The Cost of Quality: Elements of Lean Production in Foundries

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***Abstract*—**: Inefficiencies in the process chain result in bloated operational costs and ostensibly pass on to the customer. It is essential to streamline process costs and categorise them appropriately as either costs of conformance or cost of non-conformance. In this way, hidden costs due to inefficiencies in the system can be identified. A sustained continuous improvement programme to systematically eliminate waste can be employed to achieve lean manufacturing or "cleaner production". A number of factors contribute to costs in a foundry from procurement of scrap to the delivery of a casting.

***Keywords*—:** Waste, cost of conformance, cost of non-conformance, lean manufacturing

I. Introduction

THE phenomenon of product quality is as old as humanity itself and it has eluded many a practitioner over millennia.

Evidence of enforcement for quality and liability for inferior output are recorded in history. Between 1792 and 1750 BC Hammurabi King of Babylon crafted his famous Code of Laws:

> *229* *If a builder has built a house for a man, and has not made his work sound, and the house he built has fallen, and caused the death of its owner, that builder shall be put to death.*
>
> *230* *If it is the owner's son that is killed, the builder's son shall be put to death.*
>
> *231* *If it is the slave of the owner that is killed, the builder shall give slave for slave to the owner of the house.*
>
> *232* *If he has caused the loss of goods, he shall render back whatever he has destroyed. Moreover, because he did not make sound the house he built, and it fell, at his own cost he shall rebuild the house that fell.*
>
> *233* *If a builder has built a house for a man, and has not keyed his work, and the wall has fallen, that builder shall make that wall firm at his own expense.*

Pernicious liabilities await shoddy workmanship. Hammurabi exacted punishment on all those who took a casual attitude to service delivery. This sounds to be draconian antics of a brutal king of ancient Babylon. However, quality impropriety and fraudulent activity were documented much later in the London records [1]:

> *Bakers selling light weight loaves, a woman giving short measures of ale, Margery Hore put in a pillory for selling rotten fish, and Katherine Duchewoman who had tried to pass off a woven tapestry of inferior materials*

Evidently throughout history consumers have, for time immemorial, desired quality and not mere pretentions or imitations of it. The quest for quality has continued to this day although the liabilities for failure can be considered to be more civil and lenient but the consequences are still grave; ranging from total loss of business to closure of an enterprise. Quality of product is the surest guarantee for continued business in modern day, particularly in the environment of competition and product choice.

The attainment of quality comes with a cost, but is this cost justifiable and how high can such costs of quality be allowed to escalate? Philip Crosby hypothesis, "quality is free". But can quality be absolutely free? In a foundry quality of castings is influenced by a plethora of variables big and small. Thus, to make a good quality casting, control of these variables is imperative. The cost of managing quality dictates the profitability of an operation.

Traditional cost accounting tends to focus on broad terms of input and output costs without necessarily itemising the elementary constituents of these costs. This is a serious omission that that overlooks the adverse impact of hidden or intangible costs. Lean manufacturing has emerged as an attempt to redress the limitations of metrics of cost in conventional use. This paper discusses the cost of quality as it applies to a typical foundry and demonstrates the power of lean production in improving the economies of a foundry business. Most foundries can hardly pin-point the main causes of product rejection due to deficient quality systems [2].

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II. LITERATURE REVIEW

A. Cost of Quality

The concept “cost of quality” can be attributed to Armand Feigenbaum who first put forward the prevention, appraisal and failure (P-A-F) cost model in 1956 [3]. In Feigenbaum (1961) [4] divided the costs of quality into two major categories namely costs of control and costs of failure of controls. The American Society for Quality Control (1971) and the BS6143 Part 2 (1990) define cost of quality as the costs incurred in ensuring quality, together with the loss incurred when quality is not achieved. Crosby (1979) [5] defined the cost of quality as the sum of costs of conformance and the costs of non-conformance, which are equivalent to Feigenbaum’s costs of control and costs of failure of controls respectively. The costs of control (costs of conformance) are the costs incurred in attempting to meet specific quality requirement of goods or services. On the other hand, costs of failure of controls (costs of non-conformance) are the cost of failure to deliver the required standard of quality for a product or service. Since the foundation of these constructs, the jargon has become common terminologies in use by numerous researchers that followed, for example; Sumanth and Arora (1992) [6], Purgslove and Dale (1995) [7], Gupta and Campbell (1995) [8], Burgess (1996) [9], Chang, Hyun & Park (1996) [10] and Sorqvist (1997) [11].

The various costs associated with quality need close scrutiny. The cost of quality consists of cost of conformance (COC) and the cost of non-conformance (CONC). The constituent elements of the cost of quality are illustrated in Figure 1 below:

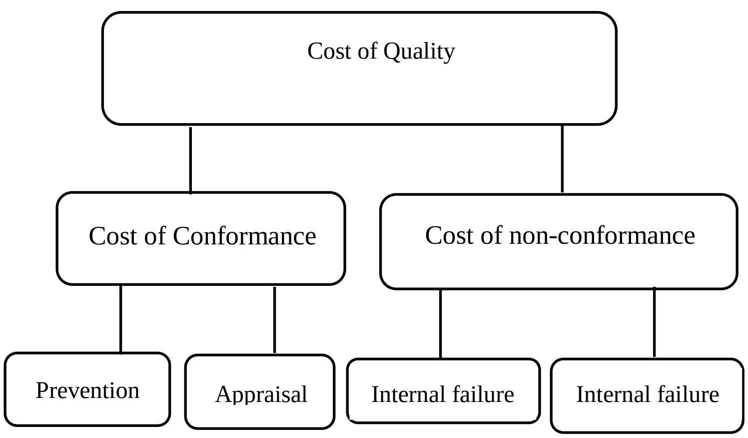


Figure 1 Elements of quality costs

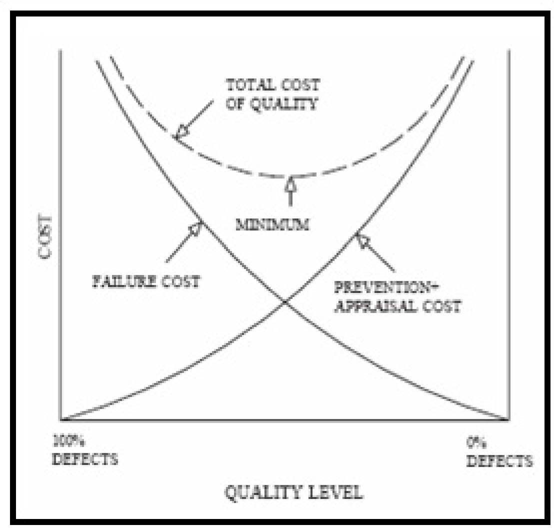
Cost of conformance consists of prevention and appraisal costs. The prevention costs are costa of initiatives undertaken to bolster the system and make it robust and defect free. Such programmes may include, *inter alia,* [2]:

1. Quality engineering, which involves translating product design or customer quality requirements into manufacturing quality controls of materials and process
2. Process Engineering i.e. implementing and maintaining quality plans and procedures
3. Design and development of quality measurement and control equipment
4. Calibration and maintenance of production equipment used to evaluate quality
5. Quality assurance

Appraisal consists of all the in-process inspection activities and acceptance tests occurring along the value chain such as; Laboratory acceptance testing, quality control inspection and testing, quality audits, internal testing and release, data processing inspection and test reports and all the actions meant to detect the occurrence of fault.

Cost of non-conformance is the cost of internal and external failure. Internal failure occurs when defects that a caused by a faulty production process is identified and quarantined prior to despatch to customers. These costs scrap, re-inspection, reworking defective products, downgrading product, concessions downtime etc. are troubles experienced by the supplier internally and are not a direct concern of the customer. The costs of external failure on the other hand directly concern the customer. When defective products are delivered to the customer, the dire consequences that follow come with irrecoverable costs of external failure. Attending to customer complaints, corrective public relations, product liability, warrantee costs and product recalls are examples of such heavy liabilities that can bring down an organisation.

B. Cost of Quality Models

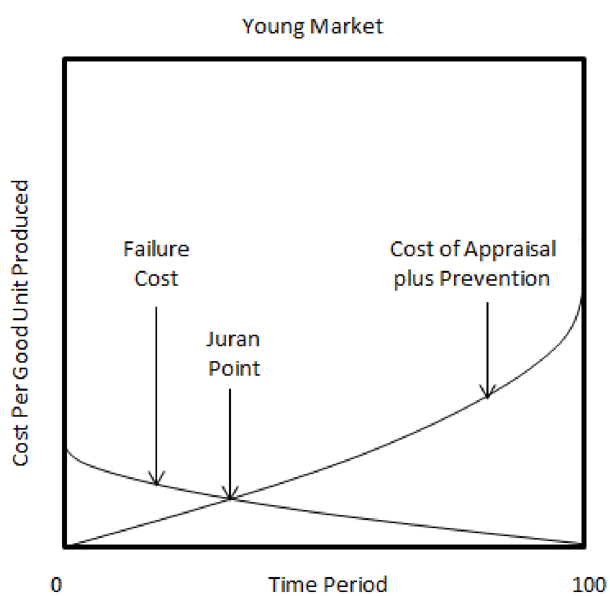


COQ = COC + CONC

Figure 2 Traditional inspection-based view (Kazaz Birgonulb, & Ulubeyli, 2005) [12]

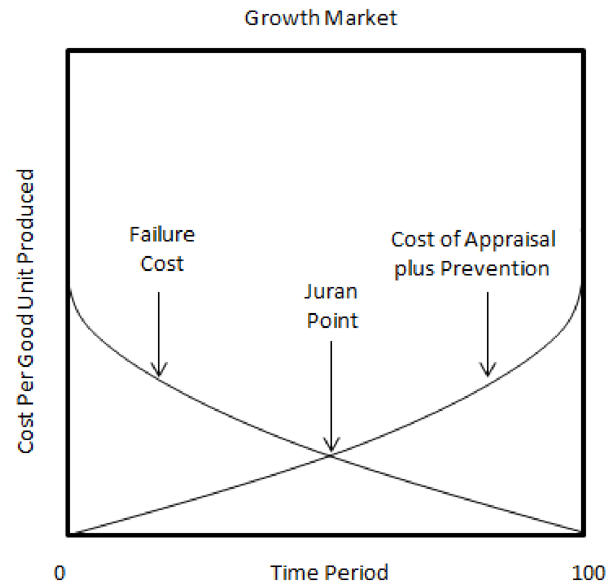
The extremities of the graph shown in Figure 2 represent high total cost of quality. The extreme left represents the worst case where total cost are attributed to cost of failure or non-conformance, while the extreme right the total cost consists entirely of cost of conformance or costs to prevent defects. Although the conformance costs sound more plausible, the astronomical investment in quality is not economically justifiable. Hence in the traditional approach to quality control the “zero-defect” ideal will not make business sense. It is therefore necessary to control cost of conformance. Deciding the optimum economical quality level or the Juran point, which is a compromise between customer satisfaction and cost of conformance is however difficult.

The Juran Point is not fixed but shifts along the quality level depending on the type of product and the maturity of market. For a young market, the Juran Point is at less than 50% quality conformance. For a new product and young market, customers are less critical of product quality. During market growth stage, the Juran Point shifts to 50% quality conformance and when market reaches maturity stage, customers start demanding greater than 50% quality conformance level. Hence as the market evolves from young to maturity, investment in prevention and appraisal increases. Figure 3 (a), (b) and (c) illustrate the position of the Juran point for the three stages, namely young market, growth market and mature market [13]. For instance, the modern additive manufacturing, where prototype with a Juran Point below 50% quality illustrated in Figure 3(a). Common foundry castings based on an old pattern belong to a mature market and the Juran Point is way above 50% quality acceptance level (Figure 3c) because customers tend to be particular on product quality.



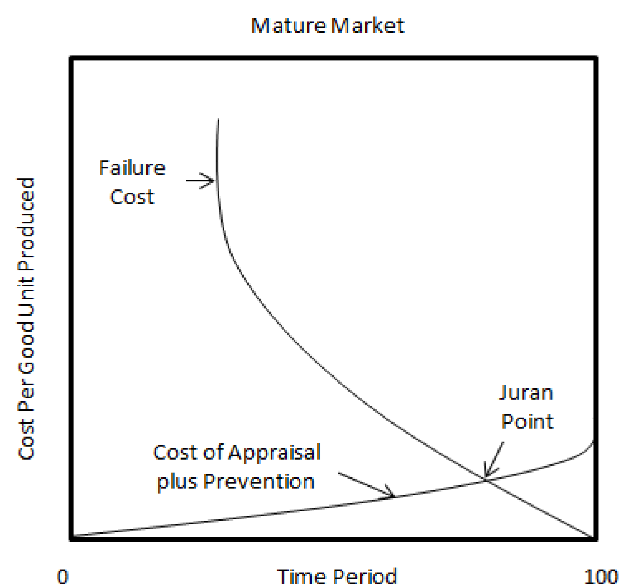
Juran Point is below 50% quality level

Figure 3 (a) Cost of quality for a young market



Juran Point is at 50% quality level

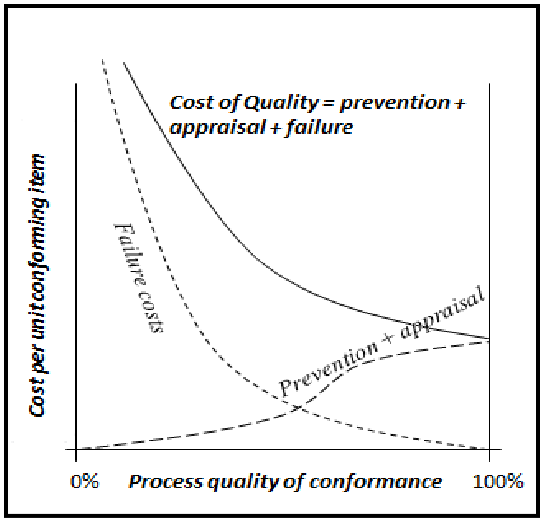
Figure 3 (b) Cost of quality for a market in growth



Juran Point is above 50% quality level

Figure 3 (c) Cost of quality for a mature market

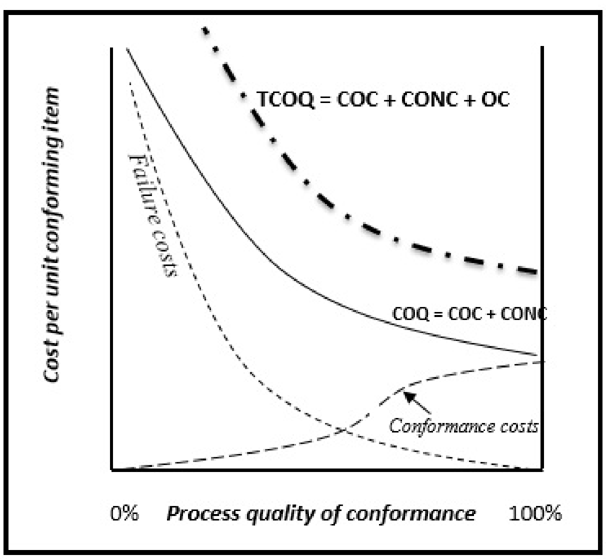
At the Juran Point even for the mature market, the defect level can be considerable to the extent that some customers may reject defect levels. In pursuit of customer satisfaction, the Juran Point has to be pushed further to the right approaching the “zero-defect” level. However, that ideal comes with extremely high cost of quality unless the entire system is geared for quality. If the organisation is characterised with a supportive culture, the cost of conformance would controllable resulting in overall gain from quality at reduced cost. Figure 4 illustrates the modern view in which the costs of conformance are within manageable levels. Quality improvement continues towards the ideal of “zero-defect”.



COQ = COC + CONC

Figure 4 Cost of quality in the modern view [14]

In the revised modern view, recognition is made of the lost opportunities which comprise revenue not earned because of under-utilised installed capacity [14], lost business as a result of poor delivery of service and reduction in revenue due to non-conforming product [15]. When these hidden costs are considered, the overall total costs of quality (TCOQ) due almost entirely to cost of conformance plus opportunity cost (OC) are higher than when opportunity costs are not included as illustrated in Figure 5 below. Missed opportunities represent a loss of investment suffered by the business.



TCOQ = COC + CONC + OC

Figure 5 Revised modern view [14, 16]

Quality engineers are preoccupied with the desire to eliminate the cost of non-conformance and keeping the conformance costs to a minimum. There is a conflict of objectives namely; of maximising quality of conformance and minimising cost. The cost of conformance has economic have merits in that the resulting profitability covers them [1]. As reported by Zimwara et al (2013) [2], a typical foundry, costs of non-conformance, which comprise internal and external failure costs contribute to over 70% of the total quality costs and quality costs can vary between 5% and 25% of the total sales volume. Hence, reducing the cost of quality and more specifically costs of failure will have immense benefit to the bottom line.

C. Lean Manufacturing

Lean manufacturing includes all steps taken in order to create value in the product. Its thrust is to eliminate “waste” i.e. anything that does not add value. Waste comes in various forms [17] such as transportation, which is, unnecessarily moving products around, an act that may not actually required for the process. Excess inventory i.e. all components, lots work-in-process and unsold finished stock is waste. Movement of equipment and people walking around for no reason constitutes waste. When workers are made to wait for the next production step, their idle time is dead waste. Overproduction of goods that are not asked for or without market demand as well as over processing due to inappropriate or antiquated causes exertion on workers adding no value.

Reducing waste improves quality, reduces production times and minimizes cost. Various methodologies are used as tools to achieve this including Value Stream Mapping, 5S, Kanban (pull systems) and error-proofing. Lean manufacturing originated from was essentially originated “Scientific Management” by Frederick Winslow Taylor in the 1880s and 1890s. The Japanese advanced the concept and perfected the art. According to the Folk Group (2009) [18], a modern company that is not adopting lean manufacturing is stagnant.

For a foundry, lean or cleaner production can bring about significant costs savings, prevent pollution and wastes generation at various stages by eliminating process inefficiencies by introduction of integrated environmental and quality management systems, lean production and good housekeeping at all stages of the process from raw materials preparation, core making, moulding, melting, pouring and shakeout [19]. However, several challenges confront foundries in the implementation of lean production, some of which include; old equipment and facilities (e.g. furnaces) that are not energy efficient, obsolete equipment (e.g. mould line) that cannot produce castings of good quality and precision, and aged infrastructure that heavily pollutes and violate environmental by-laws. Thus attempts to modernise foundry equipment, that costly in initial capital will be beneficial in the long run.

III. EXPERIMENTAL WORK

The value streaming map at the foundry is illustrated in Figure 6 where lean manufacturing tracks the flow process to identify the causes of rejection of castings, waste and inefficiencies along the value chain. Research work was conducted at a foundry based in Johannesburg.

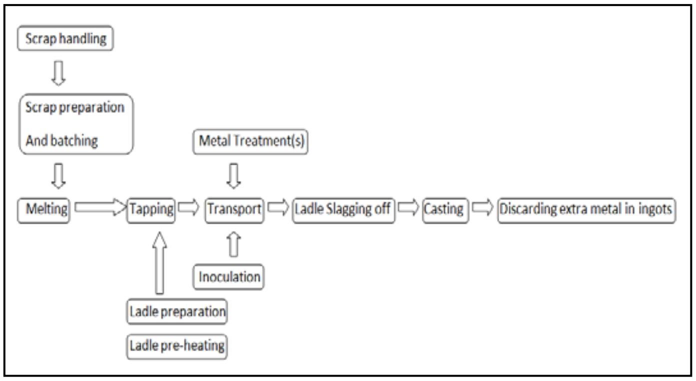


Figure 6 Value streaming map before improvement

The methodology for process improvement consisted of the following steps in order to identify and cut waste:

1. Process analysis
2. Staff interview
3. Data collection and streamlining
4. Value stream mapping
5. Identification of waste
6. Proposed changes
7. Determination of savings

Data were collected and analysed in comparison with the usual procedure. A few modifications to current procedure were made and the overall effects of the changes were quantified in monetary terms. In a typical foundry, rejects can be caused by poor surface finish arising from core making, large fins due to poor clamping, asymmetrical casting due to misalignment of cope and drag box, and short pouring, blowholes and inclusions coming from melting and casting. Example of waste in the foundry may include; worker waiting for core boxes, unnecessary motion of people and equipment to and from the casting floor, improper plant layout, excess inventory etc. Although complex reengineering would be necessary for quantum leaps, simple changes understandable to workers are potent enough to bring about process efficiency.

IV. RESULTS AND DISCUSSION

The following sections discuss the effect of simple value streaming initiatives that were carries out at a foundry in Johannesburg. These are typical *kaizen* methods that workers can be encouraged to devise at workstations. They are inexpensive and engender a sense of belonging among staff in that staff are involves and own the improvement process.

A. Increasing production by one heat per day

Half a ton residual metal in 2.5 ton furnace (actual output of 2.3 tons) provided heat for faster melting of the next charge. The heats were increased to four, one heat more than the initial practice based on a cold charge.

Improvement in yield = Improved output – Output based on old practice

= Four heats (2 + 2 + 2 + 2.3) – Three heats (2.3 x 3)

= 8.3 tons – 6.9 tons

= 1.4 tons per day

Potential gain per day = R26 6835 from production of cast steel

= R16 695 from production of cast iron

= R16 020 from production of spheroidal graphite (SG) cast iron

B. Charge preparation

Weighing out scrap into bins day before and pacing the bins close to the furnace eliminated furnace idle time by 30 minutes and also avoided furnace heat loss associated with conventional practice of preparing charge while furnace is on hold. Eliminated the hidden costs of furnace waiting and heat loss have obvious financial benefits.

C. Changing from top to bottom pouring ladles

Using bottom tapping ladles:

- Eliminates need for slag coagulant, which at present costs R7.43 per melt
- Saves time required for the slagging process
- Allows control of metal into mould using an adjustable stopper
- Excludes dross and reduces incidence of slag inclusions in the casting

Thus quality of casting is improved at lower input cost.

D. Cutting magnesium loss to flaring and inoculation

Magnesium is light and tends to rise to the surface under ferro-static pressure. In contact with the atmospheric air, magnesium readily oxidises resulting in loss. During the production of nodular iron, by charging steel scrap and ferro-silicon on top of the magnesium keeps it submerged and effectively used. A 1.8% saving on magnesium was realised, which was equivalent to R44 per ton of SG iron produced. Late inoculation of melt with ferro-silicon prevents magnesium fading that normally occurs before pouring into the mould.

V. CONCLUSIONS AND RECOMMENDATIONS

Conventional approaches of foundries are no longer tenable in present day quality-driven consumer markets. Lean manufacturing will bring novel perspectives to industry characterised by mature markets that demand high quality at low cost. Only a serious relook at quality and its associated cast can deliver quality and at reduced price. Integration of production for less bureaucracy, resource optimisation and greater efficiency is consistent with a quality culture involving all stakeholders in the process chain.

Determining hidden costs of waste will improve the economies of running a foundry business. Conventional accounting misses the essence of waste and inefficiencies by inadvertently regarding them as part of authentic operational costs. A new paradigm to unmask these intangible costs has emerged in the form of lean manufacturing. Foundries cannot be left behind in this quest to reconfigure the process cost structure of the production floor. Starting with a process flow chart, waste and inefficiencies can be identified and eliminated with the overall impact in the economies of the foundry business.

A few lean manufacturing check questions for the foundry practitioner are pertinent:

- Are there time lags between processes? Eliminate them
- How far is the casting floor from furnace? Improve plant layout
- Do you grind, trim or machine large fins? Clamp grad and cope firmly
- Is so much cleaning and finishing required? Eliminate or at least minimise.
- Is your total scrap level over 3%? This is too high, adopt best practices

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