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QUALITY IMPROVEMENT OF FOUNDRY OPERATION IN NIGERIA USING SIX SIGMA TECHNIQUE

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ABSTRACT

In this paper Six Sigma DMAIC analysis was applied in an aluminium mill in order to identify sources and causes of waste with the intention of providing veritable solutions. The foundry section was the segment under scrutiny. Re-work or defects in this firm was found to be on the average of about 37.05% of total production for the twenty-three months under study (January 2009- December 2010). Defect reduction was therefore chosen as the Critical-to-Quality (CTQ) factor. The sigma level of 1.87 in the firm indicated the existence of opportunities for improvement. Analysis was carried out using SPSS, SPC for Excel to perform regression analysis, process capability analysis, generate descriptive statistics, histograms and run charts. The results of these analyses identified three major defects and some of their behaviours. Based on the analysis, solutions were proffered in the Improve and Control phases of this project. Implementation of the proffered solutions resulted in noticeable improvement and led to the firm operating with near- perfect processes thus proving the applicability of Six Sigma.

Keywords: Six sigma DMAIC, critical-to-quality, composition error, profile error, trimming error.

INTRODUCTION

Generally, it is typical of manufacturing processes to produce up to 69.1% as waste since production processes normally function at 1-2 sigma (Kaushik *et al*., 2008). It could be worse in many production firms where little attention is paid to quality control and improvement. This lack of quality may be in terms of customers' dissatisfaction, delay in delivery, defective products and services or waste of resources. Manufacturing firms of the current age are faced with stringent economic conditions, stifling competition and increasing customer awareness among other factors. All these places high demand on manufacturers to constantly produce high quality products in the best way possible. Also, manufacturing industry occupies the central stage in nations' development and in the world economy. The well-being of a nation is thus determined by its capability to convert raw materials to desirable finished goods. One of such processes involved in manufacturing is the foundry operation.

Foundry operation which involves the melting of billets and/or scrap metals is a highly energy and labour intensive operation (Su and Chou, 2008). Waste generation and lack of quality is however a serious issue militating against the efficient performance in foundry operation. Since profit making remains a major objective of every business, value addition and quality improvement have to be given due attention in order to save money and increase revenue. Achieving this objective requires the implementation of such techniques as Six Sigma. Presently, many foundries are interested in implementing Six Sigma to improve the quality of their products (Su and Chou, 2008).

Six Sigma is the application of scientific method to the design and operation of management systems and business processes which enable employees to deliver the greatest value to customers and owners (Pyzdek, 2003; Pantano *et al*., 2006). It is a disciplined, systematic, data-driven approach to process improvement that targets the near-elimination of defects from every product, process and transaction (Evans and Lindsay, 2005; Aggogeri and Gentili 2008; Kaushik *et al*., 2008). Although, it involves measuring and analyzing an organization's business processes, Six Sigma is not merely a quality initiative; it is a business initiative (Pande and Holpp, 2002; Lee-Mortimer, 2006).

The effectiveness of Six Sigma in improving quality and reducing waste has been proved in various sectors by both scholars and practitioners (Treichler *et al*., 2002; Goffnett, 2004; Banuelas *et al*., 2005; Kwak and Anbari, 2006; Aksoy and Orbak, 2009; Ung *et al*., 2007; Gijo and Scaria, 2010; Falcón *et al*., 2012). It has, as a numeric goal; the reduction of errors in output to an outrageous but possible and much desired 3.4 parts per million (Antony and Banuelas, 2002). It also has a business goal of improving customers' satisfaction, reducing cycle time and defects (Antony and Banuelas, 2002; Rajagopalan *et al*., 2004; Evans and Lindsay, 2005; Parast, 2011). A process functioning at 6 sigma level is expected to produce satisfactory outputs 99.99966% of the time (Antony and Banuelas, 2002). The main benefit of a Six

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Sigma program is the elimination of subjectivity in decision making, by creating a system where everyone in the organization collects, analyzes, and displays data in a consistent way (Maleyeff and Kaminsky, 2002).

Implementing the Six Sigma as a defect reduction technique in the Nigeria manufacturing firm is key to national growth. Hence, the objective of this work is to reduce defects in foundry operation by applying the principal Six Sigma methodology known as DMAIC (Define, Measure, Analyze, Improve, and Control). Details of DMAIC methodology applied in this work are comprehensively discussed in Pyzdek (2003) and De Koning and De Mast (2006). The charge preparation, melting and casting operations of the foundry under study remain the focus.

PROCESS DESCRIPTION

The factory engages in secondary production of aluminium i.e. scrap processing rather than smelting or extracting aluminium from its major ore which is Bauxite. Hence the process includes scrap acquisition, sorting, bailing, weighing, charge mixing, melting and holding, casting, cold rolling, embossing and slitting; and weighing and sales. The process flowchart of the foundry is shown in figure 1. However, the processes of concern in this paper are limited to charging preparation, melting and casting operations.

Charge preparation/mixing

Pure aluminium ingots are mixed in proportion to the scrap by trained metallurgists to produce the desired class. The charge content is determined by the series of aluminium to be produced.

Melting and Holding

Charge melted in the melting furnace at roughly 850^{o}C is fluxed, degassed and dross removed manually by the use of fork lift. The molten aluminium is then poured into the holding furnace which is held at about 750^{o}C whereas the melting temperature of pure aluminium is 660^{o}C. Spectroscopic analysis of the molten aluminium is done to determine the composition. In the event of variation from the desired content, necessary amounts of the constituents are added into the holding furnace to neutralize the variation. The melt correction continues until the desired composition is attained after which the holding furnace is tilted to feed the caster.

Casting

Casting which is the continuous type is done by hot rolling at temperatures ranging from 680 to 700^{o}C. The melt flows from the holding furnace through a channel and it is deposited right in between the upper and lower rollers of the caster through a nozzle. The rollers give shape to the melt by compression and slight cooling. The rollers are sprayed with graphite which serve as lubricant and also prevent direct contact with the metal. Contact between the metal and the roller usually leads to the formation of serious defects. The cast is coiled around an iron core and allowed to cool in air thus ensuring slow cooling and homogenization of the microstructure.

MATERIALS AND METHODS

The key steps followed in using the DMAIC methodology and the tools used in each phase of the study are as shown in table 1 (De Koning and De Mast, 2006). The project goals and customer requirement were defined in the first phase. Second phase measures the process to determine current performance; analysis and determination of the critical input variables for process improvement were done in the third phase. The fourth phase improves the process by eliminating sources of defects while the fifth phase controls the improved process performance.

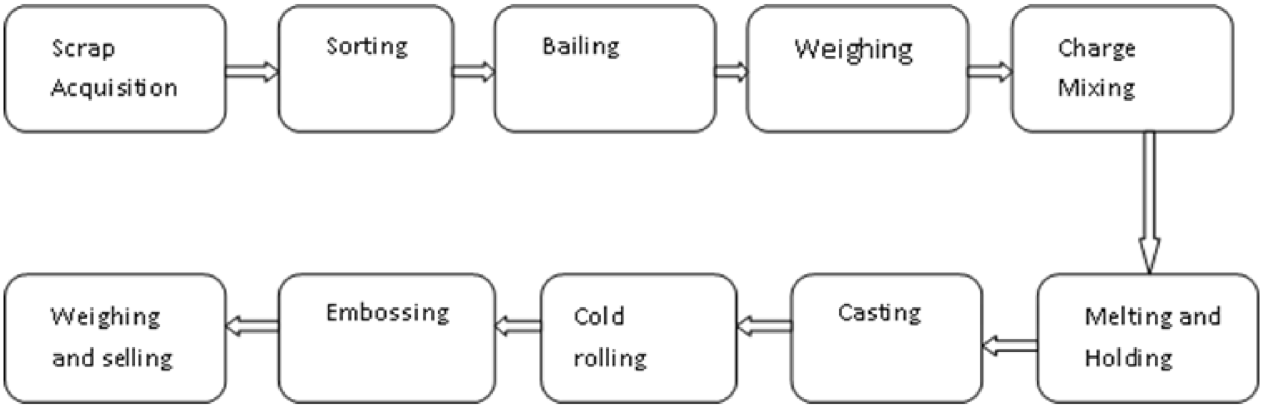


Fig. 1. Process flow chart for the foundry.

DISCUSSION

1. Define Phase

At this phase, the problems concerning (i) who the customers are and (ii) what the customers require were defined. The top management and the quality control department were considered as the customers in this case. Defect reduction was the selected Critical To Quality (CTQ) measure due to the pronounced problem of defects in the Aluminium rolling mill. Tools such as Voice of the Customer (VOC) and Voice of the Process (VOP) were used to make this selection. The Voice of Customer was obtained by direct interaction in the form of interviews and discussions with top officers of the Quality Control department. The responses showed that rework is the major concern within the scope of production.

The voice of the process was obtained from multiple first-hand observations and guided tours of the entire production line. The factors of the process observed were the people, technique, equipment, input material and environment. Observation of the process showed that defect reduction remains the primary target as the delay was not a critical problem; defective products are never sold since the final customers will be dissatisfied with the product. This further supports the selection of defect

Table 1. Phases of Six Sigma DMAIC methodology.

Phase	Items	Tools
Phase 1: Define	Who the customers are What the customer require The Critical To Quality Analysis of the ability to process improvement	Voice of customer (VOC) Voice of process (VOP) Supplier Input Process Output Customer (SIPOC)
Phase 2: Measurement	Determine the sigma level of the process Identify inputs Non-conforming products, Defect type and probable cause	Statistical Process Control (SPC)
Phase 3: Analysis	Exploratory analysis Identity potential critical inputs Description analysis Analysis of the ability to process improvement	Process capability analysis Descriptive statistical analysis Run charts Regression analysis Ishikawa (Fishbone) Diagram
Phase 4: Improvement	Analysis of improve of the process	
Phase 5:: Control	Implement control plan Verify long term capability Continuously improve process	

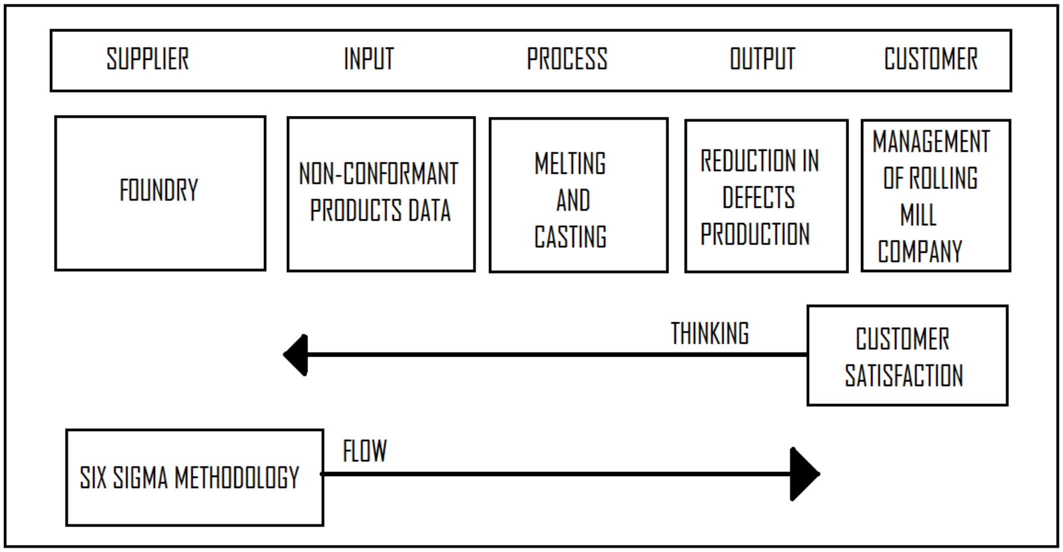
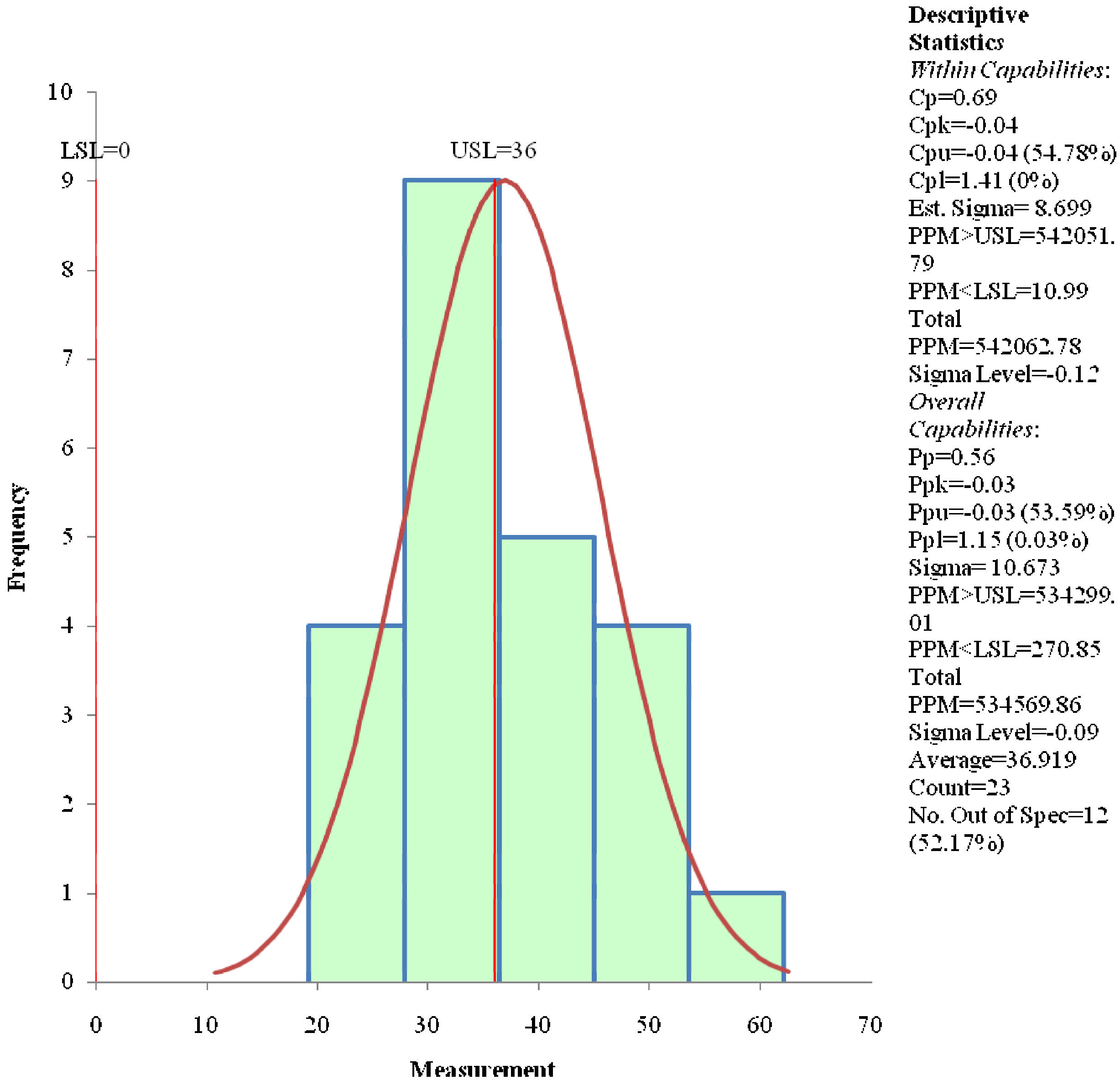


Fig. 2. SIPOC diagram for defects and waste generation.



Descriptive Statistics
Within Capabilities:
Cp=0.69
Cpk=-0.04
Cpu=-0.04 (54.78%)
Cpl=1.41 (0%)
Est. Sigma= 8.699
PPM>USL=542051.79
PPM<LSL=10.99
Total PPM=542062.78
Sigma Level=-0.12
Overall Capabilities:
Pp=0.56
Ppk=-0.03
Ppu=-0.03 (53.59%)
Ppl=1.15 (0.03%)
Sigma= 10.673
PPM>USL=534299.01
PPM<LSL=270.85
Total PPM=534569.86
Sigma Level=-0.09
Average=36.919
Count=23
No. Out of Spec=12 (52.17%)

Fig. 3. SPC process capability analysis.

reduction as the CTQ measure for this project.

A high level Supplier Input Process Output Customer (SIPOC) diagram for defects and waste production at the mill is shown in figure 2.

2. Measurement Phase

Data related to defects which were required for the CTQ measure were collected from the factory under study. The collected data span January 2009 to December 2010. This record contained information on (i) the tonnage of aluminium products produced, (ii) non-conforming products, (iii) defect types and (iv) probable causes. The analysis in this project shall be done in kilograms and as a percentage of defects to the total production run since aluminium products are measured by mass (in kilograms). The Sigma level of the process was calculated based on the data collected and this showed that the casting section functioned at an average level of 1.84 sigma. This indicated an abundant room for improvement in this section.

3. Analysis Phase

Process capability analysis

Process Capability analysis of the data (Fig. 3) was done by using Statistical Process Control (SPC) for Excel

Table 2. Statistical analysis of the three main defects.

	Composition Error	Profile Error	Trimming Error
MEAN	10.662	13.389	10.396
MEDIAN	10.017	12.007	8.081
MIN	1.711	2.880	0.664
MAX	30.653	32.185	27.837
Q1	5.239	9.219	3.6325
Q3	14.14	17.492	13.6565
Std dev	7.009994906	6.784028516	8.639155773

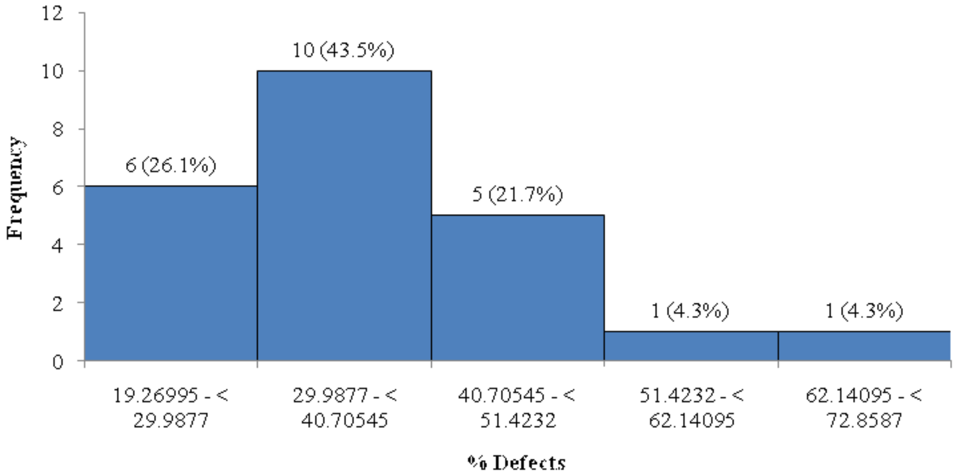


Fig. 4. Histogram of the percentage defects generated.

(Version 4.0). The result also showed the existence of opportunity for massive improvement, since Cp of 0.69 and Cpk of -0.04 are less than 1 and 1.09 respectively.

4. Statistical Analysis

Data collected were further analyzed and an overall percentage mean defect of 37.049% with wide standard deviation of 10.7018871 was obtained. This shows the need for further improvement in the foundry as it reflects excessive wastage. The analysis further showed that three defects contribute mainly to the overall non-conformant percentage. These defects include: composition errors, profile and dimension errors and trimming errors; in all, profile error was found to be the chief contributor. Other defects identified include poorly fluxed melts and line marks. Statistical analysis of the three main defects which form the focus of the analysis is shown in table 2.

Histogram showing the percentage defects generated is shown in Figure 4. The plot was normalized by the application of Sturges' rule (Nabi, 2007) expressed as:

$$k = 1 + 3.3 \log10 (n)$$

where k is the number of class intervals or "bins" to be used, and n is the number of data items to classify.

Run charts

Run charts for each of the identified main defects were generated by using the SPC for Excel software. These charts show the values of percentage composition defects, percentage profile defects and percentage trimming defects with respect to months of the year 2009 and 2010 (Figures 5 - 9). The lines of best fit and corresponding regression equations were generated to know the level of relationship between the plotted data.

Composition error

Figure 5 depicts the complete run chart for percentage composition error. Continuous increase in trend of percentage composition error with time is noticed within the study period (2009 to 2010). The percentage composition error was also observed to be minimum at the beginning of each year; the process for composition control is also veering off steadily and unless mitigated, most products would have compromised content.

Profile error

The run chart for percentage profile and dimension error gave irregular trend as shown in figure 6. The drop observed between December 2009 and January 2010 is a reflection of the major maintenance activity performed on the caster; turn around maintenance is always performed every December. Maintenance activities should be routine so as to improve process performance. The lines of best fit indicate an increase in percentage profile error with time for the plot of constituent years (Figs. 7 and 8). Better trend is found with the two plots when compared with the combined plot for the two study years (Fig. 6). It can be observed from the plots that the process is more controlled in 2010 than 2009 due to the turn around maintenance carried out on the plant in 2009.

Trimming error

The run chart for percentage trimming error for the period 2009-2010 is shown in figure 9. Investigations carried out

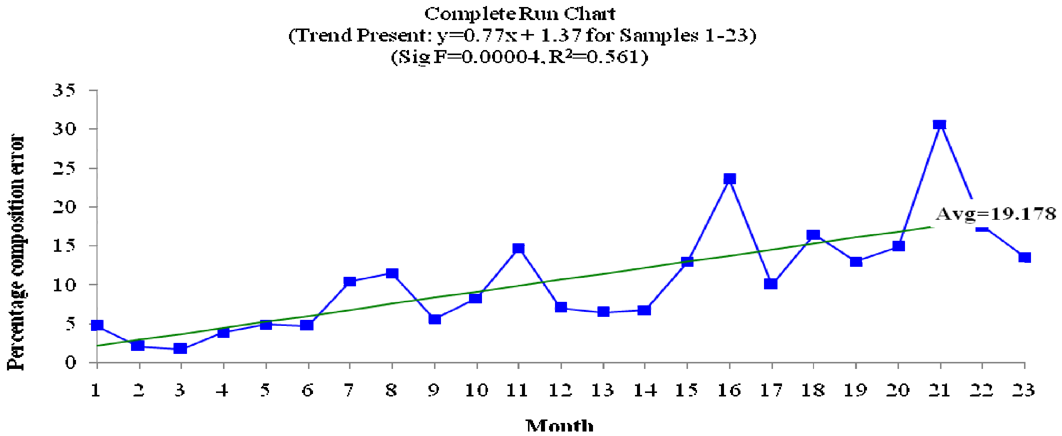


Fig. 5. Complete run chart for percentage composition error.

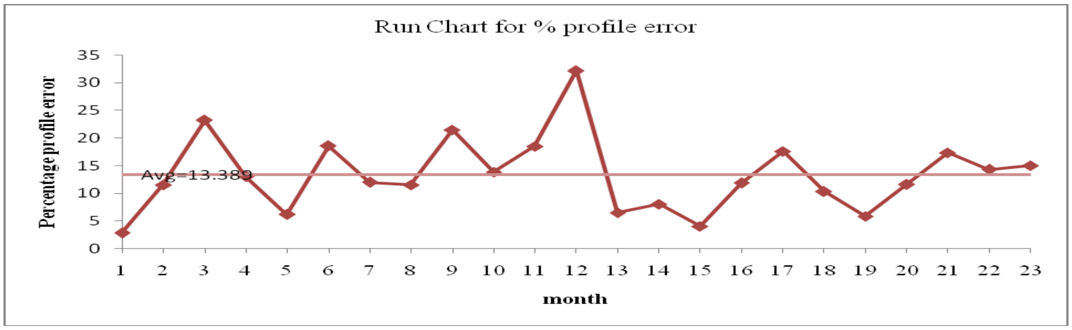


Fig. 6. Complete run chart for percentage profile error.

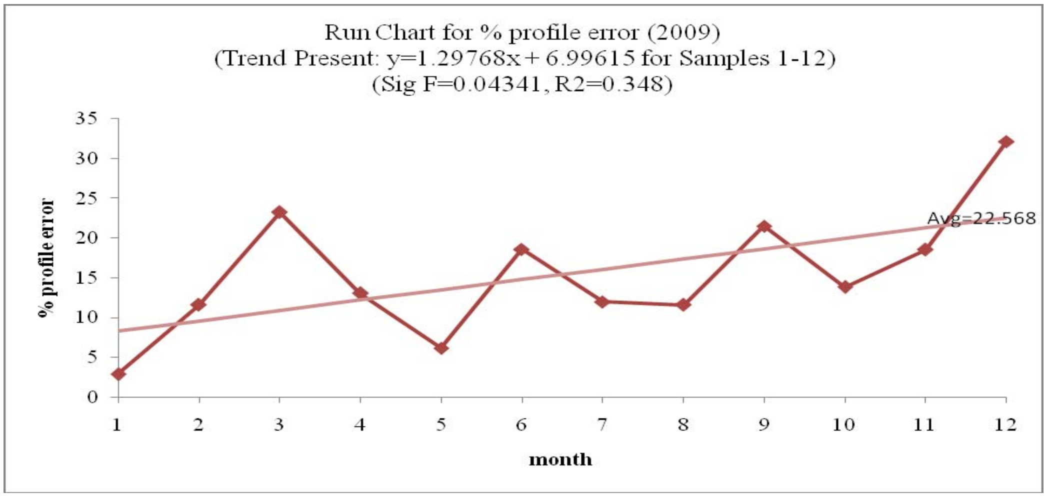


Fig. 7. Run chart of percentage profile error for 2009.

on the system showed that trimming errors were caused primarily by the failure of the edge millers' lubrication pumps. This failure is responsible for the rapid rises in the percentage trimming error; repairs were very effective in bringing down the trimming error percentage.

Regression Analysis

Relationships were established between percentage of the various defects and time for each year under study through regression analyses that were carried out between percentage defectives and the total mass produced per month as shown in table 3. This was done to find out if the mass produced had any effect on the proportion that was non-conformant.

Composition error per month

The value of the multiple correlation coefficient (R) of 0.749, shows strong correlation between proportion of products with composition errors to months from datum. The R^2 value which is 0.561 implies that the model explains only 56.1% of the total variation about the average proportion that is non-conformant. This value also indicates that there are other variables responsible for the other 43.9%, these variables must be unearthed. With the ANOVA analysis, there are less than 0.00004% that this variation can be caused by chance alone. This model is expressed in Equation (1):

$$1.370695652 + 0.77425M = CE \quad (1)$$

where M is the month from datum and CE is percentage containing composition error

Profile / dimension error per month

The relationship between percentage profile errors and the month from 2009 to 2010 is negligible (Table 3). There is a 99.71% of obtaining these variations by chance only. This model is therefore not a suitable representation of this scenario. The value of multiple correlation R for the year 2009 is 0.5901 thereby indicating moderate relationship between percentage profile errors and month with the model accounting for about 34.8% of the total variation. Also, 4.34% exist that these variations were produced by chance alone. For 2010, the variations in the analysis have a 3.9% probability of being caused by chance only (Table 3); the variables under study have moderate strength of relationship and this model explains 39.21% of the total variation for 2010. This shows the presence of other variables. The regression models for the years 2009 and 2010 are given as shown in Equations (2) and (3) respectively;

$$6.996151515 + 1.297681818M = PE \quad (2)$$

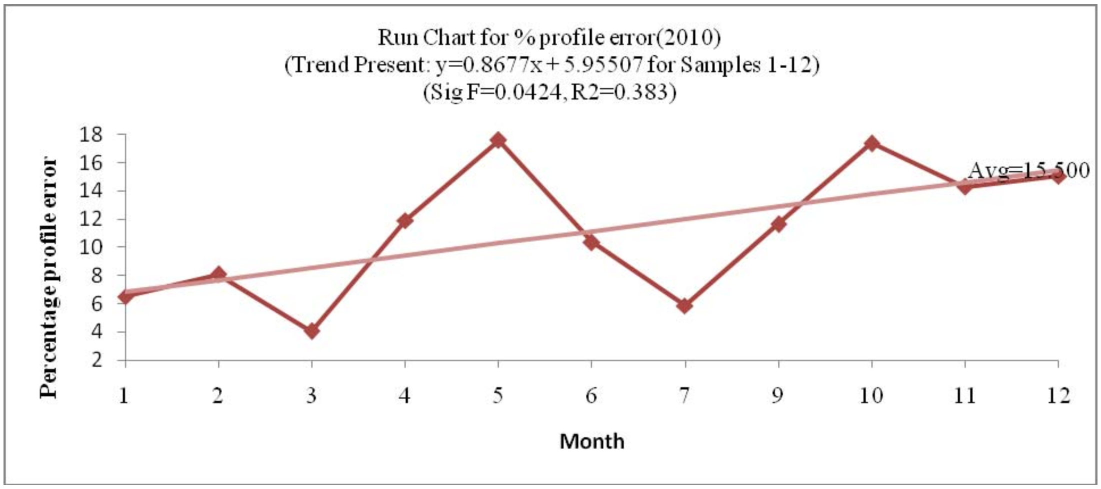


Fig. 8. Run chart of percentage profile error for 2010.

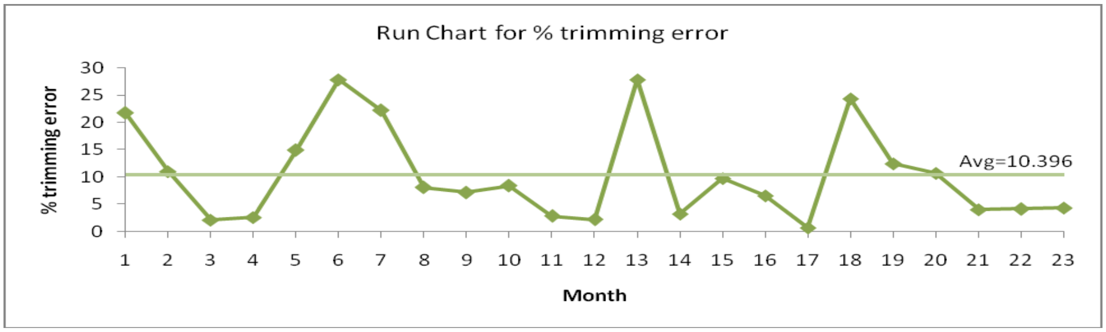


Fig. 9. Complete run chart for percentage trimming error.

Table 3. Analysis for the defects.

		Regression Statistics		ANOVA	
	Years	Multiple R	R^2	Significance F	Observations
Composition error per month	2009	-	-	-	-
	2010	-	-	-	-
	2009 - 2010	0.749104537	0.561157608	3.90475×10^{-5}	23
Profile/ Dimension error per month	2009	0.590097462	0.348215015	0.043405208	12
	2010	0.626236898	0.392172652	0.039265901	
	2009 - 2010	0.000782413	6.1217×10^{-7}	0.99717306	23
Trimming error per month	2009	0.3525915	0.124321	0.260962681	12
	2010	0.38443242	0.14778829	0.243067593	11
	2009 - 2010	0.237901388	0.05659707	0.274350822	23
Composition Error (total cast tonnage)	2009 - 2010	0.116913826	0.013668843	0.595239601	23
Profile/ Dimension Error (total cast tonnage)	2009 - 2010	0.085283243	0.007273232	0.698829118	23
Trimming Error (total cast tonnage)	2009 - 2010	0.193772243	0.037547682	0.375663614	23

$$6.21715938 + 0.77692995M = PE \tag{3}$$

where M is month and PE is the percentage profile error.

Trimming error

It can be seen from the Multiple R, R^2 and Sig F values (Table 3) that there exists a weak relationship between time and percentage containing trimming errors. The model explains only 5.7% of the variation and there are 27.4% that these variations are caused by chance. The yearly regression models also show this weak relationship as provided in Equations (4), (5) and (6).

$$14.03265217 - 0.303032609M = TE \tag{4}$$

$$16.53429 - 0.86384M = TE \tag{5}$$

$$15.57689 - 0.9037684M = TE \tag{6}$$

Ishikawa (Fishbone) Diagrams

Figures 10a, b and c show the fishbone diagram for obtaining causes of the effects in the boxes. The effects in this case are composition error, profile error and trimming error. All the causes as reflected in the fishbone diagrams were obtained through several discussions with the in-house experts and brainstorming with other company technical personnels after observation of the process.

Improvement Phase

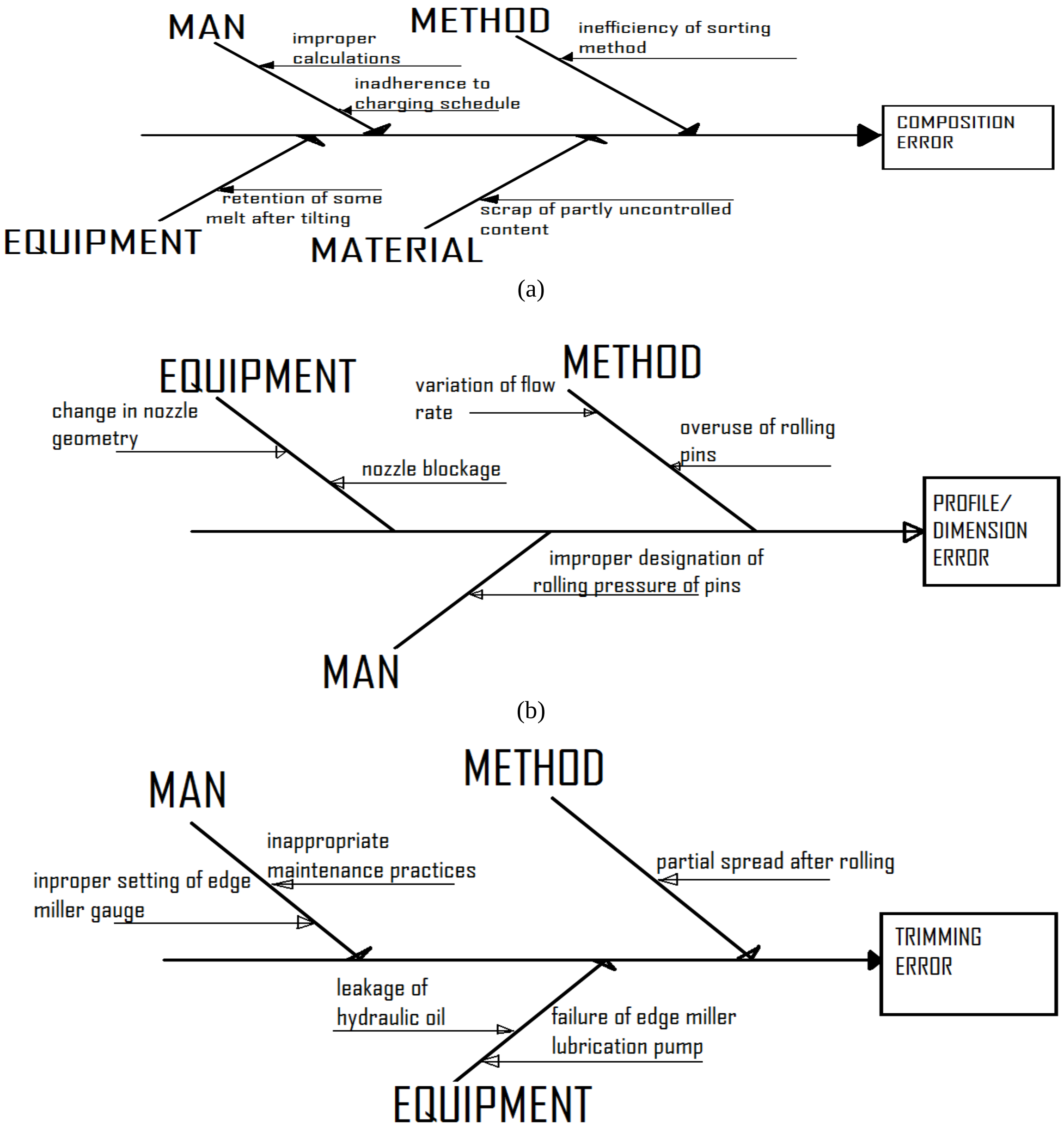
Solutions were proffered to several areas of improvement identified in the analysis phase. Among the solutions identified for the foundry include:

- Investments into scrap sorting to improve the effectiveness of sorting process to reduce sorting time.
- Continuous availability of ingots to prevent the adverse effects of ingot shortage on the product grade.
- Proper hot cleaning of the furnaces at least once in a week.
- Monitoring the state of the edge miller on a daily basis so as to reduce trimming problems.
- Condition of the nozzle should be regularly monitored and serviced.
- Installing online profile monitoring device to alert operators of immediate change in profile and/or dimension.
- Revising and following strictly the roll replacement and charging schedule.
- Automating the method of fluxing, degassing and dross removal.
- Proper lubrication of rollers which prevent coil sticking that results in cracks.
- Regular and proper servicing of the pumps, cooling tower and its constituents, to prevent improper cooling which will lead to sticking and cracking.

Control Phase

The next stage in Six Sigma deployment (after the implementation of improvement efforts) is the institutionalization of the improvement. It is aimed at locking in the benefits of the optimization and preventing the system from returning to its former state. The gains can be secured by following the following control mechanisms viz:

- Conversion of the quality control department to a Six Sigma department and to train staffs accordingly. This will serve as a take off point and guarantee high



(a)

(b)

(c)

Fig. 10. Ishikawa (fishbone) diagrams for (a) composition error (b) profile error and (c) trimming error.

quality and continuous improvement in the manufacturing processes.

- Transforming the entire company into a Six Sigma company by training every staffs the philosophy and practices of Six Sigma. This will set everybody thinking in the direction of continuous improvement such that every sphere of company activities will be geared towards increased efficiency. This will invariably increase customers' satisfaction and provide positive bottom-line impact.
- Acquisition of the latest compatible equipment and testing devices for improved efficiency.
- Carrying out monthly process audits and statistical analysis of data from each component or machine. This will provide better understanding of the process, its components and their interactions.
- Giving higher priority to staff welfare as this affects dedication, attention and also improves the performance of their various jobs.
- Provision of conducive working conditions within the factory by improving ventilation to reduce discomfort and fatigue caused by high temperatures in the factory.

- Continous revision and strict adherence to the general maintenance schedule so as to prevent failure of machines.

CONCLUSION

In this study, it has been found that Six Sigma is a veritable methodology for improving the performance of a manufacturing firm, particularly in Nigeria. In the firm studied, it was discovered that production of non-conforming or defective products was the major problem. The main defects were identified as composition errors, profile/ dimension errors and trimming errors. The causes of these errors were identified as operator skill, raw material content, operating procedures, available technology, and maintenance practices. Solutions have been documented in line with Six Sigma methodology. Implementation of these solutions will result in noticeable improvement and firm operating with near-perfect processes, hence, guaranteeing customer satisfaction.

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