BALANCING OF PRODUCTION LINE FOR CAR ENGINE COOLING SYSTEM COMPONENTS FOR INVENTORY REDUCTION

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ABSTRACT

Line imbalances result in decreased workstation and worker efficiency. The case study company is an international automotive component supplier striving to reduce waste in the form of waiting time and inventory. This paper presents an analysis of the balance of the plant and provide solutions for reduction for the inventory and waiting time at the furnace. The methods used include Pareto chart for evaluating and prioritising the products and the largest part of the total volume, analysing product mix and allocation to work centers, and generation of balancing chart fractals. Recommendations were then proposed to balance the lines so as to reduce the waiting time of the brazing furnace as well as inventory between the furnace and the assembly lines.

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1. **INTRODUCTION**

Assembly lines are flow oriented production systems for industrial production of high quantity standardized commodities and line-balancing strategy can be used to make production lines flexible enough to absorb external and internal irregularities [1]. The research was conducted for a manufacturer of car heat exchangers, specialising in vehicle air conditioning and engine cooling systems. The factory consists of three different stages of manufacturing and preassembly of components. The case study company based in South Africa is an international automotive supplier and has 13 lines feeding the brazing furnace with products. These products can be categorized into three brazing families, which need different heating profiles at brazing temperatures when passing through the brazing furnace. The furnace then feeds subsequent nine assembly lines with these brazed products. The brazing furnace has, in general, per product, the lowest cycle time. Upstream, the furnace often waited for products to braze, whereas downstream, there is a lot of work in progress between the furnace and the downstream assembly lines. This implied that there could be a line imbalance induced by the three brazing product families. Waiting time and inventory obstruct a smooth material flow during production and are thus waste. The aim of the paper is to analyse the balance in the plant and to find the reasons for the inventory behind the furnace and the waiting time of the furnace, and thus propose recommendations to abate waste through line balancing.

2. **LITERATURE REVIEW**

2.1 **Line Balancing**

Line balancing is a technique utilized to minimize imbalance between workloads and workers in order to achieve the required run rate [2]. Consequently, the analysis of the line must be in terms of assembly process, layout of workstations, and the cycle time of the workstations. A multiple activity chart can be utilized to measure and assess interrelationships between operators and machines, and could be described as an operator and machine chart. The task time variation is primarily due to human’s instability with respect to work rate, skillfulness, motivation as well as the failure sensitivity of complicated processes [3]. These sources of inconsistency are minimized by controlling the moving cost of machine and men. The worker working time and variation of operator and machine cycle time results in line imbalance. Furthermore, line imbalance is created by the change-over time for mixed model line, which is essential to apply lean techniques. Based on customer orders and call offs, the number of operators and machine at a workstation are increased or reduced to reduce line imbalance. Man and machine flexibility is achievable through open information and material flow in the production process. Balancing chart is a tool to analyse a process and is often used in combination with a value stream map (VSM) [4]. Every workstation’s cycle time is represented by a bar on a bar chart, and in this study, cycle time is referred to as the time between two units coming out of one line as finished goods [5].

The process of assembly line balancing involves three steps that include initially deriving cycle time by taking the units required (demand or production rate) per day and divide it into the productive time available per day. The second step is to calculate the theoretical minimum number of workstations. This is the total task duration time (the time it takes to make the product) divided by the cycle time. Thirdly, the line is balanced by assigning specific assembly tasks to each workstation. An efficient balance is one that will complete the required assembly, follow the specified sequence, and keep the idle time at each work stations to a minimum [6].

2.2 **Product Mix and Allocation to Work Centres**

Product mix is the total number of products that an organisation can manufacture or offers to its customer, and mixed-model assembly line can produce various products from the same assembly line, thereby providing flexible production that is aligned to variable demand [7]. Heuristics can be used to balance production lines that manufacture different product models in order to mitigate capacity constraints at workstations and escalate balancing efficiency [8]. The assembly line needs to balance so that there is minimum waiting of the line due to different operation time at each workstation. The sequencing is therefore, not only the allocation of men and machines to operating activities, but also the optimal utilization of facilities by the proper balancing of the assembly line. The allocation of work elements to work centres is crucial for responding to changes to product mix so as to introduce agility to assembly lines [7].

2.3 **Sources of Waste**

Eliminating waste requires constant effort at cost reduction to maintain continuous profits in manufacturing. The major technique to reduce costs is to produce products in a waste free environment or system. There are
different ways to analyse and implement cost reduction, from the start of designing all the way through to manufacturing and sales. One of the goals of the Toyota Production System, however, is to locate waste and eliminate it. It is possible to uncover a very large amount of waste by observing team members, equipment, materials and organization in the actual production line. In every case, waste never improves value; it only increases cost [9].

There are eight sources of waste that include inventory, over-production, defects, waiting, transportation, motion, incorrect use of staff and their skills, and over processing. Inventory is described as any excess products held in stock that is not directly needed by the customer. Therefore, the stock on hold, if not in use in production, takes up a lot of space, resulting in increased inventory cost and high possibilities of having obsolete stock while stored [10]. Most companies that have implemented lean ensures that they install IT systems to control their inventory to ensure that money is not wasted on unnecessary resources, component or products [11]. The smooth, continuous flow of work through each process ensures that excess amounts of inventory are minimized. If work-in-process develops because of unequal capabilities within the process, efforts need to be made to balance the flow of work through the system. Inventory ties up assets such as cash and real estate and often requires additional handling which requires additional labour and equipment [12].

Over-production - Over-production take place when an organisation produces more than what the customer needs. This means producing parts that are not ordered or producing more than what is needed at that time. Over-production is the worst of all the types of waste since it has a knock-on consequence of increasing all the other types of waste. Over production amplifies costs of inventory, defective parts, unnecessary transportation, waiting time and avoidable motion [13]. With waste of waiting, most activities in manufacturing are dependent on the processes that are downstream and upstream, when resources, equipment, information or labour hold-up the production line for some reason, production cost will increase and the time is wasted and that adversely impacts on profitability [14]. Defects are described as parts that do not meet the customer specifications. Defective parts result in reworks and rejects that leads to costly production processes. Defects are triggered by poor production processes as an outcome of machine breakdown or human error. Reworking or reprocessing takes extra time and hence increases the finished product cost. Rejecting or discarding products incurs extra costs and excessive resources usage that affect the production line [15].

Transportation waste is described as any material, objects, parts and finished goods movements that are unnecessary leading to waste of time, resources and money [14]. Unnecessary transport is generally compared to unnecessary movement, which falls under motion waste and that results to parts damage and failure of product. Motion relates to the additional steps taken by operators and equipment thereby wasting operator’s effort and time effort. Unnecessary movement results from poor basic procedures and training, and poor work process design [16]. Incorrect use of staff and their skills, in some cases, can also yield waste. If the skills and abilities of staff are not utilized properly, the result is loss of business time, failure to use operator’s skills and suggestions, leads to less or discarded opportunities of improvement and education. Staff needs to be integral to the entire manufacturing process [17]. The operators on the shop floor can come up with ideas in which the ideas can be used to eliminate types of waste. Engagement can improve the processes and develop the staff’s skills continuously to avoid over-processing. Over processing is the unnecessary steps taken in production process. This also refers to extra processes such as re-working and re-processing [13]. The other meaning of over-processing is producing products or an output extremely exceeding the customer’s specifications that are required. In most cases this takes place due to malfunctioning machinery, faults during re-processing, poor information transferring, ineffective methods and not using the customer requirements as a point of reference (that includes in-house customers downstream in the process).

3. CASE STUDY BACKGROUND

The factory consists of three different stages of manufacturing of components, and these include core building, brazing, and assembly, and generally, it is a norm that operators are responsible for the quality of individual work.
3.1 Plant Overview

The layout in Figure 1 shows an overview of the case study plant layout. Highlighted in blue are the core building lines, with a total of thirteen stations, from which a matrix is built, that is a combination of different small components assembled together. All the small components are provided from the core building supermarket, which is next to the core building (CB) lines on the plant layout. Lines one to six produce similar radiators while the remaining seven lines produce different components – condensers, Low temperature radiators (LTRs), Evaporators (Evaps) and Charge Air Coolers (CACs).

3.2 Production Process Flows

Figure 2 shows the full production process flow at the case study company. It commences with inbound logistics by which raw materials are brought in to core building and assembly lines. It also shows the linkages between core building, brazing and assembly, as well as reworks before the end product is sent to the finished goods warehouse.

3.2.1 Sub-Production Process Flow: Core Building

Figure 3 shows the sub-production line of core building, which is the first step of production on the engine cooling plant. This is the first stage of assembling single components into one subassembly, building of the matrix which is stacking fins and tubes together. Core building is where the headers or manifolds are hard-pressed into the matrix. Evaporators require a third step as the bended tubes have to be fitted on the manifolds. End of core building parts are packed on the jig for brazing and placed on a trolley, where the parts will be moved to the next station which is brazing.
Figure 2: Full Production Process Flow
Figure 3: Sub-Production Process Flow: Core Building

Figure 4 also shows the assembly of components and building a matrix on the core building line.

Figure 4: Core Building line - Assembly of components, building a matrix

3.2.2 Sub-Production Process: Brazing Process

Figure 5 shows the sub-production line of the brazing line which is the second step of production.

Figure 5: Sub-Production Process: Brazing Process

All parts go through this step of production, where the brazing operation is carried out in a continuous flat belt furnace under controlled nitrogen atmosphere. The parts are subsequently kept on the First-in-first-out (FIFO) lane that is aside the assembly line. Components that have an aluminium silicon cladding are joined permanently at a lower melting temperature. The brazing furnace is loaded continuously and gaps of more than 1 m on the conveyor belt must be filled with dummy heat exchangers in the manual fluxing zone in order to avoid temperature fluctuations inside the brazing furnace. Stabilization of the brazing furnace temperature at the beginning of production is also accomplished by loading a minimum of 15 dummies. Also, after finishing with production, 10 dummies are loaded into the furnace. There are products that do not need the spray flux treatment as they use Silflux, which is flux that is already applied as a coating on the tubes of those products. These products include LTRs and some types of evaporators. For that reason, they are put on the conveyor just after the fluxing station.
There has to be a waiting time of 15 minutes after brazing Silflux parts, before the next spray flux part can be brazed and a 20 minutes waiting time for the other way round. This is because Silflux and spray flux parts cause different levels of humidity in the furnace. In addition to that, LTRs are exceptional in terms of the necessary belt speed. In order to prevent corrosion of the product later in its lifecycle the brazing process requires a very low belt speed. This leads to the following three brazing profiles, the different brazing profiles and Silflux and non-Silflux products are not the only constraints regarding the furnace. Most of the products need a product-specific brazing jig, which is only available at a limited number of units. As a consequence, core building cannot supply the furnace or the FIFO lanes in front of the furnace with unlimited numbers of products as they will run out of jigs. That being the case, those products have to be brazed in order to release jigs.

3.2.3 Sub-Production Process Flow: Assembly

The last work station for engine cooling is the valve assembly station where a valve is assembled to the core. The next step is the leak testing followed by final inspection and the product is packed into the box.

![Figure 6: Sub-Production Process Flow: Assembly](image)

This process happens just after brazing, the products are packed on post braze FIFO lanes and then collected there for the next step which is assembly line. Products without manifolds pass light check before that. The assembly process consists of crimping machines and air leak testers as shown in Figure 7. In addition, the CAC OE line has a paint station, as some CACs require coating and LTRs which do not require crimping just go through leak testing. Evaporators need more steps; they pass the “oxal station” where they get chemical treatment. The evaporators subsequently go to the valve assembly station where a valve is assembled to the core. The next step is the leak testing which is the last workstation, then final inspection and the product is packed into a box.

![Figure 7: Assembly process - Crimping machines and air leak testers](image)

3.2.4 Sub-Production Process Flow: OXAL

This process flow shows the sub-production line of the Oxal station which is the first step of the assembly line, only evaporators will pass the “Oxal station” where the product is chemically treated. The product is then moved to the valve assembly station where a valve is assembled to the core.
Most of the previously described lines were designed to produce high volume parts. Very low volume aftermarket parts run on the three CAC LV lines. One operator per line builds the cores manually at the three CAC LV lines. These lines are very flexible since they consist of interchangeable units. One core builder table and one fin machine and both units are on wheels. Consequently, changeover times are very short since there are few assembly steps for fins, meshes and cores. There is no change of tools at the CB and no change of form rolls at the airway machine as the entire unit is moved in or out of the line. However, the cycle times are longer compared to the HV lines due to the manual processing. The CAC LV lines, the Condenser LV line is also entirely manual, but there is a slight difference in the sense that the core builder is not on wheels so there is a little less flexibility.

4. METHODOLOGY

The method used was evaluating the products and the largest part of the total volume, analyzing the product mix, movement and balancing analysis in the production line in order to be able to see the imbalance in the system. Balancing charts were generated helps to analyse the balance in between the three fractals in the case study plant. Firstly, the generation of the chart is depicted, then, the chart is used to analyse the current situation considering from 6 months before.

5. RESULTS AND DISCUSSION

This section addresses the line balancing analysis for the production fractals. In order to conduct a line balancing analysis, it is crucial to appreciate the product mix and allocation to work centers as well as the variety of parts produced by the case study company.

5.1 Product Mix and Allocation to Work Centers

There are several products that run on different lines and there are aftermarket products with very low volume and high volume parts that go to Original Equipment (OE) customers. A Pareto chart was prepared so as to get an overview of the different parts and volumes and then the allocation of the products to the lines was visualized. The Pareto chart aids to evaluate which products make up the largest part of the total volume, as the EC plant produces lots of low volume aftermarket parts and high volume OE parts.
The volumes for the Pareto chart are taken from the heating fractal part numbers as the same product might have different assembly part numbers. The chart shows that there are 90 different brazed products and ten of those make up 80% of the total volume. Those ten are mainly CACs, Evaps, LTRs, one OE condenser model and the OE radiators. The allocation of products to work centres is crucial for ensuring high utilization of machines and assuring greater throughput. As already indicated, high volume products are processed at the OE radiator assembly line. In order to get an overview of the products and on which line they run, a matrix with a possibility to filter was created. It shows which products run on which core building lines and then are brazed on which profile.

The routes for the high volume OE parts that could also be identified through the Pareto chart are displayed in blue, whereas the routes of low volume parts, produced once a month or less are shown in grey. As displayed, the HV lines for the CAC and the Rad. OE resp. Rad. 4 are dedicated to one product category and the assembly lines are fed by only one part-building line if the very low volume that goes from the LV Hand core builders to the CAC HV assembly line is disregarded. More complex is the situation for condensers, LTRs and evaporators since the Cond/LTR line produces LTRs are high volume and go to the Rad./LTR assembly line and low volume condensers go to the Cond. assembly line and one high volume condenser model that is leak tested at the evaporator line. The evaporator pre-assembly line only feeds the evaporator Assembly line. Figure 10 displays more grey links between core building and assembly but those routes are not described in detail as those parts are only produced once a month or less. A balancing chart was compiled in order to ascertain if there was an imbalance in the plant and establish that causes furnace idleness and high inventory level.
5.2 Generation of balancing chart for product families

The balancing chart was used to indicate the relations between the three product families during core building, brazing and assembly; and depicted as bars that consist of the net cycle time as well as additional times for defects, scrap, downtime and changeovers so that their sum results in gross cycle time. In addition, the customer takt time is displayed in the chart to see the gross cycle time in relation to customer demand.

There are multiple lines with multiple products that go to core building and assembly, which results in varying cycle times. All those parts go through the furnace but due to varying sizes of the products, the parts are brazed while stacked upon each other and the different brazing profiles cycle times vary too. As a result, the net cycle time of the balancing chart is calculated using the average cycle times of the products weighted by their volumes. The cycle times per part number and work centre were recorded on the SAP system. These cycle times are a result of time studies using videos of the process and an MTM study based on the filmed material since operators had a tendency to slow down if observed by human beings.

In addition to taking the weighted average of the cycle time for CB and Assembly, the result was divided by the number of lines that are active at the same time as there is not only one CB or Assembly line running at a time. Then the net cycle time bars for CB and Assembly indicate how many minutes one core would require. The number of lines running simultaneously is determined by the number of teams working in Assembly or CB and additional time for defects, scrap, changeovers and other downtime.

Defects occur at core building and the affected part is reworked immediately at the line by removing the damaged part e.g. a defective airway or a tube is replaced with a new part and parts that are not brazed properly are re-brazed. If parts at assembly do not pass leak testing, they are sent to a separate rework area; the defective parts get reworked and then sent back to the assembly line where they have to be leak tested again. Therefore, defective parts at core building, brazing and assembly reduce the output of the fractal, which means they increase the cycle time. Parts that go for scrap have to be rebuilt, which means a scrapped part from assembly has to be replaced which means the parts has to go through the same process again, a new core from core building, get brazed and assembled. Therefore, scrap influences the previous fractals as well because they are only detected in the assembly fractal.

Downtime records are taken per line at assembly and core building and the percentage for the balancing chart is also calculated using the weighted average of the downtimes per line and the corresponding volumes. This is not necessary for the furnace as this is only one machine with one downtime percentage. For CB and Assembly, the additional time for downtime is calculated as the quotient of the setup time and the lot size of the product. The weighted average of those times is then added onto the net cycle time, for the furnace, the percentage of downtime due to changeovers is used. Customer takt time for brazing is different from other fractals CB and Assembly customer takt time (CTT) because of the different shift patterns and the difference in number of working hours, takt time to the frequency of a part or component must be produced to meet customers’ demand.

The furnace runs two shifts without breaks, but, however, it is not fed with cores in the last hour before the furnace goes to standby-mode since it takes an hour until work-in-progress reach the other end of the furnace. Therefore, 7.5 hours per shift multiplied by two shifts equals the available time per day for the furnace. Brazing run two shifts having half an hour of break per shift and ten minutes for a continuous improvement process meeting. Therefore, for CB and Assembly there is 7.33 hours multiplied by three shifts of available time per day. The available time per day multiplied by the working days of the considered period divided by the volume of the period.

5.3 Plant balancing charts analysis

The creation of a balancing chart, as depicted in Figure 10 by using volumes, available labour and working days resulted in the chart shown in Figure 11 and the time units for net cycle time, additional time for changeover, downtime and scrap is minutes.
The three bars represent the cycle times of core building, brazing and assembly, net cycle time and the additional times on top of it. The orange horizontal lines represent customer takt time for the fractal. At first sight, one would perceive that core building was not able to meet customer demand, as the gross cycle time is higher than CTT. However, this is not the case because the additional times for downtimes and changeovers do not carry great weight. This is because core building consists of 13 lines but currently only four of them are manned at a time. Therefore, the operators work on other lines during a changeover and during longer breakdowns. Consequently, the 0.069 minutes of additional time for changeovers does not have to be taken into consideration. The cycle time of core building depends on how many lines are running at the same time, which is dependent on the labour. Therefore, the quotient of the cycle time and the CTT does not result in the loading of the 13 core building lines. Core building is able to meet customer demand and it is capable of producing at a rate of one core every 0.539 minutes not taking into account the additional times for changeovers. Then the furnace is consuming parts at a rate of one core every 0.377 minutes but only running two shifts. In order to compare the two cycle times, the cycle time of core building is multiplied with two thirds:

- Cycle times for CB: $0.539 \times \frac{2}{3} = 0.359$ min
- Cycle times for furnace: 0.377 min

The results demonstrate that core building has the capacity to feed the furnace with enough cores. The balancing chart in Figure 12 shows that the brazing furnace is not fully loaded as there is a gap in-between CTT and the gross cycle time of brazing. After brazing, the products go to assembly. In contrast to core building, the downtime for changeovers is relevant. Indeed, changeover times are generally shorter as in most cases just the leak testing jigs and crimp tools have to be exchanged but the operators help doing the changeover so that they cannot work on another line in the meantime. Even so the gross cycle time of assembly is lower than the time of core build. As a consequence, assembly must be able to process all the parts that are produced at core building and heated afterwards.

The analysis of the balancing chart revealed that there should not be a lot of inventory awaiting brazing. As the balancing chart only displays cycle time for core building and assembly as a whole it could be that there are parts that have a very short cycle time for core building but need more efforts to be assembled so that they queue in front of assembly. Or else there might be multiple core building lines feeding one assembly line which...
is then not able to cope. But only the evaporator assembly line can be fed by two HV core building lines when the evaporator line produces one special condenser and evaporators yet these products may not account for the bulk of the cores awaiting assembly. In addition, the comparison of the cycle times of assembly and core building yields that the CT of CB is always higher or equal to the CT for assembly of the specific product.

Therefore, it was noted that the high inventory level could be possibly as a result of the assembly lines that do not produce at the rate of net cycle time even if there is no downtime or defect. This possibility was investigated by performing a value stream analysis to unveil the reasons for the large core queues behind the furnace. The VSM revealed that the radiator assembly line had a shortage of the manning only two operators working instead of three operators, which would be the ideal situation. The CAC and Rad/LTR lines had neither breakdown and nor manning shortage, but the leak testers were not fully utilised to their full capacity. The leak testing process was the bottleneck of the lines, instead of immediately unloading and loading, the leak testers, when they finished one product they performing other operations instead of loading the CAC and Rad/LTR lines. For instance, it was noted that at the CAC OE line the operator was packing the products in the cardboard box for shipping and at the same time the operator of the crimping station stopped working as the FIFO lane in-between crimping and leak testing was full. After more than five minutes the crimping operator would decide to unload the leak tester that was waiting to be unloaded for that duration, thereby making it impossible to reach the SAP cycle time.

Since it was noticed that the operators were not full-time utilising the capacity of the bottleneck workstations, a workshop for the operators was proposed and conducted. A revised future state balancing chart was then generated and Figure 12 shows the revised balancing chart for the period of time from August to December 2016. Compared to the chart from July the gross cycle time of core building has slightly decreased whereas the CT of the brazing furnace has increased due to increase in the volumes of a parts that has a relatively short CT at assembly but needs a slow brazing programme e.g. LTRs. The CT for assembly also increased. It was apparent that core building must be able to provide cores for brazing in time as the additional time for changeovers actually is not as high as indicated in the chart. Moreover, the assembly process should be able to process what comes out of the furnace as core building still has a higher cycle time than assembly.

![Figure 12: Balancing Chart August - December 2016 with time values in hours](image-url)
It was noted that capacity constraints can result in line imbalance and hence it is crucial to ensure that all workstations have enough capacity so as to abate excessive work-in-progress inventory. There are changes in terms of cycle times and customer takt times compared to the balancing chart from July and the balancing chart may need to change in the future, as a function of the product demand.

6. CONCLUSION

The allocation of work elements to work centres is crucial for responding to changes to product mix so as to introduce agility to assembly lines. Balancing charts can be used to improve a process through inventory reduction and other forms of waste such as idle time. Recommendations were proposed to ensure that workstations have enough capacity so as to abate excessive work-in-progress inventory and assure balanced lines so as to reduce the waiting time of the brazing furnace as well as inventory between the furnace and the assembly lines. In addition, in case of an imbalance, corrective measures should be implemented as soon as possible to avoid production losses.

REFERENCES
