Analytical Factors for the South African Foundry Industry: A Benchmarking Study

Kulani Mageza, Boitshoko Kaelo Sedumedi and Xiaowei Pan
Metal Casting Technology Station
Faculty of Engineering and the Built Environment
University of Johannesburg
Johannesburg, South Africa
kmageza@uj.ac.za, bksedumedi@gmail.com, xpan@uj.ac.za

Abstract

The South African foundry industry is in a state of decline. From 2010 to 2020, almost 37 foundries were closed, resulting in 123 operational foundries from 160 foundries. A benchmarking study was done using analytical factors to determine how competitive SA (South Africa) foundries were compared to those in other countries. Notably, an attempt was made to map the analytical factors, such as capacity utilisation, labour productivity, process yield, and energy cost, of SA foundries and compare them to Chinese foundries. Questionnaires were formulated to acquire primary data from SA foundries and China. In South Africa, 11 out of 14 foundries responded to the questionnaires administered through face-to-face interviews, whereas in China, one out of three foundries responded through email. On average, data from SA foundries indicate that they are uncompetitive in gating systems, scrap casting, labour productivity, capacity utilisation, and energy costs. In conclusion, based on these analytical factors, Chinese foundry has a competitive edge over SA foundries and the EU; consequently, buyers may prefer to acquire casting from china due to lower production cost, which translates into cheaper casting. It is recommended that SA foundries invest in upskilling their workforces, adopt casting simulation software, and participate in energy efficiency programmes to improve their competitiveness.

Keywords
Benchmarking, Gating systems, Scrap casting, Labour productivity, Capacity utilisation

1. Introduction
The South African foundry industry is in a state of decline, and meaningful interventions are required to reverse the industry's current trends. Notably, the foundries have to assume a position of competitiveness both locally and internationally. The National Foundry Technology Network (NFTN) has identified the foundry industry as a key manufacturing sub-segment that needs to be targeted for revitalisation. Since 2010, there has been a rapid closure of foundries – between 2010 and 2015. In 2020, the industry lost 37 foundries, resulting in 123 foundries in operation (Lochner et al. 2020)

Several challenges in the industry had previously been identified by the nftn that may have contributed to the industry's poor performance.(Rasmussen 2013; nftn 2015): Lack of product volumes to achieve manufacturing economies of scale, Aged infrastructure for capital equipment parts; high levels of capital investment needed, Low capacity utilisation at many foundries, Local buyers offering ad-hoc low volume orders; and Limited collaboration in the industry to develop the collective capacity and capability (nftn 2015). In general, the closure of foundries in South Africa is primarily due to a lack of competitiveness compared to international competitors and failure to overcome challenges that have been reported for some time (Davies 2015).

To address these challenges, strategic and operational performance initiatives are required. Benchmarking is one of the strategic techniques used in production, research and development, and marketing to compare the performance against the competitors and the industry (Hanson and Voss 1995). Benchmarking techniques have been applied to a broader range of products, practices, and performances, and it is a way to compare a company's performance with the industry standard or competitors (Hanson and Voss 1995). Benchmarking can help identify where improvements can be made and can be used to measure the success of initiatives, and it can also help identify potential competitive advantage opportunities (Boxwell 1994).

The primary objectives of this study were to use analytical benchmarking factors in the field of foundry technology and casting to compare South foundry performances against international foundries and identify the strength and weaknesses of the SA foundries and potential opportunities for competitive advantage.

2. Literature Review

A literature review provides an overview of the foundry industry and benchmarking methodologies. This review provides a comprehensive overview of the foundry industry's current trends and processes. The Benchmarking literature includes the benchmarking metric, frame model and performance measurement used in the manufacturing sector. By understanding the industry and the available benchmarking methods, foundries can better assess their performance and make informed decisions about operations and investments.

2.1 Foundry Industry

Foundry technology is an essential part of metal casting, where molten metal is poured into a hollow container of desired geometrical shape to form a solidified part. The understanding of foundry technology is knowing the technical and operational aspects. Technology aspects are the operational costs and sustainability of the foundry, and the technical aspects are the analysis of production processes (Sedumedi and Pan 2015). Figure 1 below illustrates the mapping of the production process. The essential elements are mould preparation and melting, fettling, casting, heat treatment, finishing, quality control and selling. Quality control includes inspections and testing (Beeley 2001).

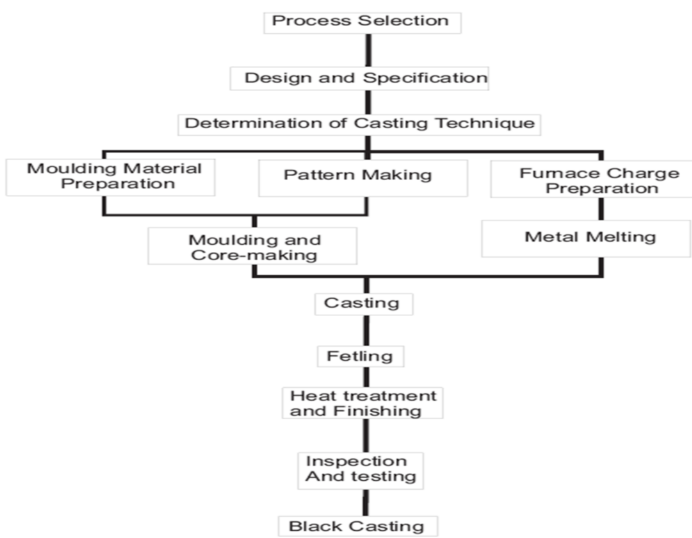

Figure 1. Flow diagram of casting production (Beeley 2001)

Over the past two decades, the foundry industry significantly influenced the development of many economies globally. Approximately 33,300 foundries worldwide produced nearly 104 million MT (Metric Ton) at ~$129.5 billion of cast components in 2021 for applications in automotive, engineering, building, construction, aerospace, Military and others (Nikhil & Yerukola, 2022). The reports indicate that China produced (48 750 00 MT), India (11,491,810 MT), the US (11,305,302 MT), Japan (5,275,700) and Germany (4,951,011 MT) hold the top five casting producers, with South Africa producing (443,000 MT) which is 0.4% to the total world production.

With more than 50 years of worldwide casting production data accumulated by Modern Casting's Census of casting production, comparing how casting production has expanded and shifted across the globe will be informative. Figure 2 shows how casting production has changed for some historically significant casting-producing nations over the past 50 years (WFO 2020).

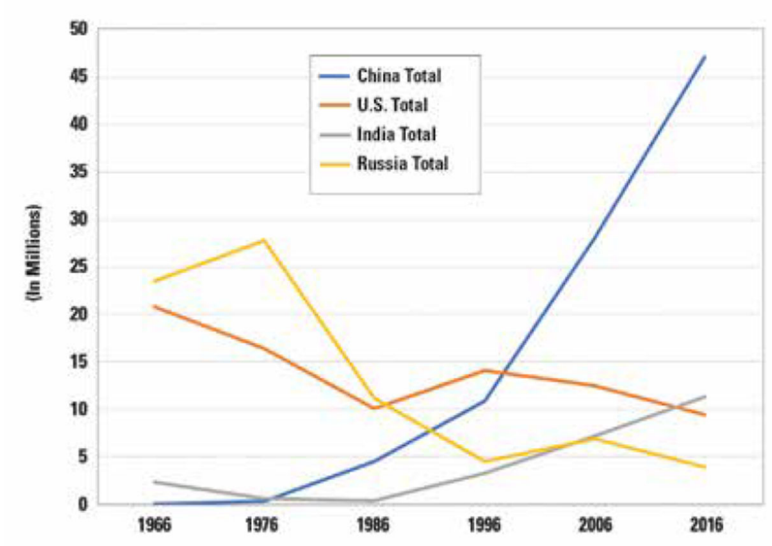

Figure 2. Trends of casting production over 50 years (WFO 2020)

Observing the trends, it is evident that there has been a significant shift in casting production from each nation, with China and India showing significant growth, while other nations, such as the United States and Russia, have shown significant decreases (WFO 2020). As a result, the number of foundries is declining from those nations due to higher costs of production and higher labour and material costs. SA foundries have also been the victim of this downward trend. There were about 450 foundries in the 1980s, and by 2020 there were 123, a decrease of 27% (Davies 2015). Even though casting demand has remained relatively high worldwide, production volume has shifted towards China and India since they are mass-produced and their castings are cheaper than the rest of the world. Generally, customers require supplies that will deliver their products on time, in the quality they require, and at the lowest possible price. Based on the trends, China and India are fulfilling the requirements of most customers hence the growth in their market.

Therefore South Africa must learn from China and India to revive their foundry industry; it plays a critical role in the South African economy as it is the primary supplier for most sectors such as agriculture, mining, and engineering. The benchmarking approach is one of the strategic techniques used in production, research and development, and marketing to compare the performance against the competitors and the industry (Davies and Kochlar 2000). Benchmarking techniques have been applied to a broader range of products, practices, and performances (Davies and Kochlar 2000). It is a way to compare a company's performance with the industry standard or competitors. Benchmarking can help identify where improvements can be made and can be used to measure the success of initiatives. It can also help identify potential competitive advantage opportunities (Davies and Kochlar 2000).

2.2 Benchmarking

The study employed benchmarking techniques for the foundry industry. Benchmarking can be defined as the identifying, understanding and adapting of outstanding practices to improve performance and outcomes over time (Mathaisel et al. 2004). The Xerox Company started benchmarking as a way to lower its production costs. In the 1980s, benchmarking methods spread through the industrial sector (Cross and Iqbal 1995). The literature review is based on the different types of benchmarking and how they relate to the technology and practice of foundries. The framework is commonly applied in context, content and process (Jarrar and Zairi 2001). This framework follows the following logic: Context framework is based on the factors of the measurement of foundry practice and can be separated into two levels: level one: Organisational context (*these are factors that are within the organisation*) and level two: Foundry practice context (*these are factors specific to the foundry practice*) (Cross and Iqbal 1995)

The content framework is based on the metrics and dimensions of the entire foundry process. Processes are methods and tools to measure the foundry practice performance (Cross and Iqbal 1995). There are several ways to measure foundry practice performance. Certain methods can be applied in an organisational setting without being specific to the sector, e.g. the balanced scorecard (Kaplan and Norton 1992). Other sectors have specific measuring systems, but the foundry practice measurements are evolving and rely on focusing on the various stages of the foundry production processes (Jarrar and Zairi 2001). The processes are mould preparation, melting, pouring, fettling, finishing and fabrication. Benchmarking has also adopted various frameworks, and developing one relevant to the foundry industry is advisable. In 1999 Beamon designed a performance framework. The framework was based on the metrics categories of resources, outputs and flexibility, as shown in Table 1 below. Each metrics group can be used for a different purpose and goal (Beamon 1999).

Table 1. Metric types, goals and purpose of their usage

Metrics type	**Goal**	**Purpose**
Resources	High level of efficiency	Impact on profitability
Output	High level of customer service	To retain customers
Flexibility	Respond to changing environment	Be able to respond to changes

2.2.1 Benchmarking approach

Benchmarking can be based on several frameworks because it is a developing field. It was initially based on reverse engineering. There are frameworks that are based on the following approaches: balanced scorecard, economic value added (Lambert and Pohlen 2001), process-based (Chan and Qi 2003a) and the fuzzy set (Chan and Qi 2003b). The balanced scorecard categorises performance metrics into four dimensions: customer, financial, business processes, and growth and learning. The metrics can be linked to a product strategy, and the balanced scorecard process is complete when the main product development objectives have been met.

The value-added economic approach follows particular steps to define the framework:

1. Mapping the production process from the first stage up to the customer
2. Using the products' relationship management process to analyse all links
3. Developing products' profit and loss statements to assess their impact on profitability
4. Realigning products' development processes to achieve determined performance
5. Defining non-financial production metrics and linking them with financial results
6. Comparing products' value and market capitalisation across the foundries
7. Revising production processes and metrics when it is required
8. Performing the analysis of each link within the production process

The fuzzy-set approach is based on promoting a measurement using fuzzy logic in a production process. Metrics are selected that are important for production goals and strategies. The metrics have a cross-influence on the production processes and the people involved. Metrics which are both qualitative and quantitative, are allocated to sub-processes and processes. Process-based approaches are also dependent on the production process being decomposed into sub-processes. This will also include activities for each metric related to the cost, time, and outcome of the production process. Process decomposition follows these steps (Chan and Qi 2003b):

1. Identification and linkage of all inter- and intra-production processes
2. Definition of core processes
3. Derivation of missions, responsibilities and functions of core processes
4. Sub-processes decomposition
5. Derivation of responsibilities and functions of sub-processes
6. Identification and decomposition of main activities
7. Creating links between processes, activities and their goals

There are practical considerations to consider when assessing which benchmarking method to adopt. Most of the methods need to be made informed by field studies; hence, field studies can bring better clarity. It is so because the organisational setting of the production processes is tested and fully understood. Therefore, choosing and adopting a benchmarking method is a function of all organisational functions and production parameters. Cox, Mann et al. (1997) distinguished two fundamental benchmarking concepts: Collaborative (or cooperative) benchmarking - where companies share their practices with other organisations—competitive benchmarking - where companies learn from other companies aiming to gain superiority over one another.

However, in some cases, both types of benchmarking might coexist, as at the strategic level, companies would compete but could cooperate at the operational level. The collaboration will also likely occur when the benchmarking aims involve learning, teaching, or mentoring (Cox et al. 1997). When competitive benchmarking is conducted, it may involve analysing business operations and processes along with comparing them against competitors. However, there is also the possibility of benchmarking against non-competitors considered sources of best practices. Collaborative benchmarking aims to improve all cooperating parties, as organisations can compare and improve their performance gaps (Li et al. 2001).

2.2.2 Performance measurement and benchmarking

Identifying key performance metrics has been a principal goal of the benchmarking process. Organisational performance metrics are compared with those perceived as best and from the best-performing organisations. Performance measurement and selecting suitable metrics and dimensions are key stages in the benchmarking process and the first step in operational benchmarking, along with the search for the companies or processes that can be classified as "best practices' (Davies and Kochlar 2000). Performance measurement allows for identifying key areas of a foundry, while benchmarking helps to assess performance based on selected metrics.

There was the analysis of various performance measurement approaches used in benchmarking, such as the: performance measurement matrix, the balanced organisational scorecard, the results and determinants model, measures for time-based competition, the performance pyramid, the Scandia navigator, the performance measurement framework, Brown's framework, and the performance prism. Using benchmarking and best practices by linking them with performance measures can result in understanding any cause-and-effect relationship, as improved performance in one area might result in lowering it in another (Davies and Kochlar 2002). Understanding best practices within and outside of the foundry industry assists in implementing benchmarking processes. It involves the phases of planning, analysis, integration, action, and maturity, cyclically referred to as the Deming cycle. Reverse engineering was another method of planning for benchmarking (Kelessidis 2000)

3. Research Approach

This study used a descriptive approach, collecting primary data with questionnaires, personal interviews, telephone interviews, and normative surveys. (Conboy et al. 2012) In descriptive research, qualitative and quantitative data are collected to determine how the thing being studied is at any given time. The Russian foundry industry benchmarking study (IFC 2010) was used to make 19 questionnaires in two categories: technology and procedures (process yield and energy) and organisation and equipment (labour productivity, capacity utilisation). These are analytical factors focusing on resources to improve productivity.

The foundries were targeted according to size, type of products, and production process, considering the limitations. The study targeted fourteen (14) SA foundries and three (3) Chinese foundries. Questionnaires were administered face-to-face in South Africa, while in China, they were emailed to respondents' foundries. The European data was available from the *International Finance Corporation (IFC) study on the European foundry industry benchmarking study* (IFC 2010).

4. Results and Discussion

The study was carried out for eight (8) months in 2021, and the following results were determined based on information obtained from foundries and data gathered from IFC reports. A total of 11 out of 14 foundries in South Africa responded to the questionnaires. In China, three foundries were emailed, but only one responded. The IFC report provides a dataset for Europe’s benchmarking. In this study, analytical factors related to the production cost of SA foundries were benchmarked with that of China and the EU in terms of gating system, scrap/reject casting, labour productivity, capacity utilisation, and energy costs factors contributing to production cost. The top performance and average data were utilised to analyse the capabilities of SA foundries and the performance of most SA foundries. Table 2 illustrates the results for the 11 foundries in South Africa, while Table 3 illustrates the results of SA foundries compared to China and the EU.

Table 2. KPIs of the 11 foundries in South Africa

Countries	Gating System (%)	Scrap/ Rejects casting (%)	Labour Productivity	Capacity Utilisation	Energy Cost(R/KWh)
S.A Foundry 1	30	7	40%	65%	1,86
SA Foundry 2	35	6	34%	55%	1,65
SA Foundry 3	40	8	35%	54%	1,34
SA Foundry 4	35	5	33%	52%	1,93
SA Foundry 5	45	10	33%	60%	1,85
SA Foundry 6	30	4	33%	75%	1,82
SA Foundry 7	30	10	32%	72%	1,68
SA Foundry 8	43	5	43%	71%	1,25
SA Foundry 9	38	7	33%	70%	1,85
SA Foundry 10	40	10	40%	63%	1.28
SA Foundry 11	33	6	38%	70%	1,85
SA Worst performance	45	10	43%	52%	1,93
SA Average Performance	37	7	36%	63%	1,73
SA Best Performance	**30**	**4**	**32%**	**75%**	**1,25**

Table 3. Results for the performance results of SA foundries in comparisons with China and EU

Countries	Gating System (%)	Scrap Rejects (%)	Labour Productivity	Capacity Utilisation	Energy Cost(R/KWh)
Average Performance	37	7	36%	63%	1,73
Best SA Performance	**30**	**4**	**32%**	**75%**	**1,25**
China	25	3.0	**27%**	**90%**	**1,24**
EU	35	3.4	**34%**	**54%**	**1,45**

4.1 Process Yield

A process yield measures the material balance during manufacturing and is expressed as a percentage. Indicators include gating systems and casting rejects. The gating systems indicators focus on liquid metal poured into the mould to produce the finished casting. It is determined by dividing the weight of the finished castings by the weight of the metal poured into the mould. As a result, this number represents the percentage of metal that is successfully converted into finished castings. High metal casting yields indicate that a foundry produces more castings per unit of metal input, resulting in lower material costs and higher profits.

4.1.1 Gating System

A gating system consists of all the components required to attach a pouring ladle to a mould to produce casting, but they are not included in the finished casting and are cut off and recycled. When the percentage of gates is high, the yield and productivity are lower. Table 2 indicates that the SA foundries achieved the best value (30%) on the gating system and an average of (37%). In contrast, Table 3 compares the gating system with China and the EU, showing that China has the best gating system at 25% while the EU has the best at 35%. Consequently, China uses 12% less liquid metal to produce castings than South Africa. Based on this result, an average SA foundry has a lower yield than China and the EU, leading to higher production costs associated with higher material costs and higher energy consumption.

A well-designed gating system is essential in obtaining defect-free sound casting, which is the basic requirement of the customer. For economical gating, the volume should be kept to a minimum, and the metal consumption should be kept to a minimum. It is important to note that most of the gating systems used in SA foundries are designed using previous experience, the patternmaker's judgment, and a trial-and-error method until a good casting is achieved. As a result, SA foundries must redesign the gating system of their product based on gating rules, gating design procedure, theoretical knowledge, casting simulation, and practical considerations to overcome higher gating systems, which result in lower yields.

4.1.2 Scrap/Reject Casting

Castings rejects represent the failure rate of castings that are rejected due to defects or quality issues and are not fit for purpose. The number of castings rejects an important analytical factor for foundries, as it can impact the overall efficiency and profitability of the production process. High levels of casting rejects can lead to increased material and labour costs and delays in the production schedule. Additionally, casting rejects can lead to customer dissatisfaction and decreased revenue. Therefore, foundries must reduce the number of casting rejects and ensure that the production process is efficient and profitable.

The results in Table 2 indicate that the SA foundries' scrap casting had the best value of (4%) and an average of (7%). As a result, comparing scrap casting between SA foundries with their best value and average compared with Chinese and European foundries is worthwhile. It was found that China has (3%) and the EU at (4%). This means that SA foundries, at their best performance, produce (1%) more casting rejects than china while, on average, have (4%) more casting rejects rates than China and (3,6%) more than the EU. Therefore SA foundries have a higher failure rate of casting than China and the EU, which again result in high production such as material cost, energy consumption and delay in order deliveries. The shortage of technical skills in engineering has been a national challenge, with the government taking the initiative to address the skills gap through the Skills Development Act. The survey suggests that 70% of the SA foundry workforce have never gone to school or have only basic education; only 25% (usually the supervisors) have a school-leaving certificate; and only 5% are university graduates (Castings 2016). To reduce cast rejects, there is a need to investigate the cause and effects of the process in detail; however, upskilling the workforce and establishing a standardised process have a greater chance of reducing scrap casting.

4.2 Labour Productivity

Labour productivity monitors the man-hours divided by the tonnage of good net castings produced. Improving labour productivity affects reducing direct labour costs and indirect overhead costs. The best practices labour productivity is between (5-25%) Automatic moulding, (12-27%) Mechanised Moulding and (22-30%) manual moulding. Most SA foundries have the manual to the semi-automatic moulding system. Table 3 shows that SA's best labour productivity is (33%) while the average is (37%), in comparison with China and the EU Table 3 shows that China has (27%) labour productivity and the EU has (34%). The key factors that greatly affect SA foundries are the availability of raw materials such as good grade of metal scrap and energy reliability. According to Global Trade Tracker, South Africa exported nearly 525 000 metric tons of ferrous and stainless steel scrap in 2019 (Beya 2022). Typically, scrap remaining in the country is of low quality, requiring a high level of process iteration to meet customer specifications. This may result in poor-quality castings because of the high degree of process control required. SA foundries must make a consulate effort to source good grades of scrap in order to minimise process iteration; however, with government restrictions banning the export of scrap metal, possible foundries can source good scrap at a reasonable cost. The unreliability of energy suppliers is a national crisis which significantly impacts the manufacturing industry. The flexibility of production schedules will enable foundries to manoeuvre this challenge. In addition, investing in modern technologies would help the foundries compete with China and the EU regarding labour productivity.

4.3 Capacity Utilisation

Capacity utilisation measures how much of a company's production capacity is being used to produce goods or services. It is calculated by dividing the actual output of a company by its maximum potential output and then expressing the result as a percentage. Capacity utilisation for SA Foundries is at (75%) at their best performance, while the average is (43%), as shown in Table 2. Table 3 shows that the Chinese foundry has (90%) capacity utilisation while the EU has (54%). South African foundries are underutilised, whereas Chinese foundries use 90% of their capacity. This has decreased SA Foundries' revenue, while Chinese Foundries have seen an increase in profits. To remain competitive, SA Foundries need to increase their utilisation rates. Several factors contribute to the low capacity utilisation: insufficient order, manual operations, and inadequate energy reliability. For SA foundries to compete in the market, they must adopt new strategies to maximise capacity utilisation.

4.4 Energy Cost

Energy is the key analytical factor for the foundry industry and constitutes one of the most critical cost factors in operations. Most of the energy in foundries is consumed in the melting section, which accounts for approximately (55%) of electricity consumption. Table 2 shows the electricity cost in SA, which is a variance of (4%), with the best rate at R1, 25kwh, the average rate at R1, 64kwh, and the worst rate is R1, 93Kwh. The variance in electricity rate is based on whether the electricity is supplied directly by Eskom or the local municipal. According to (Kaziboni et al. 2018), foundries purchasing electricity from their local municipality could pay up to (30%) more than when they purchase electricity directly from Eskom. Therefore, foundries receiving electricity from local municipalities have a cost disadvantage and are less competitive.

In this, (72%) of foundries receive electricity from their municipality, costing them R1,65-1,93Kwh. The cost of electricity for the SA foundries supplied by the municipality is higher than that in China, which is R1, 24Kwh, while competitive at 1,25Kwh to SA foundries supplied by Eskom. However, S . A foundries no longer enjoy the benefits of cheaper electricity as Eskom drastically increased the price of electricity to maintain their ageing infrastructure The SA foundries. Therefore, most SA foundries are becoming uncompetitive due to the rising electricity cost in South Africa. Energy consumption can be significantly reduced by introducing energy efficiency practices in foundries, leading to cost savings and improved environmental sustainability. Furthermore, it can also result in improved process efficiency, better product quality, and increased production throughput.

5. Conclusions

The study provided the analytic factors benchmarked with Chinese foundry. The analytic factors of process yield include gating system, scrap/reject casting, labour productivity, capacity utilisation and energy cost. All the derived analytical factors show that the Chinese foundry has an average competitive edge over SA foundries. However, they are some exceptions where some SA foundries are compared on their best performance.

As a result of this analytic factor, it demonstrated why most buyers would prefer to purchase casting from China than in South Africa. Chinese foundries provide higher process yield (less gating systems, less scrap casting), higher labour productivity, higher capacity utilisation, and lower energy costs. This factor results in lower production costs and more profitable business, which gives leverage to cheaper casting than the competitors. The main aspect that SA foundries need to focus on is the upskilling of employees, which will assist in reducing casting rejection and producing more good casting, adoption of a simulation package to optimise the liquid metal casting, and energy efficiency practices, which will assist in reducing the energy consumption. The capacity utilisation will be realised by a localisation programme which will assist foundries in the increase in orders to allow better capacity utilisation. South Africa has the potential to save their local foundries if attention is given to the analytical factor provided in order to compete with Chinese foundries, which are flooding the market with cheaper casting.

6. References

Beeley, P., Foundry Technology, pp 13–14, Reed Elsevier, Cambridge, UK, 2001.

Beya, K., Recycling Today-fall 2022 scrap recycling - a restrictive regime. Available at: https://magazine.recyclingtoday.com/article/fall-2022-scrap-recycling/a-restrictive-regime-kenya-south-africa-scrap-trade.aspx., 2022.

Boxwell, R., Benchmarking for a Competitive Advantage, McGraw Hill, USA, 1994.
Casting Sa. BDG-Service expert, is scathing South African foundries. CastingSa, October. pp. 26. 2016.
Chan, F. T. S. and Qi., H. J., An Innovative Performance Measurement Method for Supply Chain Management, *Supply Chain Management: An international journal*, vol. 8, no. 3, pp. 209-223, 2016.
Chan, F. T. S. and Qi., H. J., Feasibility of Performance Measurement Systems for Supply Chain: A Process-based Approach & Measures, *Integrated Manufacturing Systems,* vol. 14, no. 3, pp. 179-190, 2003a.
Cox, J. R. W. and Mann., L., Benchmarking as a Mixed Metaphor: Disentangling Assumptions of Competition and Collaboration, *Journal of Management Studies,* vol. 34, no. 2, pp. 285–314, 1997.
Cross, R. and Iqbal, A., The Rank Xerox experience: Benchmarking ten years on*, IFIP Advances in Information and Communication Technology*, pp. 3–10, Available at: https://doi.org/10.1007/978-0-387-34847-6_1, 1995.
Dattakumar, R and Jagadeesh, R., A Review of Literature on Benchmarking, Benchmarking: An International Journal, India, 2003
Davies, A. J. and A. K. Kochlar, Manufacturing best practice and Performance Studies: A Critique, *International Journal of Operations & Production Management*, vol. 22, no. 3, pp. 289-305, 2002
Hanson, P. and Voss, C., Benchmarking best practices in European manufacturing sites, *Business Process Re-engineering & Management Journal*, vol. 1, no. 1, pp.60–74, 1995.
IFC, Resource Efficiency in the Ferrous Industry in Russia: Benchmarking Study, Moscow, Russia, 2010.
Jarrah, YF and Zairi, M., Future trends in benchmarking for competitive advantage: A global survey, *Total Quality Management*, vol. 12, no. 7-8, pp. 906–912, 2001. Available at: https://doi.org/10.1080/09544120100000014.
Kaziboni, L. and Stern, M., The impact of local content policies on EU exports, investment, and South Africa's economic transformation, *Pretoria: European Union– South Africa Partners for Growth Programme,* 2018
Lambert, D. and Pohlen. T., Supply chain metrics, *International Journal of Logistics Management,* vol. 12, no. 1, pp. 1-19, 2001
Mathaisel, D.F.X., T.P. Cathcart and Comm, C., A framework for benchmarking, classifying, and implementing best sustainment practices, *Benchmarking: An International Journal*, vol. 11, no. 4, pp. 403–417, 2004.
NFTN, Report to the Portfolio Committee of Trade and Industry. DTI, Cape Town, RSA, 2015
Nikhil, M. and Yerukola, P., Metal casting market share, trend - industry forecast 2031, *allied Market Research*, 2022.
Rasmussen, S, Production Economics: The Basic Theory of Production Optimisation, Springer Publishing, UK, 2013.
Sedumedi, K and Pan, X., Benchmarking in the Ferromanganese Production Processes, pp. 763–771, INFACON, Kyiv, Ukraine, 2015.

Acknowledgement

The authors wish to thank the University of Johannesburg Metal Casting Technology Station, South African foundries, and a Chinese foundry for participating in this study. Their support, collaboration, and expertise were invaluable for the success of this study.

Biography

Kulani Mageza, who holds a Master's degree in Engineering Management and a diploma in business management from the University of Johannesburg, currently serves as technical Manager at the University of Johannesburg Metal Casting Technology Station. Kulani has 15 years of working experience in multidisciplinary engineering related to Metallurgy. He has published and presented papers at conferences both locally and internationally in the field of Metal casting and Foundry Technology. His work experience spans technology innovation and management, manufacturing, research and development.