Process Flow Modelling and Optimization of a Foundry Layout in Zimbabwe using Simulation

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Abstract

Foundry industry technologies have evolved over the years largely due to rapid changes in technology resulting in complexities that require careful planning and organization. Materials in the foundry industry pass through various stages and a number of factors, ranging from preparation of charges, materials handling and routing, furnace and production scheduling influence the process flows through these interconnected stages. Such a complex network of activities pose some challenges to companies that traditionally employ manual means of production planning. Research was carried out at one of Zimbabwe's largest foundry companies, prompted by the company's failure to produce affordable grinding media on time and in turn forcing their main customers to prefer cheaper imports. The work study revealed that the company's key challenges were in materials handling and transportation distances through the various workstations. This research focused on modelling the process flows using simulation with the aim of optimizing and reorganizing the foundry layout to reduce production costs, improve productivity and enhance efficiency. The resulting model of the optimal layout and process flows has been adopted and the company is gradually regaining its competitiveness and market share.

Keywords
Foundry, Layout, Modelling, Optimization, Simulation

1. Introduction

A multitude of factors influence the process flows of materials in a foundry, ranging from the raw materials storage area where the charges are prepared through the weighbridge, back and forth laboratory analysis for materials quality and content, materials handling and transportation to the various furnaces, smelting, casting, fettling and finally sales and dispatch to customers. Owing to the interconnectedness and multiplicity of factors through these various stages, systems of this nature increasingly become complex posing some challenges in the analysis of these dynamic factors. In such a scenario, advanced techniques such as modelling and simulation, genetic algorithms, neural networks or fuzzy logic are required to assist in analyzing or predicting the performance of the system (Negahban & Smith, 2014). Each of the techniques has its own advantages and disadvantages in much the same way as each will be more suitable for certain scenarios and environments than others. In this research and case study, modelling and simulation were chosen because of available expertise and the suitability of the techniques in process flow analysis. Models to be simulated can represent a real-world process more realistically because fewer restrictive assumptions are required (Baldwin et al, 2010). Consequently, simulation provides a more realistic replication of the dynamic nature of the flow of materials within a factory rather than to rely completely on static analysis, which can be misleading in establishing a good system (Patel et al, 2010).

The case study for this research was a foundry and general engineering company which was founded in 1905 to become the largest foundry in Southern Africa and has the largest machine shop in Zimbabwe, with the ability to machine individual castings in excess of twenty tons. The core business of the company is the casting and machining of grinding media of all specifications, ball mills, pumps, valves and numerous spares for all industries for the local and export markets. The company has been capitalizing on the opportunity for import substitution by designing and developing pumps, valves, stokers for tobacco curing systems, automotive and rolling stock spares. The plant consists of fully equipped departments with the following main divisions; Foundry, Castings, Metallurgical lab, Pattern Shop, Engineering Drawing and Design Office and the Machine Shop. In view of their planned expansion to incorporate a new rolling plant, they initiated part of this research with the aim of modelling and simulation of the whole plant in order to improve productivity and production efficiency. Due to the hash operating environment, the company thrives for engineering excellence by focusing on 'made to order' customer specified products as and when the orders come through. The other motivation to carry out this research was the general recession and financial crisis that affected the Sub-Saharan African region in 2008, forcing many companies to scale down and in some severe cases, liquidations and company closures (Bakrania & Lucas, 2009). Although the company is fully equipped, albeit with conventional machine tools, they scaled down operations owing to this crisis that resulted in reduced orders from traditional customers, who preferred to buy cheap imported substitutes particularly from Asia. In order to remain in business, they embarked on a program to diversify and in this regard they have invested significantly in new product development, including the setting up of a new rolling plant that will assist in increasing their turnover by producing flat and deformed bars, angle and channel irons, H and window frames as well as sheet metals, taking advantage of the capacity they have in terms of human resources and equipment. In addition, the company also sought ways to reduce their production costs through enhancing their efficiency and improvement of productivity. The recently installed state-of-the-art Continuous Casting Machine (CCM) in the new rolling plant added another dimension of complexity in their process flows, now requiring modelling and simulation tools for analysis, planning of production as well as predicting performance.

Observations made during the 'As-Is-Analysis' and work study revealed a number of flaws in the manufacturing setup, that if improved would reduce production costs. The major challenge noted was the distance travelled by raw materials throughout the various stages of production, coupled with the crisscrossing of process paths. The company has several furnaces commonly used in foundries such as, induction, arc, cupola and crucible furnaces for smelting different grades of metals. These processes are all energy intensive, requiring uninterrupted power supplies. However, the financial crisis also affected smooth supplies of power, in some cases load shedding that forced the company to halt operations. This challenge also required careful production planning to make use of the off-peak periods when power is generally available. The transportation of charges from the store yard through the weighbridge and eventually the molten metal from furnaces to the casting moulds is labour intensive even though the company has a durable 20 tonne crane within the foundry. Materials handling in all these stages and processes is manual, resulting in some spillages along the way and thus reduced productivity. The focus of this research was on the foundry furnace areas, linked with the various other units and stages in production with the aim of process flow modelling and optimization of the foundry layout through the use of modelling and simulation tools in order to reorganize and optimize the process flows to reduce operating and production costs as well as improving productivity and efficiency. The background of the research and other related cases were outlined, followed by a description of how the research was carried out, including modelling of the original plant, simulation using Arena and how this was used to optimize the plant layout. Finally, the reorganized model of the plant was presented followed by discussion, recommendations and conclusions.

2. Background and Literature Review

In recent years many engineering and manufacturing companies around the world have focused on addressing issues revolving around competitiveness while finding ways to remain in business through generating sufficient profit (Goldratt & Cox, 2014). Global competition in all spheres of engineering and manufacturing is gradually forcing companies to look at ways to cut on their production costs. Companies in the developed world, particularly Asia, are expected to outgrow the global market in the medium to long term because of their strategies to cut costs as well as using readily available labour (Deutsche Indusriebank, 2015). Thus, the companies in this part of the world have withstood the pressure because of their capacity to invest in new equipment and efficient technologies and thus are able to produce the same products as those manufactured by the case study foundry but at much less cost. The new equipment and technologies are able to deal with materials handling competences and the rise in complexities of casting alloys, thereby reducing waste through spillages. The growing trend in foundry industries around the world are pointing towards the production of completely finished cast parts ready to be used by customers unlike the traditional trends where cast parts are frequently reworked on or adjusted to customers' requirements before use (BDG German Foundry Association, 2015). This is partly the reason why traditional customers for the case study company have been opting for cheaper and ready-to-use imports. This will necessitate investment in new technologies and equipment in the future, to deal with global competition as well as complexity of foundry materials which are also rapidly changing.

The case study foundry uses different technologies for smelting and casting. Owing to the scaling down of production, the company now focusses on using the induction furnaces more than the arc, cupola and crucible furnaces. The available five induction furnaces vary in capacity from 400 kg to 2 tonnes. This induction technology uses the magnetic coupling principle where the housing is lined by refractory bricks and surrounded by a continuous coil which produces a magnetic field that links up with the charge in the housing, generating eddy currents which heat up the raw material charges to temperatures of about 1600^{o}C. The two arc furnaces use graphite electrodes that produce arcs to melt the raw material charges, similar to the reverse of arc welding. The arc furnaces have a similar range of temperature and thus consuming more or less the same energy as the induction furnaces. However the arc furnaces have the capacity to have their temperature ranges adjusted upwards. The three cupola furnaces use the conventional method of smelting similar to the blast furnace where the mild steel cylinder, lined by refractory bricks is surrounded by coke which is heated by blowing hot air through the chamber up to temperatures of about 1500^{o}C. Although this is the more affordable technology for smelting in terms of energy, the case study foundry has not been using these furnaces because of unavailability of coal, hence the production of cast and white irons has been scaled down a great deal. Non-ferrous metals such brass, bronze, copper and aluminium are also cast from time to time using the crucible (Morgan Tilt) furnace which uses the same principle as the cupola furnaces. The recently installed CCM for the new rolling plant will employ the induction furnace technology. Products at the company are either die casted, in the case of medium (80mm) to large (120mm) grinding balls or sand casted, in the case of liners, valves and other jobbing requests brought in by customers. The smaller size (35mm) balls are produced by sand moulding machines. The 3 casting areas are adjacent and close to each other such that molten metal from any of the furnaces can be poured onto any of the casts depending on demand and requirements. Due to lack of capacity and equipment, the company rarely employs other forms of casting such as shell moulding and investment casting which is mostly used for ornamental trinkets in gold, silver and other precious metals and also for complex shapes that cannot be produced easily such as turbine blades (Venkata Rao et al, 2013). The major challenge in the company's production is the need for fettling after casting in order to clean burrs and remove excess waste created by the runners. This process is manually handled and hence the costly products. Although the focus of this paper was not on automation but production planning and materials movement, recommendations were made to automate the fettling of products before dispatch to customers.

The flow of materials between workstations should be coordinated, balanced, natural, flowing and characteristic to avoid overload at any workstation during production, which can be resolved by parallel processing (Kadane & Bhatwadekar, 2011). The effective flow between departments is used to evaluate the flow within a facility which depends on effective flow between workstations. There should be minimal crisscrossing and backflows of process paths otherwise long distances travelled by parts will raise the cost of production. This can be achieved by ensuring that materials are transferred directly to where they are required in such a way that the flow pattern is expandable in case new materials are added to the flow. Work in process should be minimized in-order to reduce waiting time for raw materials to be processed (Curry & Feldman, 2011). The positions of workstations in any manufacturing setup have to be done in a strategic way in relation to the movement of materials through the system in order to ensure; an even flow of work, materials and information, efficient utilization of resources, minimization of production time and handling costs and elimination of bottlenecks. As such, documentation of the materials handling and process flows and mapping require that performance objectives and functional specifications of the methods are completely defined and that materials handling equipment, methods and software are consistent within the limits of accomplishing overall performance objectives without forgoing the required flexibility and throughput (Kay, 2012). Along with these recommendations, previous researchers have also highlighted the need to carry out analysis of the quantum of materials loaded and transported, human resources capabilities, utilization of available space within the boundaries of the factory, automation of the materials handling as far as possible, integration of the process flows and workstations to form a coordinated and operational system and life cycle analysis and projection of the materials handling system (Kay, 2012). The manufacturing throughput time i.e. processing, inspection, movement and waiting (idle) time is the key parameter to focus on in order to reduce product costs. Concentrating on each of the four times and experimenting with simulation helps in reducing throughput time which leads to improved quality, lower inventory costs, flexible system and timely delivery of customer orders (McBride, 2003). One of the key objectives in any manufacturing setup is to reduce waste as much as possible as this does not add value to the product but instead it raises production costs (De Felice & Petrillo, 2015). The major contributors to product costs are within the seven wastes of lean manufacturing, i.e. transportation, inventory, movement, waiting (idle), over-processing, overproduction and defects (Rahani & Muhammad, 2012)

Although modelling and simulation tools have been used widely in engineering and manufacturing such as the case studies that have been outlined, the application of the same tools in foundries and in particular, casting has been limited (Nimbulkar & Dalu, 2016). In the few cases, challenges have been encountered such as porosity defects in sand castings of spheroidal graphite cast irons and handling of fluctuating materials content (Ohnaka, 2015). Having established the background to the case study company, the challenges it has been facing, this study set out to answer research questions revolving around what the major challenges giving rise to high cost of production are, what technologies are employed by other companies, especially in Asia to be able to produce the same grinding media at much lower costs? From the observations made during the work study and 'As-Is-Analysis', it was evident that the bottlenecks were more pronounced around the furnaces with delays in the transportation of materials before and after smelting as well as the smelting process. Hence the focus for modelling and simulation in this research was centered on these areas to answer the question on how these techniques can help in lowering production throughput times and how this would impact on the overall product costs, production efficiency and productivity.

3. Research Methodology

The research was carried out in 2015 at the company's main division of foundry and general engineering machine shop in Harare over a period of six months, focusing on the 'As-Is-Analysis' and work study where models for the original setup were developed in parallel with data collection. Further to this, the data was analyzed and deciphered for use in simulation using Arena followed by experimentation and eventual derivation of the optimal layout based on the simulation results. The drawings, models and illustrations in this paper were developed using AutoCAD 2012 or extracted as snapshots from the simulations carried out in Arena and these are annotated accordingly in the paper.

3.1 Work Study and Data Collection

The company's raw materials are mainly scrap metal supplied by scrap metal dealers and merchants as well as from the mines. Most of the dealers and merchants bring in their scrap metal mixed with different materials and the company carefully segregates these before smelting and all their products are tested either by the Standards Association of Zimbabwe or the Metallurgical Quality Testing organization and the certificates they obtain are not only used to market their products but also for back-up and customer support. For general engineering (jobbing) and repairs, the raw materials are the parts supplied by customers for either casting or machining. The company currently has 5 engineering departments as shown in Table 1 but will soon have a 6^{th} one for the CCM. In conjunction with the projects division, the electrical and mechanical maintenance units provide servicing and repair of all machines.

Table 1. Departments Machinery, Operations and Processes

Department	Machinery	Operations and Processes
Pattern Shop & Drawing Office	Wood processing machines - rip saws, bend saws Lathes, pattern millers, planers and sanders	Cutting raw timber to specific sizes and profiles Turning and milling required patterns and shapes
Foundry	5 Induction, 3 Arc, 3 Cupola & 1 Crucible Furnaces Grinders	Smelting the different types of scrap metal Grinding and fettling cast products
Machine Shop	Centre Lathes, Milling & Drilling Machines	Turning, Milling & Drilling (Jobbing)
Projects & Maintenance	Lathes & Drilling Machine Press Machine	Turning & Drilling components and spares Pressing parts together during repair
Metallurgical Lab	Spectrometer, Hardness Tester, Drop Tester	Analysis of Metal Tensile Strength, Yield Analysis of Metal Strength and Hardness Testing the weight/quality of balls
CCM Rolling Plant	Induction Furnace and plant under construction	Rolling of flat, angle and channel iron bars

Focus for this research was however on the foundry section although this is central and interconnected to the rest of the departments. The research assistants who collected data were also attached to the various departments and units in order to have a comprehensive and appreciable understanding of the entire operations. The data that was collected was mainly process flow distances from one workstation or department to another as well as the processing, transportation, waiting (before and after processing) times focusing on the production of 80 mm grinding balls, a detailed typical batch shown in Table 2. This was carried out for different batches over the six months period.

Table 2. Activities and Time for the Flow and Manufacture of 80 mm Grinding Balls

Activity	**Time / mins**
Baling	10
Waiting	5
Loading - Truck	45
Transportation - Foundry	10
Offloading	10
Loading - Crane	3
Transportation - Furnace	5
Offloading	1
Charging into Furnace	10
Processing (Smelting)	220
Lab Testing & Inspection	20
Offloading into Ladle	2
Transportation - Casting	10
Pouring into Die	40
Waiting for solidification	5
Waiting for cooling	120
Loading - Truck	60
Transportation - Fettling	10
Offloading	110
Fettling	1080
Loading - Dispatch	110
Transportation - Dispatch	10
Offloading in Dispatch	60

The average number of movements of materials per day between interacting workstations were also recorded as shown in Table 3 and the distances between these workstations were measured and are shown in Table 4.

Table 3. Number of Movements per Day

Workstation	Scrap Yard	Furnace	Casting	Fettling	Lab	Weighbridge	Machine Shop
Scrap Yard		5	5	0	3	5	0
Furnace	6		7	1	1	3	0
Casting		8		5	2	0	4
Fettling	0	1	10		2	5	3
Lab	20	15	5	12		3	4
Weighbridge	3		2	2	3		3
Machine Shop	0		2	3	0	1	

Table 4. Distances between Interacting Workstations

From	**To**	**Distance (m)**
Scrap Yard	Weighbridge	25
Weighbridge	Induction Furnaces	237.7
Induction Furnaces	Laboratory	18
Induction Furnace	Casting/Fettling	31.7
Fettling	Stores	205

3.2 Modelling of Original Setup

Apart from observing and recording the number of movements of materials between interacting workstations as well as measuring the distances between them, the original setup at the company was also modelled to show the process flows through all the departments and units as shown in Figure 1, a snapshot developed and extracted from AutoCAD 2012.

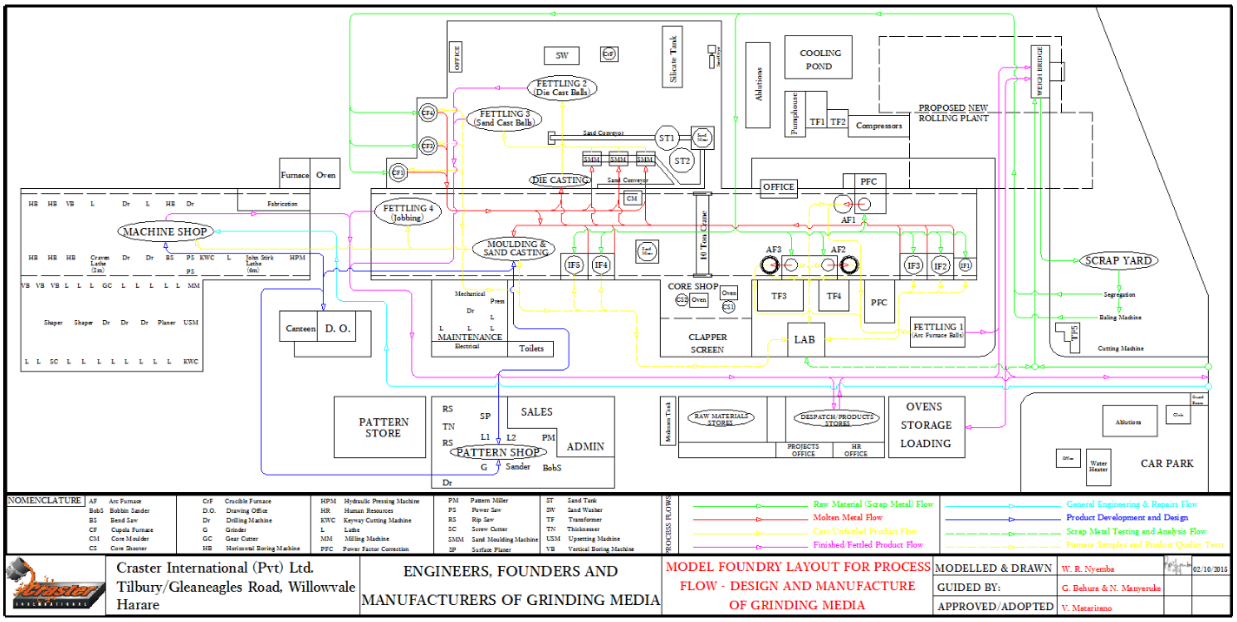


Figure 1. Model Process Flow Foundry Layout in Production of Grinding Media

3.3 Modelling, Simulation and Optimization

Following the study of the processes and the collection of the times and distances data between interacting workstations, the model of the layout as given in Figure 1 was developed in Arena simulation software. This was the only available simulation software at the time of carrying out the research. The key parameters that were set and used in the Arena model were processing times and the various machines at each workstation, focusing on the furnace areas and their interconnections to the other workstations. The machines were scheduled to a Seize-Delay-Release action, implying that the machines would receive the batch (seizing), process it (delay) and release it after the processing. The priorities of the processes were set as high, medium or low depending on the priority for each process and whether it was value adding or non-value adding. The times were also used for the model as triangular delay type, implying that apart from the average processing time, the maximum times as well as the minimum times were also entered in the model. Figure 2 shows a summary of activities in the production processes for the 80 mm grinding balls. The models developed were however limited in size because of the academic version of the Arena simulation software used, hence some of them had to be broken down and synchronized later.

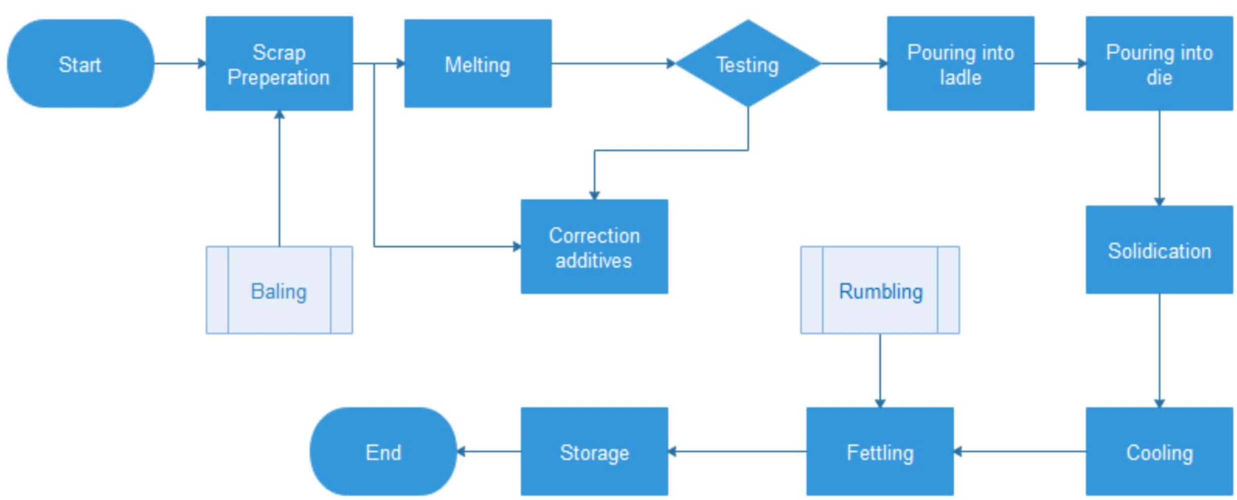


Figure 2. Process flows for the production of 80 mm grinding balls

4. Results and Optimization of the Foundry Layout

A detailed analysis of the processes involved in the manufacture and production of 80 mm grinding balls was performed through the various stages in the foundry. Based on the original model foundry layout as shown in Figure 1, the process of the die casting of the grinding balls was modelled in Arena followed by simulation which provided an overview of the process flows in the system. The series of figures that follow are snapshots obtained from the simulation runs, showing the results that were obtained.

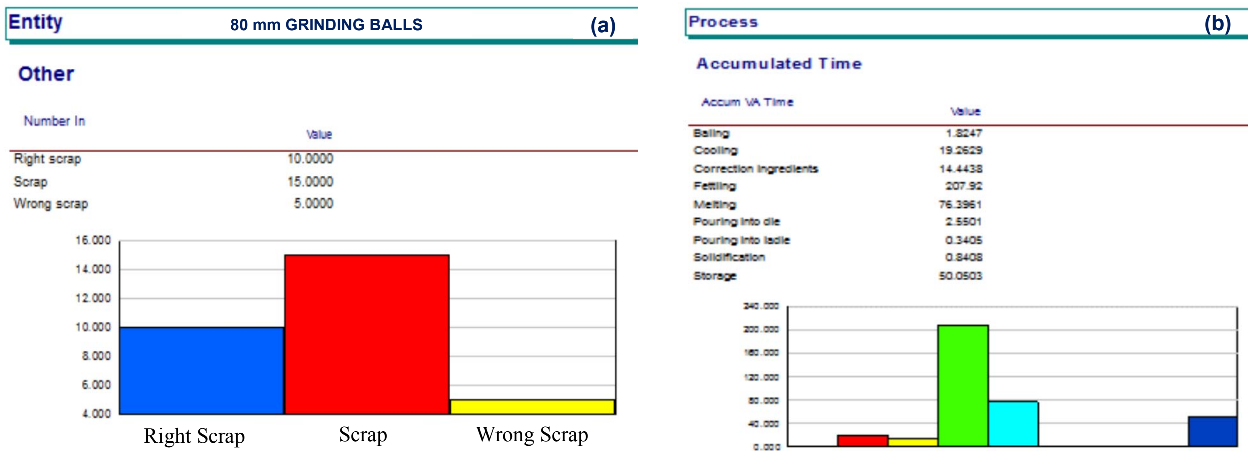
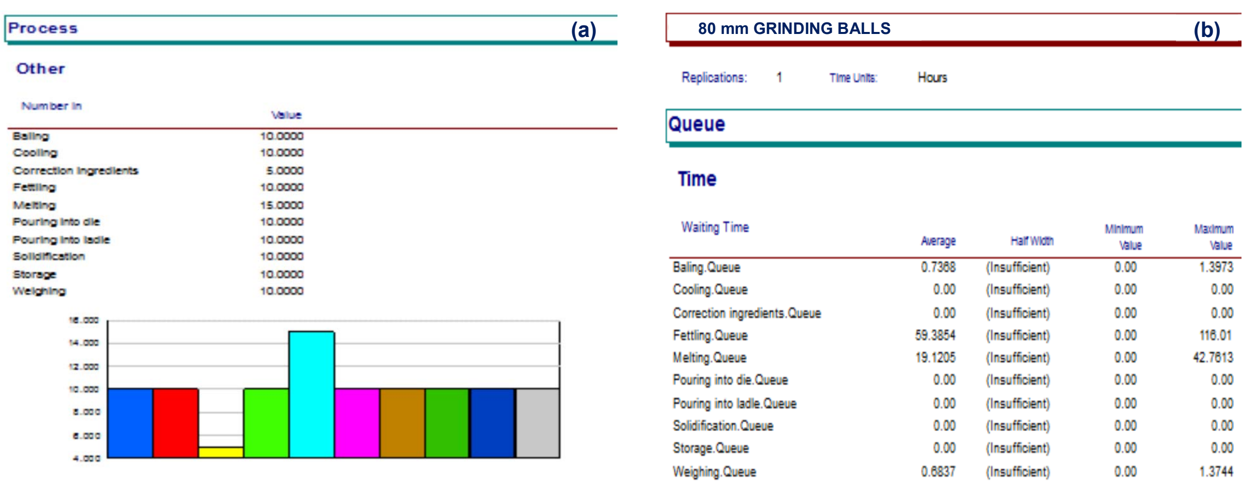


Figure 3(a). Scrap quantity into of production and (b) Accumulated time for the die casting process

Figure 3(a) shows that out of a total of 15,000 units of scrap, 10,000 units were acceptable (blue) and the other rejected (yellow). Valuable times per entity were obtained from the Arena simulation at the various stages of production together with non-valuable added time per entity for the weighing process. The processing and waiting times for each entity at the various stages were obtained and noted. The accumulated value added time as shown in Figure 3(b) is for the production processes after 20 replications were made as well as the accumulated non-value added time for weighing. Figure 4(a) shows the number of entities which entered and left the different processes while Figure 4(b) shows the queuing and waiting times at each stage of the production processes.



Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Baling.Queue	0.7368	(Insufficient)	0.00	1.3973
Cooling.Queue	0.00	(Insufficient)	0.00	0.00
Correction ingredients.Queue	0.00	(Insufficient)	0.00	0.00
Fettling.Queue	59.3854	(Insufficient)	0.00	116.01
Melting.Queue	19.1205	(Insufficient)	0.00	42.7613
Pouring into die.Queue	0.00	(Insufficient)	0.00	0.00
Pouring into ladle.Queue	0.00	(Insufficient)	0.00	0.00
Solidification.Queue	0.00	(Insufficient)	0.00	0.00
Storage.Queue	0.00	(Insufficient)	0.00	0.00
Weighing.Queue	0.6837	(Insufficient)	0.00	1.3744

Figure 4(a) Number of entities into production and (b) Waiting times at every stage of production

Figure 5(a) shows the scheduled usage of resources for the individual processes while Figure 5(b) shows the quantities seized at each of the workstations.

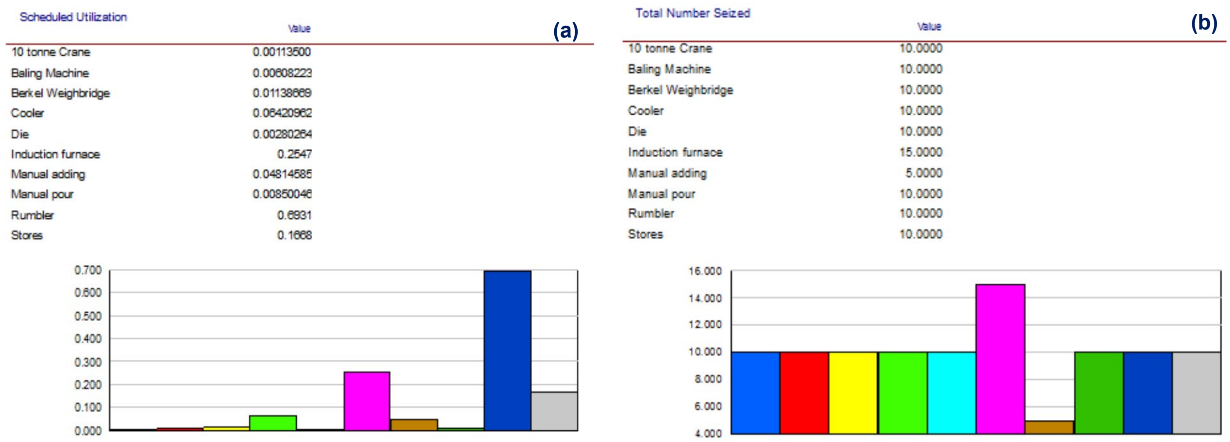


Figure 5(a) Scheduled usage of resources and (b) Quantities seized at each workstation

Evidenced by the 'As-Is-Analysis' that showed that process paths were either unnecessarily long or crisscrossing, the first stage in obtaining an optimal layout was to reorganize the routes with minimal changes to positions of workstations in the foundry in order to reduce the distances travelled by parts through the system. Most of the workstations were located adjacent to each other except for the weighbridge and stores. Because of space constraints, only the weighbridge was recommended to be moved close to the scrap yard such that charges are weighed immediately after baling and transported straight into the foundry. The distance from fettling to stores was also reduced by introducing a more direct route between the two. Space for the revised routes could easily be managed by moving obsolete equipment stored between the scrap yard and foundry. The rerouted process paths are summarized in Table 5.

Table 5. Distances and Times between Workstations before and after rerouting

Workstations	Distance before/m	Distance after/m	Transportation time before/mins	Transportation time after/mins
Scrap Yard – Weighbridge	25	15	1	0.6
Weighbridge – Furnaces	237.7	33.3	11	1.54
Fettling - Stores	205	150	10	7.32

Queueing times at some of the workstations prompted the need for the addition of extra machines for baling and fettling implying that more materials would be seized. In cases of high demands for grinding balls, the company uses the 2 tonne induction furnaces which are adjacent to the hand-moulding section from where the crane is used to carry molten metal from the furnace to the end of the hand moulding section. However the crane's movement is limited thus the remainder of the distance, rails are used. This challenge was resolved by introducing another rail across the 2 tonne furnaces to the die casting section and the use of smaller ladles owing to the lower cost of running a rail compared to extending the overhead crane. This also helped in reducing energy costs by enabling the company to produce during normal working hours instead of during the off peak periods. The simulation results and data collected during the research, particularly the average times spent by products on specific processes and the waiting times were the key parameters used to obtain an optimal layout. Qualitative and quantitative analysis were also done through observation of the simulation runs to feed into the optimization process. The undesirable scrap that entered the production process was observed to queue on the baling, weighing, smelting and fettling processes contributing to unnecessary delays in production. From the quantitative results it was also observed that fettling and baling processes were taking more than expected times and thus required attention in-order to speed up processes at these workstations. During the experimentation, an additional machine was incorporated in each of these 2 processes resulting in a marked improvement in the reduction of waiting time as shown by the following statistical graphs, Figures 6(a) and (b).

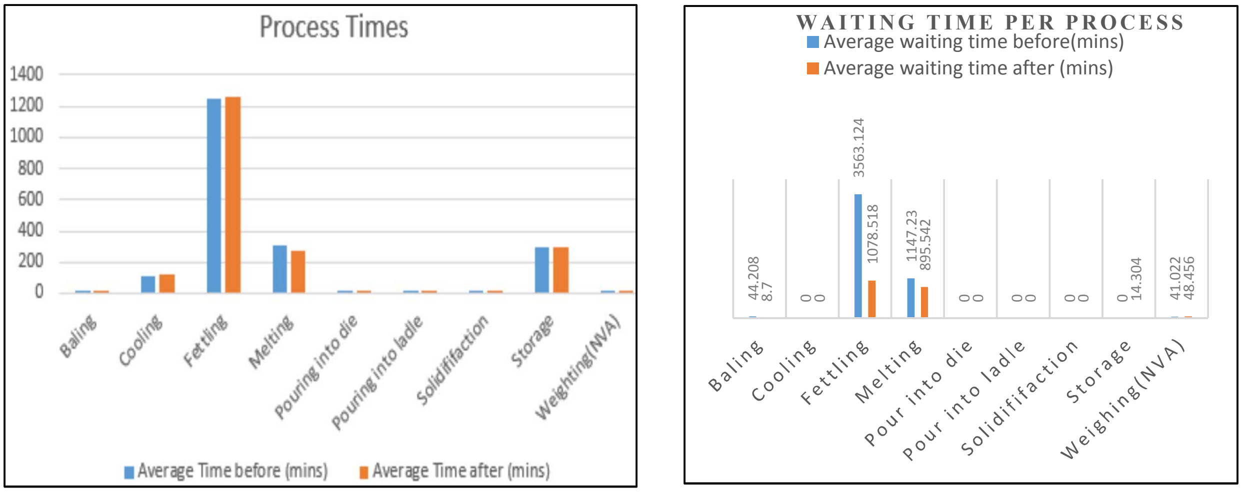


Figure 6(a) Process times before and after optimization (b) Waiting times before and after optimization

Decreases in process times were observed in most of the processes with slight increases in storage, weighing and pouring into the ladle. The highest waiting times were observed on fettling with the lowest on weighing. Decreases in waiting times were observed on baling, fettling and melting with slight increases in the storage and weighing times. The throughput time per batch was used as a manufacturing measure to gauge the efficiency of the processes. This was determined by summing all time variables at each of the workstations and then comparisons were made between the throughput before and after the reorganization of the foundry layout and process paths.

5. Discussion and Recommendations

Facility layout challenges in manufacturing environments such as a foundry can be quite complex to be resolved by traditional means especially if there are different workstations in operation but intertwined and depending on each other. When the number of units within the company is large, the material flow volumes between departments are random and a flexible layout is desired, the problem becomes much more complex and usually intractable analytically. This requires more advanced techniques and in this research, modelling and simulation were used to experiment on different options in the foundry layout. The capacity of each workstation at the foundry and the bottlenecks were identified from running the model in Arena and the results obtained thereof. Experimentation through further simulation runs of the model was carried out on the different and feasible possibilities such as rerouting the process paths, varying the positions of some of the workstations and adding parallel machines at workstations where queues were observed. As these different variables were tried out, it aided in deciding whether or not to revise the capacity until minimal distances and times were obtained, which was considered the optimal arrangement. The remodeled plant layout with workstations in their new positions were also simulated to verify and validate the optimal arrangement. Based on the 2 models' expected output, the throughput for each layout was used to compare the different possibilities and in particular the original foundry layout. The results of the simulation runs helped to identify bottlenecks within the process flows which corresponded to the problems identified during the work study as well as interviews with shop floor personnel and management, challenges that were replicated in running the simulation model for the original layout, thereby validating the causes. The major problems identified were, long and crisscrossing process paths that contributed to inefficiencies in production as well as long processing, transportation and idle times at some of the workstations, which contributed to high costs of production. Although focus for this research was on the furnace areas, the entire processes of the foundry are interconnected and any adjustments that were made in that area impacted positively on the rest of the processes in the foundry.

The number of movements and the transportation times between interacting workstations were also analyzed from the simulation output to identify problems areas in order to address these through experimentation of variables and options. Each improvement was analyzed separately and from the reorganized layout, savings were realized through rerouting and use of additional machines at busy workstations. Fortunately the company had additional machines which were not being utilized because of low demand brought on by customers preferring cheaper imported grinding balls. This research assisted in decision making on where to use the machines that were idle. Additional machines at the seemingly busy workstations such as baling and fettling assisted in reducing idle and waiting times. The manufacturing throughput time per batch was computed from the summation of all the variable times for processing, waiting and transportation at each workstation. The throughput time for the original arrangement was compared with the times for the proposed and reorganized foundry layout obtained from the simulation runs and the setup that gave the highest reduction of 58% was chosen as the optimal layout. This reduction corresponded with the reduction in transportation distances from 467.7m to 198.3m as a result of the proposed direct process paths between interacting workstations as well as the proposed relocation of the weighbridge to an area adjacent to and between the scrap yard (baling) and the furnaces (smelting).

With the anticipated savings from the reorganization of the foundry layout, the company is expected to gradually lower the production costs of grinding media, thereby remaining competitive. The savings can also be used to invest in other forms of high technology tools such as the Andon Light System for detecting manufacturing systems abnormalities and resolving them through viewing real time processes and tracing production events. Effective workstation management can be achieved through different alerting options such as emails, audio announcements and visual displays. Even though fuzzy logic was not employed in this research, it is recommended for condition monitoring and control of the various machine tools at the workstations. Further investments were recommended for automation, especially in view of the recent instalment of the CCM as well as the use of a commercial version of the Arena simulation software. In line with automation and the challenges observed in materials handling, Automated Guided vehicles (AGVs) will also be of great value to the company especially in the jobbing section for quick loading and unloading of parts or materials through the foundry and its auxiliary sections.

6. Conclusions

Appropriate layout of machine tools in any manufacturing environment is critical, more so for a foundry where each workstation in the system is dependent on the others. The flow of materials through the system and the processing thereof, increasingly become complex in a setup where there are several units interconnected. The case study company has several such units that are interconnected in the processing and production of grinding media for the mining industry in Zimbabwe. Their traditional customers were preferring cheaper imports which were readily availed when needed but this company was failing to meet these needs coupled with failure to match prices for the imported products. A number of changes were proposed such as the relocation of the weighbridge, more direct process paths and flows between interacting workstations as well as adding more machines at workstations that were observed to have consistent queues. There were marked decreases in processing, waiting and transportation times within the reorganized layout, while the distances of the rerouted process paths decreased from 467.7m to 198.3m, which is expected to translate to reductions in product costs and improvements in yield and process efficiency. The manufacturing throughput time correspondingly decreased by about 58% compared to the original layout. Bottlenecks observed during the work study were identical to those obtained from the simulation runs and experiments, thereby validating the models. Although the company has gradually been implementing the proposed changes, there has been some slight increase in customers placing orders for grinding balls. This is however expected to improve as all the changes are completely implemented, coupled with the functional CCM. While this research contributed to resolving some of the challenges faced by the company in developing an optimized foundry layout, the company should consider investing in more equipment and technology such as the Andon Light System for detecting manufacturing defects, commercial version of the Arena simulation software, AGVs for ease of transportation of materials through the system as well as the use of fuzzy logic for monitoring and control of machine tools at workstations.

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