marked in red is often used to store brazed parts.

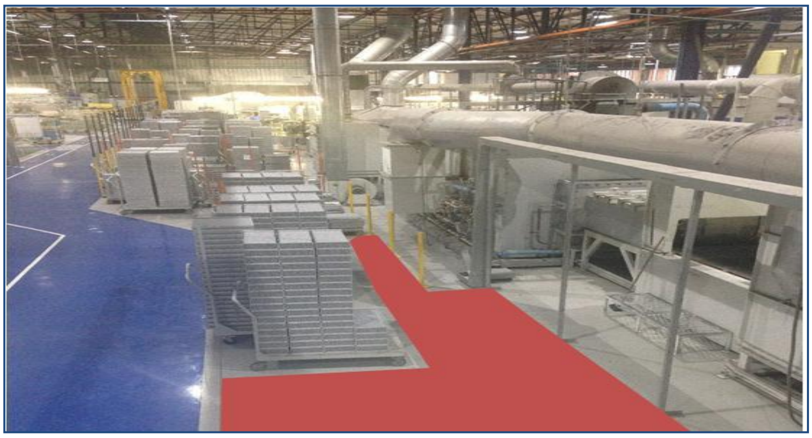

Figure 5: Inventory next to the furnace

In order to find out how many heated parts are awaiting to assembled, function in SAP was used to identify all the part numbers, quantities and value that are scanned after brazing. The evaluation of the inventory using SAP and manual counting done for CW 29 and 30 revealed that there were 6 348 heated cores/parts on average. This includes parts that are already in the processing at the assembly lines and assembled parts that are packed into a box but not scanned yet. The data was filtered by MRP controllers in order to see which parts account for the highest proportion, and as the pie chart in Figure 6 shows, the number of CACs is almost half of the total quantity, followed by radiators that come from the core building lines. The percentages of evaporators and condensers, LTRs and radiators from the other core building lines are quite small compared to CACs and OE radiators. Therefore, the majority of work in progress was being processed on the CAC lines and the second most parts are parts that are supposed to go to the Rad. AM or the Rad. OE line.

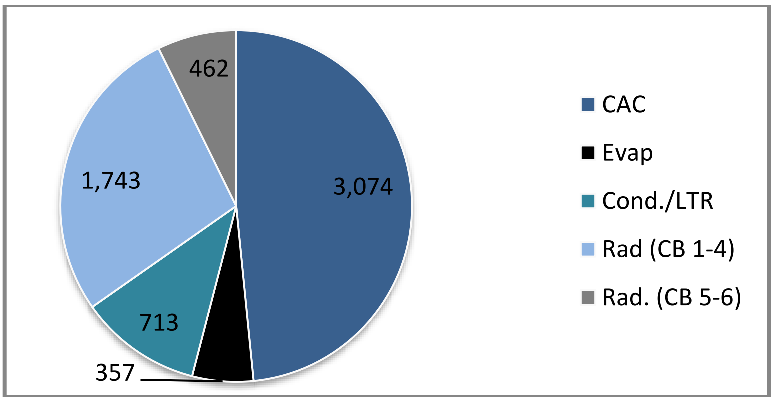

Figure 6: Summary of Inventory Level for brazed parts awaiting assembly

Overall, the average of the manual core count and the result of the SAP analysis is 5500 parts of work in progress between brazing and assembly. The remaining question was to ascertain the number of parts should ideally be the WIP inventory. About 5500 parts is more than two daily production quantities, volumes for July divided by 23 working days in July.

5. DISCUSSION OF CONTINUOUS IMPROVEMENT INITIATIVES

Balancing charts were drawn and they revealed that there is no heavy imbalance in the plant although there was notable inventory behind the furnace. As the balancing chart is based on SAP times and includes scrap, defects, downtime and changeovers it must be the case that assembly section does not achieve their targets even if there is no documented downtime, defect or scrap. This could possibly be due to several reasons such as that the targets were too high which means the cycle times in SAP times are too low. However, this was very unlikely as the SAP times are the result of a MTM study done according to a video of the actual process. Moreover, the employees responsible for those time studies are trained. Alternatively, the lines run with fewer operators than planned, which can happen because of absenteeism or when the plant has to run on short time due to low volumes. Either the operators did not run the lines properly thereby failing to achieve their targets. This is exactly what the VSM revealed, the operators at assembly did not fully utilise the bottleneck workstations and therefore could not produce according to the SAP times. In addition, some lines were less manned yet the balancing chart assumes that the lines run with maximum number of heads. In addition, the VSM revealed that there are two planning points in the EC plant instead of one. Those two plans sometimes differ, and as a consequence, it is impossible to use the FIFO lanes after the furnace as FIFO lanes because often products that got brazed after another product are assembled first.

5.1 Improvement Opportunities for Training and Removal of Second Planning Point

A major problem that the value stream analysis revealed was that the assembly lines often could not achieve targets even if there are no defects or downtime. This is often due to operators not full-time utilizing the capacity of the bottleneck workstations. In order to improve situation, a workshop for the operators was proposed. The workshop would raise operator awareness of the existence of bottlenecks and the importance of utilising them all the time. The workshop should emphasise that a chain is only as strong as a weakest link and the criticality of teamwork. In case one operator at the bottleneck workstation has difficulties to cope, the other operators should help. After the theoretical part, the lessons learnt should be practised on the shop floor. It was antciapted that the assembly lines would be able to process all the brazed material after operator training , and thus it would be possible to introduce dedicated FIFO lanes after brazing. Moreover, when the FIFO lanes are used properly, the second planning point will not be necessary anymore.

The training of operators and the removal of the second planning point allows the reduction of work in progress so that a saving of costs of carrying inventory is possible. Besides, lead times will be shorter and the FIFO lanes at the furnace will be clearer with the result that it will not be necessary to search for the right trolley for assembly anymore. In addition, training can possibly increase the motivation of the operators. However, there are cost inplications since the operators are not working during the training sessions. An estimate of costs from the Training and Development department was R8 410 for the preparation and three rollouts of the training as there are three shifts of operators. Still, there would be a saving of R99 000 per year, presuming that a workshop is performed once a year.

5.2 Continuous Improvement from Economical Evaluation of the VSM

Compared to the current situation, the workshop and the elimination of the second planning point do help to reduce the level of inventory and therefore also the cost of carrying inventory. The costs of carrying inventory comprise of cost for the physical space occupied, the opportunity cost because of the capital lockup, handling costs and the cost for deterioration and obsolescence [9]. In order to compare the annual cost of carrying inventory in the EC plant with and without the implementation of the proposal the focus lies on the cost for the space and for the tied up capital. This is because there is one worker per shift responsible for the internal material handling. Deterioration was also not taken into account. This is because products are made to order and even if the products spend more time awaiting brazing, there is no chance that they are not taken by the customer.

Table 2: Required Space for Post Braze FIFO lanes

Required Space For Post Braze Fifo Lanes

Assembly line	Min. qty on trolley	Cycle time CB	Produced qty in one CB shift	required FIFO lane bays	provided FIFO bays at line	provided post braze bays	Cycle time brazing	Time to Braze Qty (hours)
CAC OE	30	1.50	293.20	10	9	6	0.28	1.37
CAC AM	30	4.00	109.95	4	4	6	0.18	0.33
Rad.	42	2.56	171.93	5	8	6	0.42	1.21
LTR	45	1.60	274.88	7	2	6*	0.51	2.35
Rad. AM	87	1.98	222.57	3	6	6	0.47	1.73
Evap	42	1.71	257.19	7	7	-	0.15	0.62
Cond.	45	1.62	271.48	6	6	-	0.26	1.16
Rad. OE	50	1.20	366.50	8	6	6	0.26	1.59

Table 2 shows the required space for post-braze FIFO lanes, and currently, the brazed parts occupy about 183 square meters in the plant. This space includes the area of the post brazing FIFO lanes next to the furnace and the FIFO lanes at the assembly lines. Furthermore, the area between the post-braze FIFO lanes and the steps of the control panel of the furnace is included as CACs and radiators are stored. In the course of the manual core count, brazed cores were seen in different places, but most of the time the previously mentioned area was covered with cores. This yields inventory costs of R96 782 per year including rent, insurance and overheads. Assuming that there are 5 500 brazed parts on average, which is the average quantity of the manual count and the observation using SAP, and an average value of R246 per part, this results in R94 710 of opportunity costs. This is presuming a rate of imputed interest of seven percent per year, which is the rate used for calculations.

After the workshop and the removal of the second planning point the inventory level will be lower. At an average there would be one sixth of the daily production quantity of core building. This is because the daily production quantity is built at core building during three shifts. The furnace is able to braze this quantity during two shifts whereas assembly processes this quantity during three shifts. Using the gross cycle time minus the additional time for changeovers of the balancing chart for the period from august to December, this results in an average daily production quantity of 2 587 parts. One sixth of this quantity times the average value of a brazed core of R246 results in the average value of R106 069. This results in opportunity costs for the tied up capital of R7 422 per year.

Concerning the space, it was possible to use the provided post brazing FIFO lanes and the assembly FIFO lanes so that the extra space that is currently occupied by cores is not required anymore. This is because they were designed to cater for the brazed parts. This proposal can save R107 650 of costs for carrying inventory per year and Table 3 shows the calculation of inventory costs. Consequently, the required space will reduce to 129 meters square, which results in annual costs for the space of R68 006. Therefore, proposal could save R107 650 of costs for carrying inventory per year.

Table 3: Inventory Carrying Costs Before and After Implementation of Proposal 1

	CURRENT	AFTER WORKSHOP/ ONE PLANNING POINT
average qty awaiting assembly	5500	431
average value per unit (ZAR)	246	246
imputed interest	7%	7%
opportunity cost of capital per year (ZAR)	94 710.00	7 421.82
required space (sqm)	183.30	128.80
cost per squaremeter per year (ZAR)	528.00	528.00
cost for space (ZAR)	96 782.40	68 006.40
cost for carrying inventory post braze	191 492.40	75 428.22
average qty awaiting brazing	431	431
average value per unit (ZAR)	201.00	201.00
imputed interest	7%	7%
opportunity cost of capital per year (ZAR)	6 064.17	6 064.17
required space (sqm)	61.60	61.60
cost per squaremeter per year (ZAR)	528.00	528.00
cost for space (ZAR)	32 524.80	32 524.80
cost for carrying inventory pre braze	38 588.97	38 588.97
annnual cost for carrying inventory pre and post braze	**191 492.40**	**75 428.22**

5.3 Continuous improvement opportunities on shift models

As the furnace is running two shifts and assembly and core building is running three shifts there is always WIP building up in front of the furnace when it is not running. On the other side, the inventory level is increasing behind the furnace when it is running and decreasing when it is not running [10]. The average number of parts awaiting brazing must be one sixth of the daily production quantity sincecore building is producing the daily production quantity during three shifts and the furnace brazes that quantity within two shifts. Moreover, there is one sixth of the daily production waiting brazing at the other end of the furnace on average, since assembly consumes the number of parts in three shifts that the furnace brazes during two shifts. In order to reduce this level of inventory it would be an option to run core building and assembly on a two-shift model as well. If all three sections were running in two shifts, the inventory level could be reduced even more. In addition, lead times would decrease, provided that all cores are brazed and assembled within the same day. Besides, running the EC plant only on two-day shifts would save the night shift allowance for the operators.

5.4 Roadmap for Reduction of Waste

Three proposals to improve the situation in the EC plant are developed. The first embraced a workshop for the operators at assembly, which should enable them to meet their targets for the hourly production quantities. In addition, it would be possible to use the post brazing FIFO lanes as dedicated FIFO lanes again and the second planning point will not be necessary. The introduction of this proposal was highly recommended as it generates a saving due to the reduction of inventory and does not entail disadvantages, except for the fact that the high inventory level currently works as a huge safety buffer. After the implementation of this proposal there remains an imbalance due to the different shift models of the three production sections, two further proposals were developed. The other proposal was on adjusting the shift models to a two-shift model for the entire plant. In order to achieve this, high investments would be required and it would not pay off, as the potential saving of inventory costs is small. This would only be a short-term improvement, as the furnace would have to run three shifts again in the following year when demand is anticipated to increase.

The other option was to create a slower brazing profile, so that the furnace runs three shifts, as CB and assembly. Nevertheless, the economical evaluation revealed that this option would not generate a saving and would fall in line with the organisational strategy of increasing volumes in the near future. Nevertheless, even if the adjustment of the shift models did not make good economic sense, the implementation of the first proposal allowed a good saving. Table 2 summarises the arguments that speak for and against the proposals and costs estimates with anticipated savings.

Table 4: Summary of Proposals

Summary of Proposals				
	Status Quo	Training + One Planning point	Two Shifts	Three Shifts
basis for comparison of savings and costs				
cost of carrying inventory for post braze WIP	ZAR 191 492 per year (space and opportunity costs)	ZAR 75 428 per year (space and opportunity costs)	probably less than ZAR 75 428 per year	probably less than ZAR 75 428 per year
cost of carrying inventory for pre braze WIP	ZAR 38 589 per year (space and opportunity costs)	ZAR 38 589 per year (space and opportunity costs)	probably less than ZAR 38 589 per year	probably less than ZAR 38 589 per year
other costs and required investments	-	• Workshop (once a year) ZAR 8 410	• tools and LT jigs: more than ZAR 1.350 million •space for additional machines	• labour ZAR 610 580 per year • energy ZAR 826 000 per year • brazing jigs, • brazing trials, research
savings	-	ZAR 107 654 per year	• no saving because of high investment for tools etc.	• no saving because of costs for energy and labour and the investment in brazing jigs
(+)	-	• reduction of inventory • no more searching for brazed material • reduction of lead times	• further reduction of inventory •further reduction of lead times for most parts	• removal of constraint of brazing families • further reduction of inventory
(-)	• chaotic, products are hard to find in piles of material	• imbalance of the 3-2-3 shift model	• **high investment in tools/ LT jigs or entire lines** • expensive HV CB and ASSY lines are only utilized for two shifts • **not future oriented as furnace must probably run three shifts next year**	• **feasibility** • high investment • higher costs for energy and labour • **furnace runs out of capacity when volumes increase as expected**

6. CONCLUSION

Utilising lean manufacturing as a culture that creates and sustain long-term commitment is a challenge to most organisations. Value stream mapping is an excellent starting point for impementing continuous imrpovement initiatives in organisations. Removing the second planning point in the EC plant and the training of the operators allows the reduction of inventory, as it aims to reduce all non-value adding activities or waste. The balancing chart was converted into a template so that new parts and volumes as well as changes in shift patterns or in terms of the scrap, defect or downtime rates could be readily monitored.

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