INVESTIGATING THE IMPACT OF POOR UTILISATION OF QUALITY MANAGEMENT SYSTEM IN A SOUTH AFRICAN FOUNDRY

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ABSTRACT

Background: In 2007 alone, twenty six foundries were closed down when the castings industries directory was released. A high scrap rate due to a lack of quality management is one of the root causes of low productivity and low profits, resulting in closures.

Method: This research paper focusses on the impact of defects on productivity and monetary losses due to poor utilisation of the quality management system in sand casting. Data was gathered on defects and productivity and the company's quality control records were used for monetary losses due to scrap. The study was conducted over a period of one year at a South African foundry. The standard multiple regression analysis method was used to assess the ability of five defects (cross jointed, bad mould, shrinkage, core fault, and gas porosity) to predict monetary and productivity losses.

Results: Cross jointed and bad mould defects had a correlation coefficient of 0.727 and 0.716 respectively which indicated a strong positive correlation. The overall variance explained by the model was 61%, $F = 16.263$, $p<.005$. Thus the prevalence of these two types of defects can significantly predict monetary losses, while core fault predicted productivity.

Conclusion: Foundry should concentrate on eliminating cross jointed and bad mould defects to avoid a high scrap rate, and core fault to improve productivity.

1 INTRODUCTION

The South African foundry industry is faced with a high number of foundry closures. In 2007 alone, twenty six foundries were closed down [1]. The factors leading to these closures were identified by literature review as inability of South African foundry companies to compete with countries like China, India and Brazil [2]. It is said that lack of skilled personnel, high scrap rate, lack of quality management system, and technology transfer all contribute to South African foundries not being able to compete with these emerging countries. These factors are root causes of low profits and low productivity, resulting in closures.

The foundry industry forms part of the manufacturing sector, and the manufacturing sector contributes about 15% to the South African total gross domestic product [3]. In a survey done by the South African Institute of Foundrymen (SAIF), it was discovered that the local foundry industry has been earmarked as one of the manufacturing sectors with a significant potential for growth, in both the domestic and export markets [4]. According to SAIF, South Africa casts some 500 000 tons of metal a year, generating a turnover of R10,3-billion a year, and contributes 0.32% to the country's total GDP [4]. The industry has about 230 companies, employing over 15 000 workers with 80% of them being previously-disadvantaged people [4].

Sand casting is the most popular casting process with low cost, high efficiency and reuse cycles. Of the total tonnage of castings produced each year, the greatest percentage is produced by sand casting, and it produces the highest scrap rate [5]. The aim of this research paper is to examine the types of defects that have a high negative effect on productivity, and also identify the defects that contribute to high monetary loss in a South African foundry company, specifically when using sand casting.

This research study undertakes a case study conducted at a South African foundry company. The study looks at the processes followed in sand casting process and the utilisation of the quality management system in this foundry company.

2 THEORETICAL FRAMEWORK

2.1 Foundry overview

A foundry is a factory that produces metal castings from either ferrous or non-ferrous metals including copper, brass, bronze, aluminium, zinc, lead, nickel, and all their various alloys [6]. A metal casting is a shape obtained by pouring liquid metal into a mould or cavity and allowing it to solidify and thus to take the form of the mould. Different types of casting processes are used by individual foundry companies, depending on the quantities they produce and the size of castings they produce. The most commonly used casting processes in South Africa include: sand casting, die casting, investment casting, and spin casting [2].

2.1.1 Sand casting

Sand casting is a metal casting process characterised by using sand as the mould material. A suitable bonding agent (usually clay or chemical binder) is mixed with the refractory sand. In order to produce a casting, a pattern is required [6]. A pattern for metal casting is a form used to make a cavity in sand. It is a replica of the product to be cast, used to prepare the sand cavity into which molten material will be poured during the casting process [6]. A wooden pattern is cheaper to design and most companies make use of it. In a construction of a wooden pattern, accurate layout is important, and this requires skilled personnel with excellent drawing skills. Poor design of patterns or inadequate pattern equipment results in a number of defects which include [7]:

- broken or cracked castings
- crushes

- cuts or washes
- particles of foreign material
- gas defects
- metal expansion

After the pattern has been designed, it is sent to the moulding section. Moulding is the operation necessary to prepare a mould for receiving the metal. It consists of ramming sand around the pattern placed in a support, or a flask, removing the pattern, setting cores in place, and creating the gating/feeding system to direct the metal into the mould cavity created by the pattern, either by cutting it into the mould by hand or by including it on the pattern [8]. Metal melting is done concurrent with the moulding process. Metal melting is carried out in a heat furnace, and there are different types of furnaces used to melt metal and these depend on a type of alloy being produced. The most commonly used furnaces are gas, electric, and cupola.

For melting aluminium, gas furnace is used and an electric furnace is used for melting copper. The right heating temperature of a furnace is very important to ensure good quality castings are produced. Usually, a standard temperature is stipulated in the quality manual when the quality system is implemented. The molten metal is poured into the mould at a right temperature and is given time to solidify. This process is followed by fettling which is the removal of gates and risers from the casting, and the removal of adhering sand scale, parting fins, and other foreign material that is not supposed to be in the casting, to get it ready for other processes or delivery. Inspection follows, to check for defects in the casting as well as to ensure that the casting has dimensions specified on the drawing and/or specifications [8]. Below is a figure showing a typical sand casting production plant.

Figure 1: Sand casting plant. Source: South African foundry, 2011.

2.2 Casting defects

Metal casting is the vital process in metal casting foundry companies, and it is in this process that much attention should be focused in terms of quality management. Quality control implies both prevention and cure of casting defects and wasted production effort. There are a number of casting defects that are found in castings and some of their causes are known, which makes it possible to prevent them if proper quality control procedures are followed adequately. Casting defects are those characteristics that create deficiency or imperfection to quality specifications imposed by design and service requirements [7]. Defects can be classified into two categories, first being ones based on nature of defect, second based on contributing factors. Table 1 shows some common casting defects.

Table 1: Common casting defects [7].

Defect	Description	Causes
Cross Jointed	These appear as veins or fins that cross on top of each other.	Pattern design Pattern equipment Gating and risering
Bad mould	Improper venting in green sand mould. Sufficient venting must be done to permit back-pressure in the mould.	Moulding sand Mould practice
Gas porosity	These are smooth bubbles that appear on a casting and they result from entrapped gases. This occurs because most liquid materials can hold a large amount of dissolved gas, but the solid form of the same material cannot, so the gas forms bubbles within the material as it cools.	Melting practice Pouring temperature Moulding sand
Shrinkage	Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies.	Cooling temperature Gating and risering Pouring practice
Core fault	Uncured cores, including oil, resin and hot box cores, provide an excess of gas which would normally be removed during the baking.	Core practice Moulding sand Pattern equipment
Broken or cracked castings	This refers to castings which have been broken or cracked by mechanical action or rough handling.	Pattern design Pattern equipment Flask equipment and rigging Gating and risering Moulding sand

In the next section, we look at quality and the quality management system which if applied adequately; can eliminate these defects.

2.3 Quality overview

According to Juran [9], quality means those features of a product which meet customer needs, that is, freedom from deficiencies. Quality does not pertain to a single aspect of a product, but a number of different dimensions. These dimensions of quality include performance, special features, conformance, reliability, durability, and service after sale [10].

Deming [9] taught that by adopting appropriate principles of management, organisations can increase quality and simultaneously reduce costs by reducing waste, rework, staff attrition and litigation while increasing customer loyalty. This is the problem facing foundry companies, as they do not set targets.

The statistical tools are useful in manufacturing industries, especially foundry. The casting benchmarking report released by the Network Foundry Technology Network in conjunction with CAST in November 2009 [2] revealed that foundry companies do not collect data, which is an indication that they do not make use of statistical tools. The tools are listed in the quality management manual that is provided during implementation of the quality system, but companies either do not have resources or skilled personnel to use these tools or they do not see the value.

2.4 Quality management system

ISO was established as a United Nations Agency in 1947 and is made up of representatives from more than 90 countries and includes the British Standards Institution for the United Kingdom and the American National Standards Institution for the United States [11]. According the book written by Tricker [11], since the introduction of ISO, there have been a growing number of bodies to give accreditation to companies that have a quality system in place, including amongst others, the South African Bureau of Standards (SABS). But according to the report released in 2009 by Who Owns Whom [12], in terms of regulations, the foundry industry lacks common standards which enforce conformance to internationally recognised quality assurance standards such as ISO 9000:2000.

The ISO 9000 series identifies the basic disciplines of a quality management system that can be used by manufacturers, suppliers, distributors and end users. The series specifies the national, regional and international accepted procedures and criteria that are required to ensure that products and services meet the customers' requirements [11]. The series is divided into a number of different parts which provide details of all the essential requirements for quality assurance during the design, manufacture and acceptance stages of a product. ISO 9001, 9002 and 9003 are the standards by which a company can be certified, if they so desire [11].

3 RESEARCH METHODOLOGY

The case study method was chosen to conduct this research because it captures the real life events in a natural setting as explained by Yin [13]. The data collection methods used in this study are: direct observation, documents, and records.

3.1 Site selection

The study was conducted at a South African foundry. The company was chosen because it is a small company and has a quality system in place, ISO 9001:2008. It makes a good case study because it has the quality system in place and yet it still faces a high scrap rate.

The company makes castings for electrical components using die casting and sand casting processes. The metal used is Aluminium 6, copper and steel. Aluminium 6 (LM6) has high resistance to corrosion under both ordinary atmospheric and marine conditions, and has excellent castability [6]. Its ductibility enables castings to be rectified easily or even modified in shape, for example, simple components may be cast straight and later bent to the required shape. The type of sand used for sand casting is green sand.

3.2 Data collection

The study was conducted over a period of one year starting with direct observations in the patternmaking department. This was done to understand the procedure followed when designing a pattern since this is the first process for sand casting. The concentration was on the quality control of drawings issued, design specifications, and design equipment.

The next section that was observed was the sand casting, which includes mould making process and metal melting. Machining procedure involves processes like cutting, milling, and grinding, and was the last section observed. These observations assisted in understanding the whole process from patternmaking to shipping of a casting.

Defects and productivity data was collected, while monetary losses due to scrap data was taken from the company's quality control records. The regression analysis was then performed to predict monetary loss and productivity. The next section presents the results of the data gathered.

3.3 Data analysis

Five defects (independent variables) were identified as recurring defects, contributing to a high scrap rate. These defects are: bad mould, gas porosity, core fault, shrinkage, and cross jointed. The two dependent variables used are monetary losses due to scrap and productivity, entered separately in the model. All independent variables are entered into the equation simultaneously. Each independent variable is evaluated in terms of its power to predict the dependent variable. Therefore the results will present two regression results with the first one presenting five independent variables and monetary losses, and the second with five independent variables and productivity.

The model is also used to check the multicollinearity amongst the variables. Multicollinearity refers to the relationship between independent variables [14]. It exists when independent variables are correlated (r = 0.9 and above).

The Pearson's correlation coefficient (*r*) is defined by:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2] * [n\sum y^2 - (\sum y)^2]}} \qquad (1)$$

Where r = the correlation coefficient

x= the values of the independent variable

y= the values of the dependent variable

n= the number of paired data points

4 RESULTS

4.1 Monetary loss and defects

In this section, data figures and regression analysis results are presented. The standard regression analysis method with all the variables and cases entered into the equation is used.

4.1.1 Descriptive statistics

Table 2 presents the mean values and standard deviation for each variable. The average for monetary loss for fifty days (N) is 2325.97. The table also shows that the defect with a highest average is cross jointed. This means that more cross jointed defects occurred during this fifty day period.

Table 2: Means and standard deviation (Monetary loss)

	Mean	Standard deviation	Sample size (N)
Monetary loss in Rands	2325.97	3288.50	50
Cross jointed	5.36	21.256	50
Gas porosity	4.86	14.580	50
Shrinkage	5.06	10.790	50
Core fault	4.48	12.445	50
Bad mould	4.12	12.758	50
Total scrap (Kg)	23.88	47.601	50

4.1.2 Correlation between variables

Table 3 presents correlation results. The correlation table shows the strength of a linear association between independent variables and a dependent variable. In the second row of the table, we look at the correlation between monetary loss and defects. Cross jointed and bad mould have a correlation coefficient of 0.727 and 0.716 respectively which means a strong positive correlation. Core fault has 0.545 which means a moderate positive correlation. Shrinkage has a weak positive correlation with r=0.338. Gas porosity shows no correlation as r=0.009. This means that the defect which has a strong relationship with monetary loss is cross jointed followed by bad mould. The correlation between the independent variables is shown from row two and column four. Cross jointed and bad mould have a correlation coefficient of 0.883, which is a strong positive and is considered to be too high. The other independent variables have a weak correlation, which is below 0.5. The second row shows that a 1-tailed sig was used. This explains whether each variable is significantly contributing to the equation for predicting monetary loss from the whole set of predictors. Thus, bad mould and gas porosity are significantly contributing to the equation.

Table 3: Correlations

		Monetary loss	Cross jointed	Gas porosity	Shrinkage	Core fault	Bad mould
Pearson Correlation	Monetary loss (Rand)	1.00	0.727	0.009	0.338	0.545	0.716
	Cross jointed	0.727	1.000	0.032	0.267	0.374	0.883
	Gas porosity	0.009	0.32	1.000	0.468	-0.079	-0.017
	Shrinkage	0.338	0.267	0.468	1.000	0.056	0.230
	Core fault	0.545	0.374	-0.079	0.056	1.000	0.496
	Bad mould	0.716	0.883	-0.017	0.230	0.496	1.000
		Monetary loss	**Cross jointed**	**Gas porosity**	**Shrinkage**	**Core fault**	**Bad mould**
Sig. (1-tailed)	Monetary loss		0.000	0.476	0.008	0.000	0.000
	Cross	0.000		0.412	0.031	0.004	0.000

	jointed						
	Gas porosity	0.476	.0412		0.000	0.293	0.454
	Shrinkage	0.008	0.31	0.000		0.349	0.054
	Core fault	0.000	0.004	0.293	0.349		0.000
	Bad mould	0.000	0.000	0.454	0.054	0.000	
N	Monetary loss	50	50	50	50	50	50

4.1.3 Prediction of variance by the model

Table 4 gives the model summary. The table presents the **R** (0.806) and Adjusted R square (0.609). Thus, this model is predicting 61% of the variance in monetary loss, which indicates a good model. According to Cohen [14], this is a large effect. In the coefficients table 5, Beta value of the core fault is the highest with 0.603. This means that this variable makes the strongest unique contribution to explaining the dependent variable, when the variance explained by all other variables in the model is controlled. Table 5 also presents Tolerance and VIF (Variance inflation factor) which is the indicator of the variability of the specified independent variable which is not explained by other independent variables in the model. In the table, this value is above 0.1, which indicates that the multiple correlation with other variables is low, and it is suggesting that there is no multicollinearity. VIF, which is an inverse of the Tolerance value, is below 10, which is highly acceptable, indicating no violation of the multicollinearity assumption.

Table 4: Model Summary

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the estimate**
1	0.806	0.649	0.609	2056.32661

Table 5: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	1236.707	342.061		3.615	.001					
	Cross jointed	73.456	30.084	.475	2.442	.019	.727	.345	.218	.211	4.739
	Gas Porosity	-17.807	23.087	-.079	-.771	.445	.009	-.116	-.069	.762	1.313
	Shrinkage	63.599	32.168	.209	1.977	.054	.338	.286	.177	.716	1.396
	Core fault	79.582	27.608	.301	2.883	.006	.545	.399	.257	.731	1.368
	Bad mould	25.182	53.246	.098	.473	.639	.716	.071	.042	.187	5.347

4.1.4 Significance of the results

As can be seen from the ANOVA (Analysis of Variance) Table 6, F = 16.263 and is significant (p<.005), and therefore the model with all the variables entered significantly predicts monetary loss.

Also, the Normal Probability Plot of the Regression Standardised Residual in Figure 2; the points lie in a reasonably straight diagonal line suggesting no major deviation from normality.

Table 6: ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	343845623.759	5	68769124.752	16.263	0.000
Residual	186053081.452	44	4228479.124		
Total	529898705.211	49			

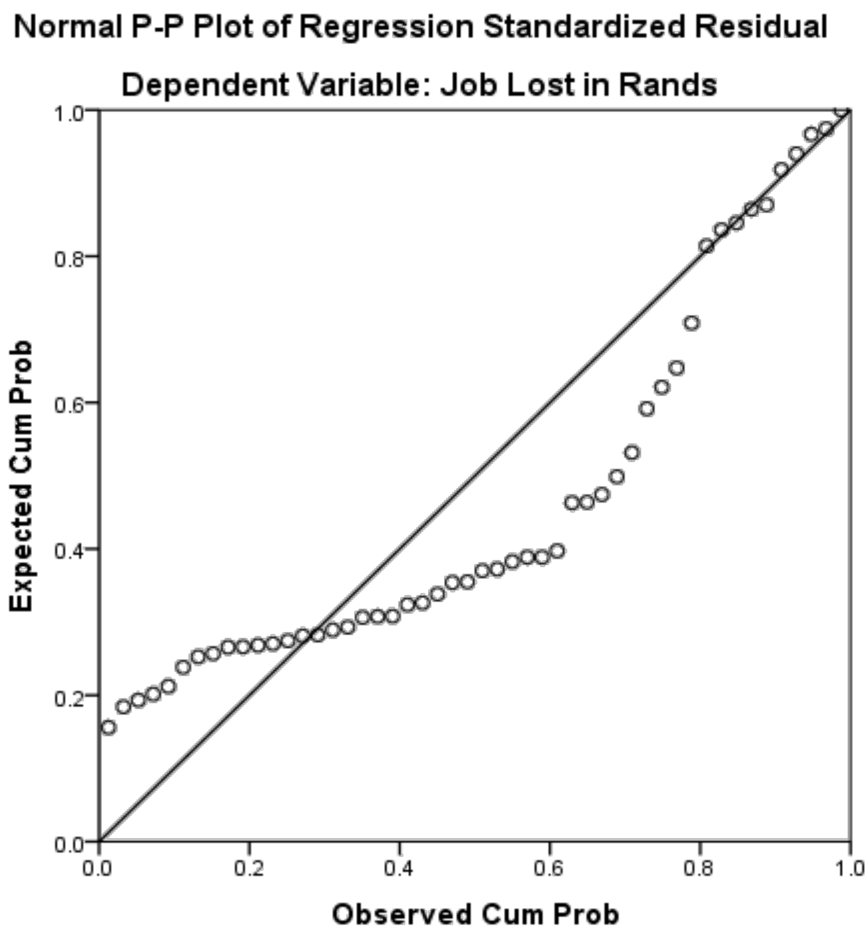

Figure 2: Cumulative probability plot.

4.2 Productivity and defects

In this section, the regression analysis results for productivity and defects are presented. Three models were used, that is, stepwise, forward, and backward regression; and all predicted significant results. Mallows' Cp value was calculated for all models to determine the best model, and for the model with the intercept and core fault as predictors, p=2, the Cp value = 4.222. For the other model where the predictors are the intercept, gas porosity and core fault, p=3, the Cp value = 2.509. The model with a Cp value that is less or equal to p; is the best model and therefore the backward regression model was selected to present the results. The independent variables were recorded as no defects or defects occurrence, which is different from the calculation of monetary loss vs defects. This was done due to the fact that productivity is calculated as a ratio.

4.2.1 Descriptive statistics

Table 7 presents the averages and standard deviation. The frequency of occurrence for cross jointed defect is 15, which accounts for 30% of the sample taken. Gas porosity occurred 50%, shrinkage 38%, core fault 30%, and bad mould 20%. This shows that the defect that occurred the most is gas porosity.

Table 7: Means and standard deviation

	Mean	Std. Deviation	N
Productivity (%)	88.56	13.547	50
Cross jointed	0.30	0.463	50
Gas Porosity	0.50	0.505	50
Shrinkage	0.38	0.490	50
Core fault	0.30	0.463	50
Bad mould	0.20	0.404	50

4.2.2 Correlation between variables

Table 8 presents the relationship between variables. Although gas porosity shows to be the highest, its correlation to productivity is weakly positive. The correlation is also not significant with Sig. = 0.176 which is >0.05. The variable making a significant unique contribution to the prediction of productivity is the core fault with a Sig. value of 0.006.

Table 8: Correlation

		Productivity (%)	Cross jointed	Gas porosity	Shrinkage	Core fault	Bad mould
Pearson Correlation	Productivity (%)	1.000	0.161	0.134	-0.097	0.353	0.028
	Cross jointed	0.161	1.000	-0.131	0.027	0.238	0.327
	Gas porosity	0.134	-0.131	1.000	-0.371	-0.306	-0.300
	Shrinkage	-0.097	0.027	-0.371	1.000	0.117	0.227
	Core fault	0.353	0.238	-0.306	0.117	1.000	0.546
	Bad mould	0.028	0.327	-0.300	0.227	0.546	1.000
Sig. (1-tailed)	Productivity (%)		0.131	0.176	0.251	0.006	0.425
	Cross jointed	0.131		0.182	0.426	0.048	0.010
	Gas porosity	0.176	0.182		0.004	0.015	0.017
	Shrinkage	0.251	0.426	0.004		0.209	0.057
	Core fault	.006	.048	.015	.209		.000
	Bad mould	.425	.010	.017	.057	.000	
N	Productivity (%)	50	50	50	50	50	50

4.2.3 Prediction of variance by the model

Table 9 presents the model summary. The adjusted R squared value is 0.233. This indicates that 23% of the variance in productivity is explained by the model.

Table 9: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Backward	0.652	0.426	0.233	12.517

4.2.4 Significance of results

The combination of all the defects significantly predicts productivity as Sig. value in ANOVA Table 10 shows Sig.= 0.007, *F* = 5.498, with all five variables significantly contributing to the prediction.

Table 10: ANOVA

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Backward	Regression	1705.008	2	852.504	5.498	0.007
	Residual	7287.312	47	155.049		
	Total	8992.320	49			

5 CONCLUSION

The quality management system implemented provides the company with tools and techniques to use for data collection and analysis. The data analysis is to help to point areas that require improvements. The study suggests that the company does not utilise these tools, resulting in high scrap rate. This is evident as the company is unable to point which defects lead to high monetary losses and low productivity. The results in this study suggest that the foundry should concentrate on eliminating cross jointed and bad mould defects to avoid a high scrap rate that leads to high monetary losses. It also shows that the elimination of core fault defect may improve productivity.

The study looks at a problem that is facing many foundry companies, and as mentioned before, most South African foundries fall under small companies. The SMME sector generally creates more employment than large companies, thus supporting small companies will directly impact on job creation and preservation.

The previous studies [10] mention that foundries do not collect data, and this was evident when this research was conducted. It then suggests that foundries cannot measure their performance as there are no set goals. It is important for any company to be able to measure its output in order to improve. In the literature review it was mentioned that foundries lack skilled personnel in specific areas. These areas were identified to be namely quality, metallurgy and industrial engineering.

Due to time limitations, the study could not measure the impact when the quality management system is utilised, but recommendations were made available to the company. Future studies can look at the implementation of lean manufacturing in foundry companies for improvements.

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