Development of a manufacturing cost estimating model for sand casted components using the design mass, for preliminary quote purposes at a Transnet foundry.

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Declaration

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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Mhlangabezi Boyce

08th ………………..day of September 2020 ……………………., ………………….

Abstract

The purpose of this study was to develop a manufacturing cost estimating model, that uses design mass of the component as input, for a steel and sand casting foundry. A relationship between design mass, mould mass, mass with risers and manufacturing cost of the component was to be established. Then, standard costing principles were to be used to develop a parametric relationship linking design mass to manufacturing cost. Lastly, foundry experts were to be consulted for validation of the developed model.

A Pearson correlation of 0.764 was found to exist between the model's intended input (design mass) and the intended output (manufacturing cost). The developed model was found to have a Mean Average Percentage Error (MAPE) of 9.23%. Statistically, it was found that the mean of the manufacturing cost as predicted by the developed model is the same as the mean of the manufacturing cost as predicted by Transnet Engineering Koedoespoort's current foundry model. Experts that were surveyed, using a questionnaire, found the developed model to be easy to use, flexible, consistent, accurate enough and of appropriate scope.

Key words: sand casting; standard costing; cost estimating.

Acknowledgements

I would like to thank the Lord and Saviour of my very life, Jesus Christ of Nazareth, for the grace and strength to see this through.

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Usebenzile Tolo. Mchenge. Dlangamandla.

Table of Contents

List of Figures

List of Tables

List of Symbols

D_m = Standard mould mass of the component (kg)

x = design mass of the component (kg)

M_z = Standard amount of melt required (kg)

P_1 = Cost of the product when it has passed through the moulding section (R)

y_1 = standard amount of sand required by the product (kg)

P_2 = Cost of the product when it has passed through the melting section (R)

y_2 = standard amount of melt required by the product (kg)

P_2 = Cost of the product when it has passed through the melting section (R)

w_1= standard amount of time required to shakeout, shotblast, inspect & pack the product (hours)

P_{MC} = Total manufacturing cost (R)

F = Cost to Cut and Fettle (R)

H = Heat Treatment cost (R)

CER – Cost Estimation Relationship

Definitions

Technical compliance – Meeting the design dimensional, chemical grade and solidity requirements as specified by the mechanical drawing and component specification.

Design mass – Intended mass of the component as it appears on the mechanical drawing of the component

Standard mould mass – The amount of sand required to mould a technically complaint component

Manufacturing cost – The internal cost to make the product, excluding the external costs incurred from the use of external suppliers.

1. Introduction

1.1 Background and purpose of the study

Transnet Engineering (TE) is the manufacturing division of Transnet SOC Ltd. It has depots in Koedoespoort (KDS), Uitenhage, Bloemfontein, Salt River and Durban. The division mainly manufactures and maintains rolling stock for Transnet Freight Rail (TFR) and other external customers in the African continent. TE is partitioned into three customer facing businesses, Wagons, Locomotives and Coaches Business. There are 6 internal facing businesses that are mainly responsible for supplying and servicing the customer facing businesses. Internal facing businesses are the Foundry, Wheels, Rotating Machines and Rolling Stock and Equipment. As one of TE's internal businesses, the foundry business is not positioned to be profit making, but rather as a means to support the customer facing businesses and reduce the supply risk associated with rolling stock components.

This research work will be focussed on TE's KDS foundry business. The business is a sand casting foundry, using both chemically bonded sand and green sand. The foundry business operations are supported by product development (engineering), logistics, finance, sales, quality and lean departments. When a new product is developed, the product development (PD) department designs the gating and the risering systems, together with the heat treatment path the new casting ought to follow to meet technical specification. Upon completion of technical development, PD hands the bill of material (BOM) to the logistics and finance departments for calculation of the product cost. Internal customers (customer-facing business) are charged at manufacturing cost because TE's KDS foundry is an internal support business. Costing follows the technical development because TE' KDS foundry is mainly mandated to supply components to the company's customer facing businesses.

However, TE's organizational vision for the future means the foundry business has to move to being a profit center. the mandate has to change to both internal supply and establishing an external market. This is due to two reasons. One, the prevalent tough economic conditions demand the full use of an organization's available resources, particularly ones that have high fixed cost implications. Two, Transnet SOC Ltd is looking to increase its foothold in Africa (Transnet SOC Ltd, 2019), TE as the engineering arm will be one of the key drivers of such an expansion. Therefore, there lies an opportunity for the foundry business, to not only be an internal supporting business, but to have external customers. External customers could potentially demand a higher level of service, agility, responsiveness and competitive products.

The evolving mandate means the foundry business will need to adopt a more versatile pricing method to meet the more stringent needs of external customers. Additionally, the tough economic climate, particularly in the manufacturing sector in South Africa (Mbanjwa, 2015), leaves businesses with no choice but to review and continuously improve their process methodology. The foundry business has potential even beyond rolling stock, because cast products are extensively used in the agricultural, automotive and mining sectors. TE is cognisant of this fact and plans are in place to tap into those external markets.

1.2 Research background

According to Leedy and Ormrod (2015), research problems stem from an identified opportunity to improve or as a means to answer a certain question. This research work was motivated by the former. Transnet Engineering had the ambition of being an Original Equipment Manufacturer (OEM) by 2021. Their vision was to be a supplier of assembled rolling stock, rolling stock components and maintenance services thereof, to the African continent. Transnet Engineering's KDS foundry business currently manufactures and supplies components to TE's wagons, locomotives and coaches business. At the beginning of every financial year, the foundry business draws up its annual production and sales budget, as per the projected demand. The standard cost of each component was then calculated. Some of the products being currently produced at TE's KDS foundry for internal consumption are shown in figure 1.1.

However, due to mainly the dynamic rolling stock market, TE's KDS foundry business receives additional work to the planned activity in the budget. Often times, this activity cannot be passed on because there is a supply crisis up the value chain, threatening completion of the final product at the customer-facing business. This results in additional production output for TE's KDS foundry business. However the business works on a fixed overhead structure and cost allocation. Therefore, the additional production results in a funding gap - additional production resulting in a discrepancy between planned raw material usage versus planned allocation of resources. Production scheduling is further complicated as resource consumption attached to this unplanned activity is unknown.

Currently, the customer has to wait for completion of technical development before there is an indication of the manufacturing cost. Further to this, each foundry has its own way of calculating the anticipated cost of cast components due to the variance in process inputs. Chougule and Ravi (2006) suggested that cost estimations based on the weight method work well for foundries that produce high volumes of similar products, as is the case in Transnet Engineering's KDS foundry. Therefore, this research work seeks to develop a model to estimate cast product costs, based on a component mass method, to facilitate the foundry business' dealings with external customers and for control and planning on an operational and management level.

Currently, the difficulty with new product cost estimation was rooted in the old mandate the Foundry Business primarily carried. The foundry business was primarily mandated to supply components to the customer facing businesses within TE. This means selling at manufacturing cost. As mentioned, internal customers are looking to reduce supply risk and will pay whatever the manufacturing cost is. Therefore, there is no preliminary cost estimating mechanism in place. Additionally, most foundries around the world have their own custom-made estimation models because there is no simple standard method available. As the mandate is evolving to include the servicing of external customers, the foundry business needs to have a preliminary cost estimating mechanism in place.

Figure 1.1: Some of the products produced at TE’s KDS foundry

Traditionally, the function of cost model development has not always been a straightforward task. Curran, Raghunathan and Price (2004) posited that numerous skills are required in order to develop a cost model. See figure 1.2. In an organization where the need for a cost estimating relationship (CER) had never been present, the task becomes even more difficult. However, authors such as Maciol (2017) advocated for the use of engineers in spearheading the process. This is due to intimate knowledge of the system. In a foundry environment, this is especially true due to the sheer number of variables involved.

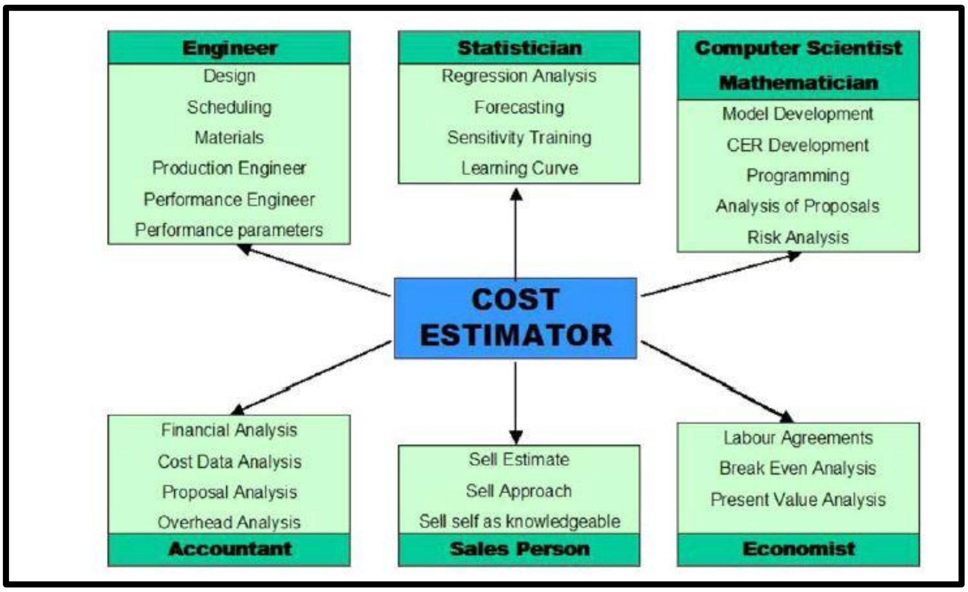


Figure 1.2: Skills needed for cost estimating (Curran, Raghunathan & Price (2004))

1.3 Research motivation

According to Miles and Snow (1994) one of the reasons businesses lost their competitive edge and disappeared, was the lack of awareness and inability to recognize new opportunities. Therefore, it is important for any organization to understand its own strategic intent and how the strategy will be managed. Thompson and Martin (2005) went on to show what a typical strategic management framework looked like. See figure 1.3. Transnet SOC Ltd realized the opportunity for growth in the movement of goods by rail in the African market. Transnet Engineering as the engineering arm of Transnet SOC Ltd was given the objective of increasing its foothold in the African rolling stock market. TE formulated a corporate strategy to meet these objectives, termed Vision 20-2-1. As one of the competitive strategies, the company grouped its businesses into customer-facing and support businesses. This research work was anchored on the assumption that one of the strategic decisions TE will take is to utilize its support businesses by extending their current scope to both internal and external customers.

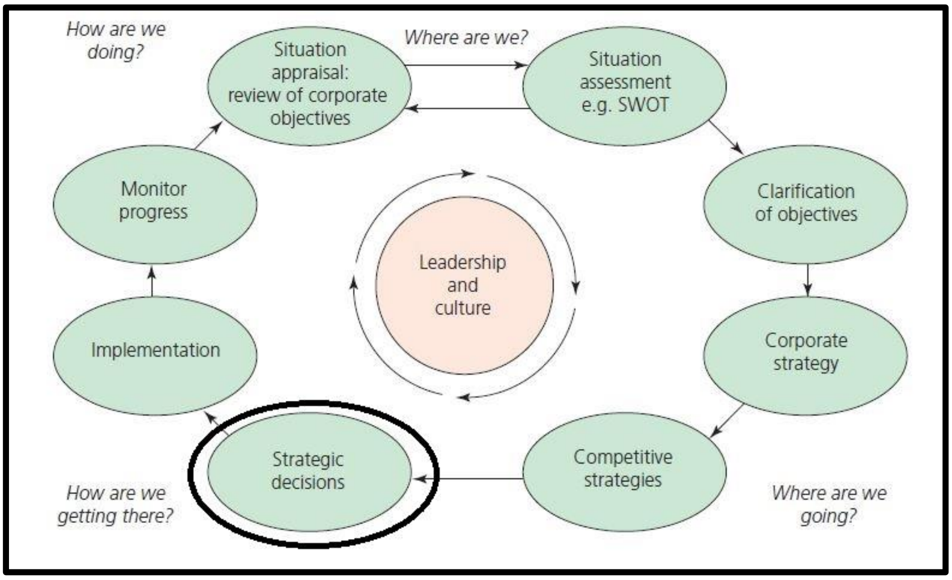


Figure 1.3: Strategy management framework (Thompson & Martin (2005))

There exists parts of literature (Davies (2015); Krieg and Cunningham (2014)) that support the full utilization of foundry businesses to achieve strategic objectives. These sources revealed that foundries can be utilized to generate revenue on various fronts such as mining, agriculture, rolling stock and general engineering industries. Currently, the KDS foundry business was budgeted to generate over R60 million revenue in internal sales for the 2019/2020 financial year. According to the African Development Bank (2015), railway development opportunities are ripe in the African continent due to urbanization, industrialization and large volumes of bulk commodities produced. Figure 1.4 shows the kind of business TE's KDS foundry is currently participating in, and with whom it conducts that business with. Additionally, it shows the kind of future business it can do with current clients and the kind of new clients it can extend its current business to. TE's KDS foundry business is a direct participant in the markets coloured green in figure 1.4, through the supply of general engineering, railway and rolling stock components. These opportunities exist locally and more especially across the continent. There exists therefore strong financial motivation also, to undertake this research effort.

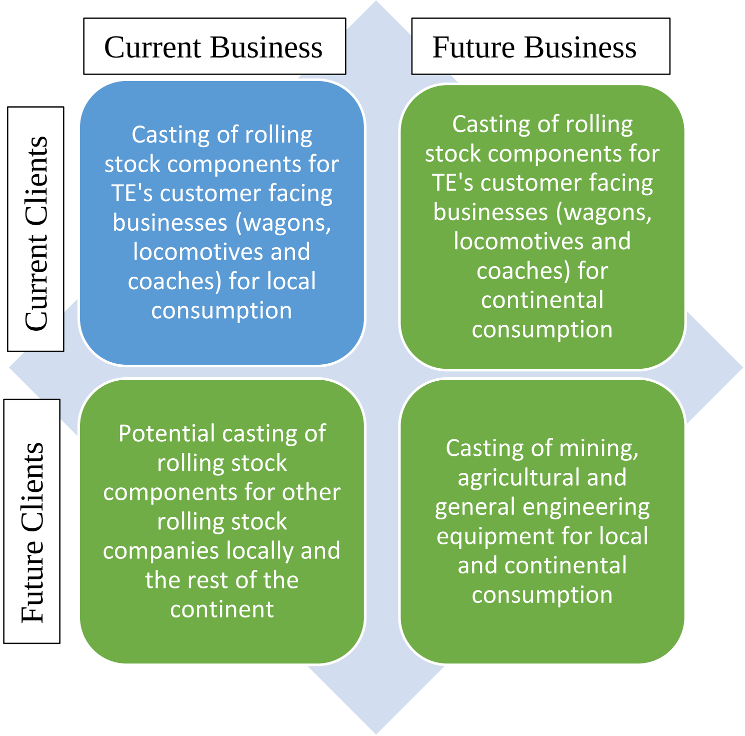


Figure 1.4 Scope and profile of TE's KDS foundry business

In order to compete in all these markets and potentially increase revenue and profit however, TE’ KDS foundry needed to have a product-cost estimating mechanism in place. Maciol (2017) indicated that in the modern competitive market, customers expect quick answers (in the case of quotations). Furthermore, there needs to be a balance in accuracy and risk. This shows the importance of having a valid and reliable cost estimating model in a foundry if the goal is to tap into all these markets.

1.4 Assumptions

A comprehensive breakdown of the assumptions made, is found in Appendix B. In summary:

1. Ultimately, Transnet Engineering will make the strategic decision to utilize its KDS foundry business to service external customers

2. The design mass and a technically complaint component casting mass are interchangeable

1.5 Delimitations

The most important delimitation related to this study is the use of manufacturing cost instead of selling price. This boundary was intentionally set because the manufacturing cost is a function of factors a foundry business can control. Selling price on the other hand includes considerations related to profit margins and costs outside of the control of TE’s KDS foundry. Therefore, the study focussed on what could be controlled to maximize usefulness.

The choice of experts to review the model were chosen to be those familiar with TE’s KDS foundry costing model so that the comparison with the developed model is meaningful. Furthermore, it was deemed appropriate (scoping and resources reasons) to develop the model for a specific foundry, before attempting to develop a general cost estimating model that can be tested across all foundries.

1.6 Research questions

Critical Research Question (CRQ): *Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product?*

Based on the CRQ, this research aims to answer the following:

(a) What is the relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost?

(b) How accurate would a model, using the design mass of a cast component be in predicting the final cast product's manufacturing cost?

(c) Can the developed CER be reliably used in practise?

1.7 Research objectives

The objectives of this research are to:

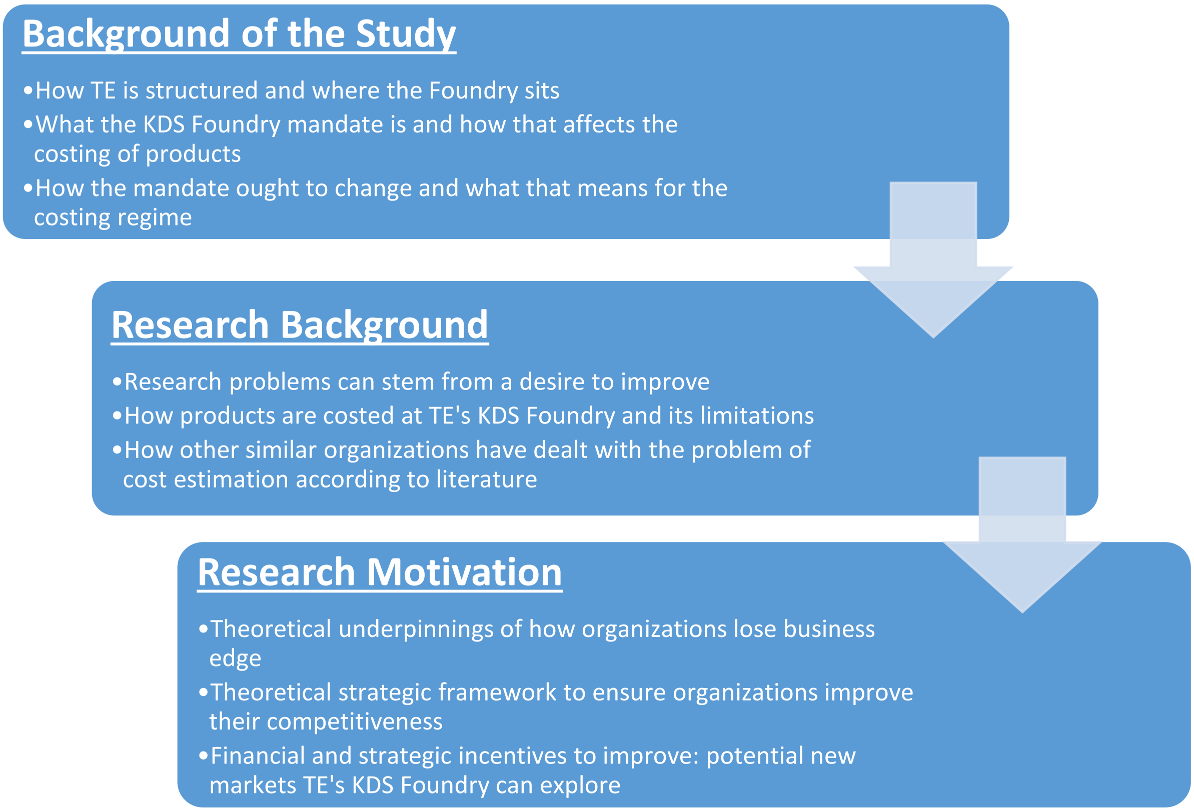
a) Establish a relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost.

b) Develop a costing model with cast component design mass and final product cost as the output for Transnet's KDS foundry.

(c) Develop a questionnaire for expert judgement on the usability of the developed model for validity and reliability purposes.

1.8 Summary

A summary of all the introductory themes and how they link, is shown in figure 1.5. This is to give an overview of what motivated and informed the entire research effort.



Background of the Study

- How TE is structured and where the Foundry sits
- What the KDS Foundry mandate is and how that affects the costing of products
- How the mandate ought to change and what that means for the costing regime

Research Background

- Research problems can stem from a desire to improve
- How products are costed at TE's KDS Foundry and its limitations
- How other similar organizations have dealt with the problem of cost estimation according to literature

Research Motivation

- Theoretical underpinnings of how organizations lose business edge
- Theoretical strategic framework to ensure organizations improve their competitiveness
- Financial and strategic incentives to improve: potential new markets TE's KDS Foundry can explore

Figure 1.5: Summary of how the introductory themes link

2. Literature Review

2.1 Introduction

The purpose of this literature review was to frame and position the proposed research work relative to what other researchers in the same knowledge area had already done. This, according to Jesson and Lacey (2006), was the essence of a literature review. The key objective of this proposed research work was to develop a cost estimating model for cast products at TE's KDS foundry.

The literature review aimed to first identify current foundry industry status and prevailing practises. This was an attempt to put every other aspect that was to be reviewed, into proper context. Globally, the performance and state of foundries was explored. This included establishing what the current economic state was, state of technology and general industry practises for the past 20 years. A similar analysis of the South African foundry context then followed. The aim being to draw attention to the similarities and differences between South Africa and the rest of the world, contrasts that were later linked to the academic case for this research work in general.

Secondly, the literature review aimed to draw attention to the strengths and limitations of the general costing methods that foundries currently used. This was done in order to interrogate the appropriateness of the costing method employed in this research work. An in-depth review of standard costing and activity based costing (ABC) as costing methods was done. The two methods were then reviewed as they had been applied in academic work related to the foundry industry, in South Africa and the rest of the world.

The different cost estimating methods, as they applied in the manufacturing sector, were critically analysed. A sector wide analysis, in this instance, was advantageous as the entire manufacturing sector has the same aim: convert raw materials into a useful product of higher value than the value of the sum of the individual materials. Parametric methods, analogous methods and generative-analytical methods were considered. The strengths, limitations, similarities and differences were evaluated relative to how appropriate each method was to the research context. This was done in order to establish and qualify the appropriateness of the chosen estimation method.

Lastly, important characteristics that speak to the usability of manufacturing cost prediction models were identified, together with the use of expert judgements to validate numerical models.

2.2 Foundry industry status and management practices

2.2.1 What is a foundry

A foundry, in simple terms, is a facility that produces metal castings. According to Beely (2001), a metal casting is a shaped article produced by pouring molten metal into a mould. The process is illustrated in figure 2.1.

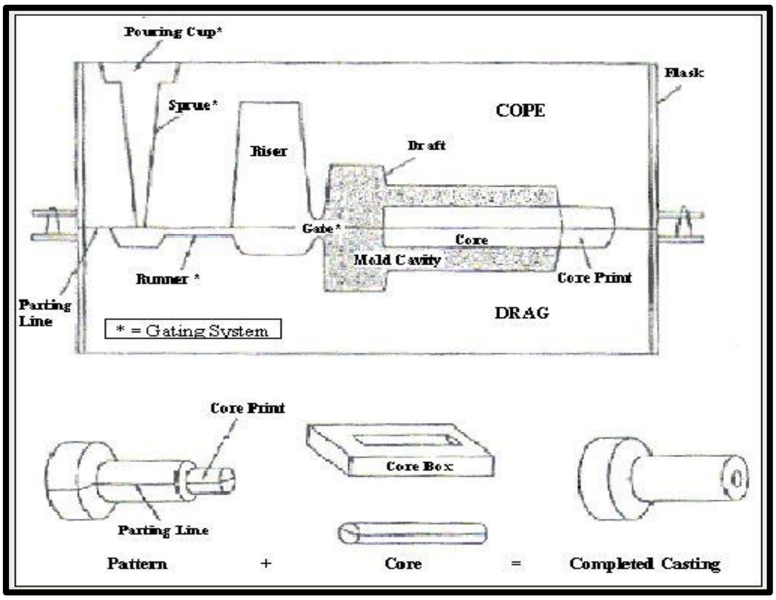


Figure 2.1: Metal Casting process (Sum Ngai Brass, 2018)

Various combinations of metal and mould are possible, to give a plethora of foundry setups. However, the primary purpose remains the same. Beely (2001) further noted that cast iron, steel (low carbon, mild and stainless), copper, aluminium, magnesium, zinc and nickel as the most common metals that foundries melt. In general, foundries are differentiated along various characteristics. However, the mould type is the most common characteristic used. Figure 2.2 illustrates the possible foundry setups based on the mould type.

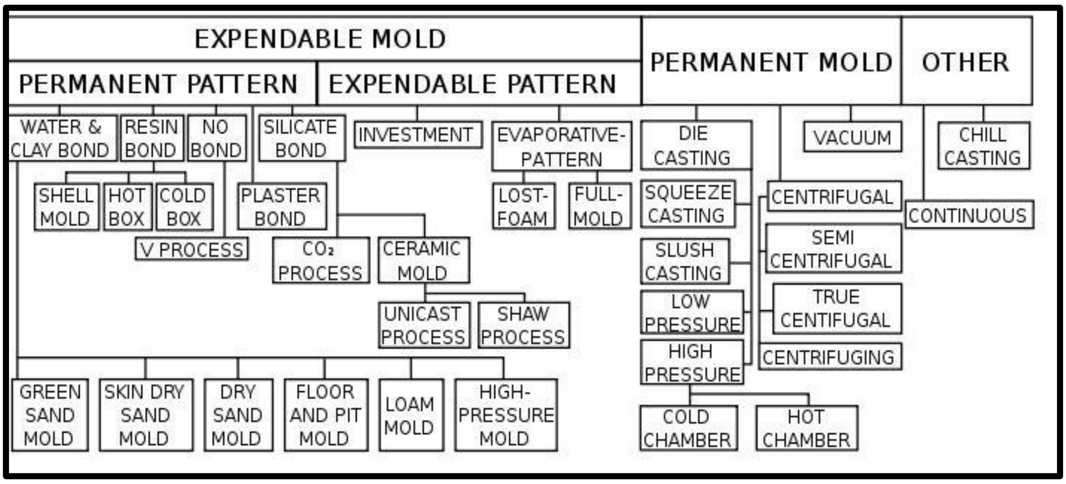


Figure 2.2: Possible foundry setups based on the mould type (Feng Li Group, 2017)

Pertinent to this research work, is the sand casting process. The process is illustrated in figure 2.3. As described in the introductory section (section 1.1), the first requirement of the process is a mechanical drawing (part (a) in figure 2.3). In this research context, the client provides the mechanical drawing to TE’s KDS foundry. A top (cope) and bottom (drag) pattern box (part (b) , part (c) and part (d)) are then made, which is a translation of the mechanical drawing into the desired component, to size. The pattern is made of wood, epoxy resin or metal. If the component has hollow (cavities, holes, etc) design features, a top and bottom core pattern box is made. The process is similar to part (a), part (b) and part (c), albeit the core patterns are smaller than the main patterns. Inside the top main pattern boxes, sleeves are placed to act as metal reservoirs (risers) that will compensate for volumetric shrinkage once the molten metal solidifies. Additionally, a sprue, which forms part of the runner system for the molten metal is placed on the top main pattern box. Part (f) shows placement of the sprue and the sleeves. Sand is then poured and compacted on the top main pattern box (part (g)).

Continuing, the bottom main pattern box does not need as much preparation as the top main pattern box (part (h)). Sand is poured and compacted. TE’s KDS foundry uses wooden boxes to hold the patterns. Consequently, after the sand has cured inside the pattern boxes, the sand moulds are shaken out of the wooden pattern boxes. The same pouring, compacting of sand and shakeout after curing, is followed in making core moulds. After shaking out the core sand moulds, the top and bottom halves are put together as shown in part (e). This is the same thing that happens to the main sand moulds, although the core mould is placed inside (part j), before the moulds are closed and ready for pouring (part (k)). Molten metal is poured in the closed sand mould, after solidification, the casting is shaken out, shotblasted to remove the surface sand and then heat treated to achieve the desired mechanical properties (part (j)). After heat treatment, the casting is then cut and fettled in order to remove the gating system, risers and any excess material. The casting is then visually inspected to insure dimensional and surface finish compliance. Mechanical properties and non-destructive tests reports, as required by the mechanical drawing, are also prepared. Casting is then ready for shipment (part (i)).

Pandey (2015) defined sand casting as the formation of a component by molten metal in a sand mould. The author noted that the oldest known sand mould dates from 645 BCE in China. Indicative of how old the casting process is. Chemically bonded sand and green sand are the two most common types of sand used in the sand casting process, even though Weiss (2018) mentioned the use of zircon, chromite and olivine. According to Banchhor and Ganguly (2014), green sand is a combination of silica sand, bonding clay and water. It is commonly used for small articles that are required in high volumes, due to the recyclability and use of cheap additives. Chemical bonded sand is a combination of silica sand and artificial binders that ensure the mould does not erode under metallostatic pressure and resist distortion. This type of sand is used for larger and complex articles. Weiss (2018) and Beely (2001) asserted that the most important characteristic of a moulding medium is the ability to compact to uniform density and the medium’s ability to be handled without distortion.

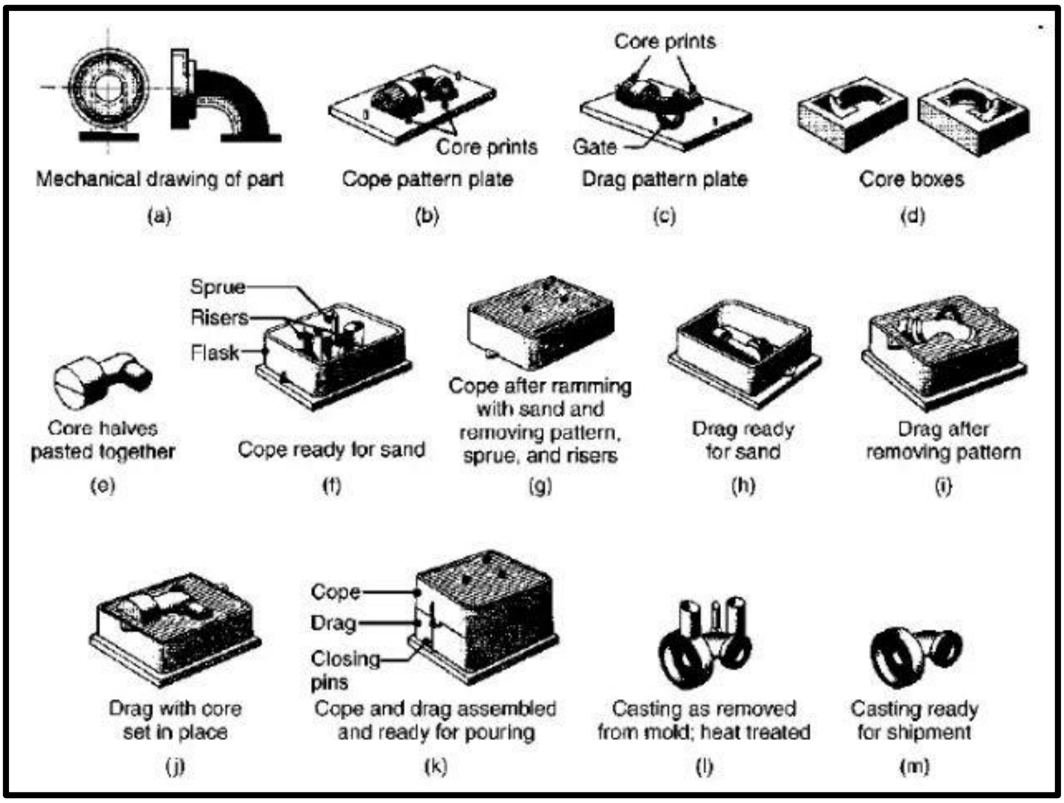


Figure 2.3: Sand casting process (Kalpakjian & Schmid, 2016)

The next significant aspect of the sand casting process, is the melting and preparation of the molten metal that is to be poured into the sand mould. There are three types of commonly used foundry furnaces: cupola furnace, induction furnace, and an arc furnace. El Wakil (2019) pointed out that the modern version of the cupola furnace was first used for foundry purposes by John Wilkinson in the 1700's. Patil and Ghatge (2017) provided a historical account of the use of induction furnaces for foundry purposes. Importantly, the authors noted that the first practical use of the induction furnace was in Sweden in 1900. Figures 2.4 shows a schematic of an induction furnace.

Induction furnaces play an important metallurgical role in a foundry. In terms of capacity, induction furnaces can range from 500kg-50tons. It is important that elemental mixing occurs properly, in order for the mechanical properties to be uniform in the castings. According to Green (2018), induction furnaces have good mixing action which allows the uniform dispersion of alloys. This then possibly explains the extensive use of induction furnaces for melting foundry scrap. Typically, induction furnaces are operated together with heat exchangers, as shown by the presence of the water cooling cable in figure 2.4. TE’s KDS foundry uses an evaporative cooling tower. Another important aspect of induction furnaces is lining. According to Goswami et al. (2015) choosing the right lining material was important. The authors pointed out that electrical induction requires lining material to be refractory, resist corrosion from hot metal, thin but thick enough to protect the copper induction coils. The number of heats that it takes to degrade the lining material to unsafe and unusable levels is also important for production scheduling because relining the furnace requires considerable furnace downtime.

Furthermore, it was reported (‘The Gap Narrows”, 2019) that environmental considerations make the induction furnace an attractive choice over the other type of furnaces. Maj, Werrtz and Pieklo (2017) compared environmental considerations versus foundry engineering practise in Asian and European foundries. They found that stringent environmental restrictions in Europe give Asian foundries a price advantage. Therefore, environmental considerations cannot be ignored. The subject foundry of this research work employs induction furnaces.

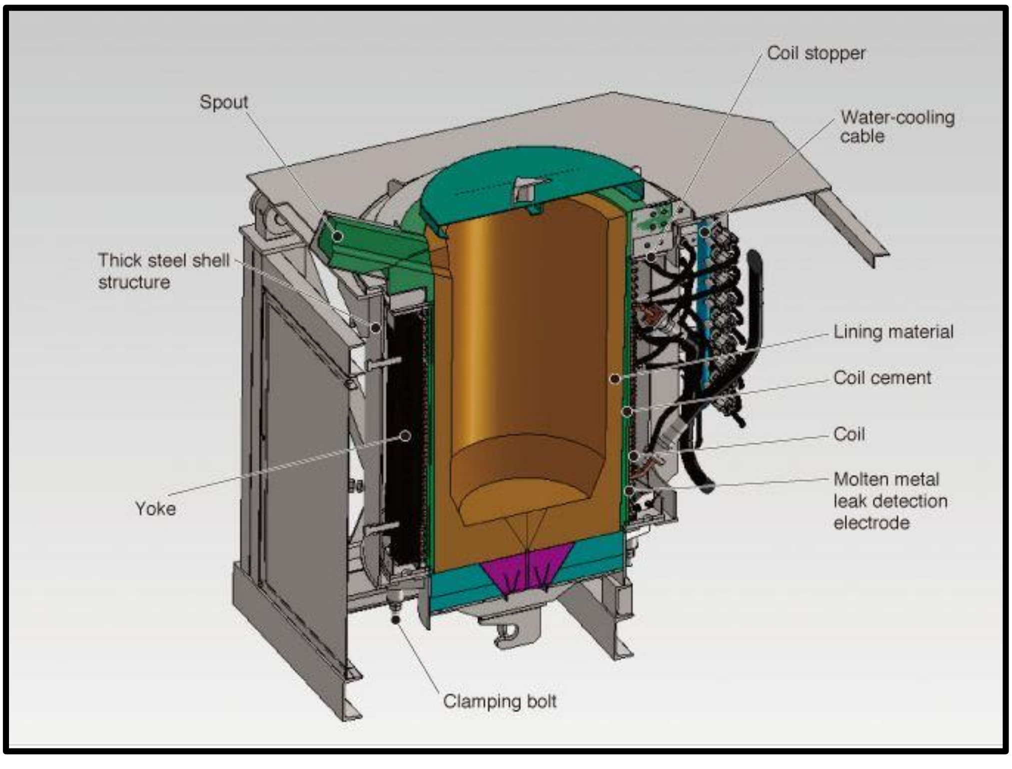


Figure 2.4: Electric coreless induction furnace (Sinfonia Engineering Co Ltd, n.d.)

In summary, figure 2.5 illustrates a typical overall process flow for a sand casting foundry. It clearly illustrates the intersection of the moulding process, melting process and the finishing stages. Beely (2001) emphasized that the cleaning (fettling and dressing) processes were primarily for the removal of excess metal, flash , adhered sand, together with the gating and feeding systems. Furthermore, heat treatment and repair welding of the components occur between stage 8 and stage 9 of figure 2.5. The process flow shown in figure 2.5 is representative of most sand casting foundries, including the subject of this research work, TE's KDS foundry. There are however, subtle but material differences. TE's KDS foundry strictly does the casting of the components only, and the machining function is outsourced. Therefore, stage 9 of figure 2.5 does not feature in the scope of this research work. This is due to the fact that, from a costing perspective, there isn't much control that can be exercised over an outsourced service. The model to be developed is also for internal product cost control exercises.

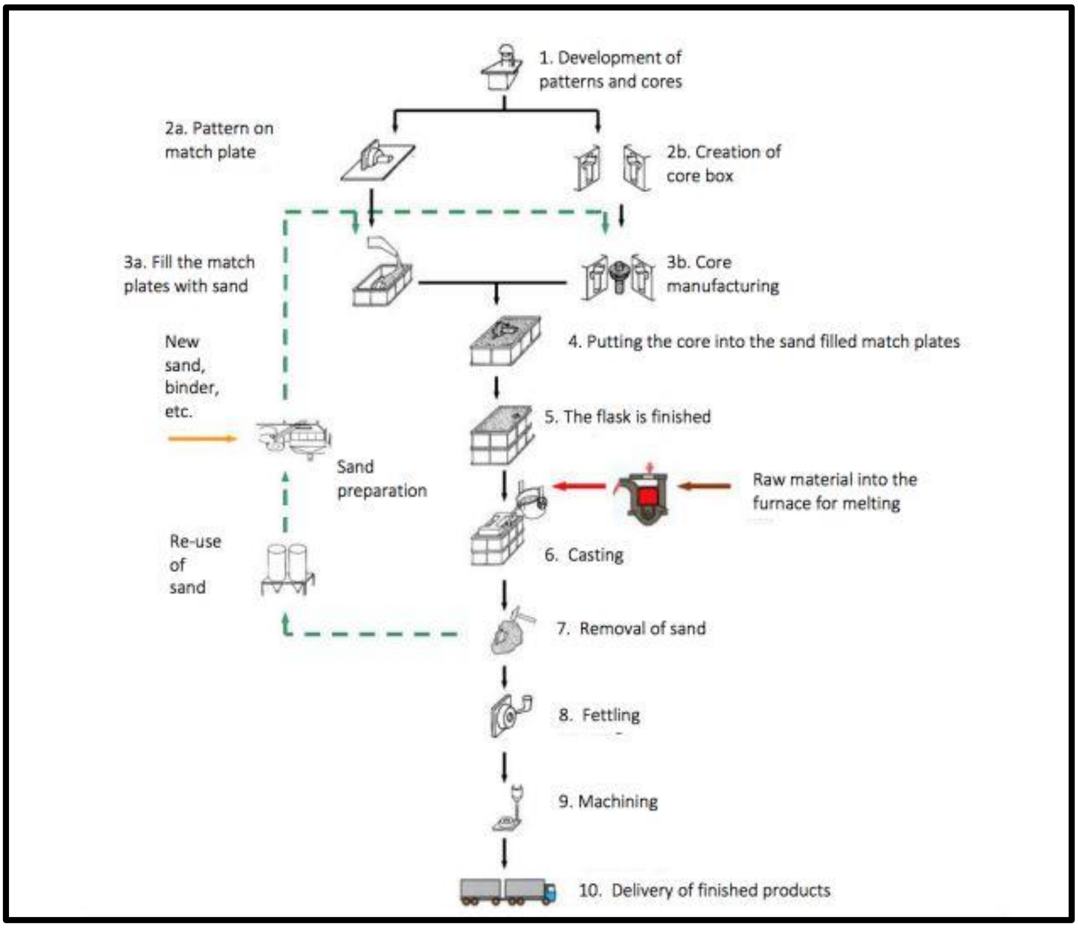


Figure 2.5: Typical overall foundry sand casting process (Dawson & Lindahl, 2017)

Now that the important aspects of what make a foundry, what it is have been reviewed, the global context is going to be considered. This is to ensure that a comprehensive picture is painted, framing the subject foundry relative to how and why other foundries work.

2.2.2 Global context

As of one the oldest industries, there is a foundry in every part of the world. Annually, the American Foundry Society (AFS) conducts a survey to ascertain global industry outputs and trends (“Census of World”, 2018). However, the survey excludes the African region. A summary of global industry outputs, per country, in 2017, is found in table A.1, Appendix A. Additionally, in Appendix A is table A.2 that shows the number of plants, per country, in 2017.

It is evident from table A.1 and table A.2 that BRICS (Brazil Russia India China South Africa) countries and other developing countries dominate the foundry industry. Of the total output, per Table A.1, BRICS countries contributed approximately 62% of global output in 2016. China on its own, had 57% of all the foundries in the world. The dominance of developing countries is likely attributable to the labour intensive nature of a foundry. In 2017, the unemployment rate in China, according to Statistic South Africa (2018), was 3.9%. The corresponding figure for South Africa in 2017 was 27.5%. South Africa only had 0.37% of the world’s foundries in 2016. In the absence of other factors, it cannot be speculated that having more foundries would lower a developing country’s unemployment rate. Nonetheless, intuitively, it is an idea worth considering since South Africa already has the biggest consumers (automotive industry) of foundry products on its shores. It was reported (Maromo, 2019) that in 2016 Ford Motor Company invested R3 billion in its South African operations.

In terms of the economic status of the global industry, certain trends are apparent from literature. The World Foundry Organization in 2018 compiled a report from across the globe, detailing key information at foundries across the world. Summary is found in table 2.1. It is evident from table 2.1 that foundry shops play an important part in the global economy. Most importantly, the countries with the largest number of foundries were showing positive growth in terms of output. However, it is worth noting that data in Table 2.1 is from 2016-2017. Global economic outlooks were a lot more positive. Holtzer, Zymankowska-Kumon and Danko (2012) in their analysis of the current state and future developments of the foundry industry echoed the strong correlation of the foundry industry's wellbeing to the global economy. They further note that demand from countries such as India, China and Brazil will be a significant factor. This is supported by the analysis of table A.1 and table A.2, where it was seen that BRICS countries constituted more than 62% of the global foundry industry.

Table 2.1: Foundry related economic information about certain countries (World Foundry Organization, 2018)

Country	**Economic Information**	**Number of Employees /Number of Foundries**
Austria	Total production = 318190 tons (+1.1% from previous year) Sales = €1.4 billion (+6.9% from previous year)	7098 employees (increased by 4% from previous year)
Belarus	Total Installed Capacity =557000 tons Total production = 259000 tons	135 cast shops
China	Total production = 49.4 million tons (+4.7% from previous year) Sales Exports = $2.64 Billion	-

Finland	Total Production = 19.5 tons (+28% from previous year) Sales = €228 Million (+7 from previous year)	1731 employees (increase of 10% from previous year)
Germany	Total production = 5.440 million tons Sales = €13.180 billion tons	77700 employees
India	Total production = 11.35 million tons (+5.4% increase from previous year) Sales Export = $2.366 billion (-5.47% decrease from previous year)	-

Having understood the global status of how and why foundries work, the review moved to a South African context. As noted in this section, the global foundry industry had been found to be sensitive to the general wellbeing of the world economy. The South African economy is not immune to turbulences in the global economy, it was therefore worthwhile understanding if the foundry industry in SA behaved the same as the global industry. Ultimately, this informed the applicability and limitations of the model that was to be developed. The CRQ stated '*Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product?'*. Reliability is tied to applicability and limitations. This necessitated the understanding of both global and local contexts.

2.2.3 South African context

In order to contextualize the entire research effort, a review of literature pertinent to the status of the South African foundry industry was necessary. The review was done in reference to section 2.2.2, which looked at the global context.

Mpasha (2014) conducted an analysis of the competitiveness of the South African foundry industry compared to international foundries. The author reported the distribution of foundries across South Africa in 2003, 2007 and 2011. Table 2.2 showed that the number of foundries in South Africa, between 2003 and 2011 decreased by over 19%. These could have been due to closures or mergers. However, Krieg and Cunningham (2014) noted in their study of opportunities for South African foundries in the global automotive supply chain that the local industry lacked some strategic competitive approaches, compared to their international counterparts. The theme of lacking strategic competitive approaches is also echoed by Mbanjwa (2015), who reported on how the local industry was being squeezed by cheaper foreign imports.

Table 2.2: Number of foundries in 2003 and 2011 (Mpasha, 2014)

Province	**Number of foundries '03**	**Number of foundries '07**	**Number of foundries '11**	**% of total foundries '11**
Gauteng	110	108	97	54
KZN	20	26	24	13
Western Cape	26	16	15	8
Eastern Cape	16	10	10	6
Free State	10	7	6	3
North West	10	9	5	3
Northern Cape	6	6	6	2
Other	15	15	18	10
Total	213	194	178	

The automotive industry was the biggest consumer of foundry products in South Africa, a trend that was also evident in the rest of the world, as per Holtzer, Zymankowska-Kumon and Danko (2012), figure 2.6. Abioye et al. (2018) also noted that the automotive industry in India was the biggest consumer of foundry products. In South Africa however, the mining industry was also a huge market for the foundry industry, figure 2.7. This is concerning however, due to the downturn in the mining industry in South Africa (Stoddart, 2020). Foundries in SA therefore may need to look into gaining more market share in their other existing markets, in order to remain competitive. As per the Research Motivation (section 1.3), TE's KDS foundry seeks to remain competitive also, like any other business.

As an internal supplier of only rolling stock components, it is evident from figure 2.7 that TE's KDS foundry is absent in the biggest markets that other South African foundries service. Perhaps, this is due to the fact that TE's KDS foundry is a steel producing foundry and markets like the automotive industry consume cast iron products than they do steel. However, the remaining industries are potential markets. Furthermore, TE's KDS foundry may also be absent from these other markets due to the strategic intent of TE, manifested through using the foundry as an internal support business to reduce supply risk. This therefore further justifies this research effort, whose core intention, as per the research motivation (section 1.3), is to develop a model that will allow TE's KDS foundry to compete in new markets.

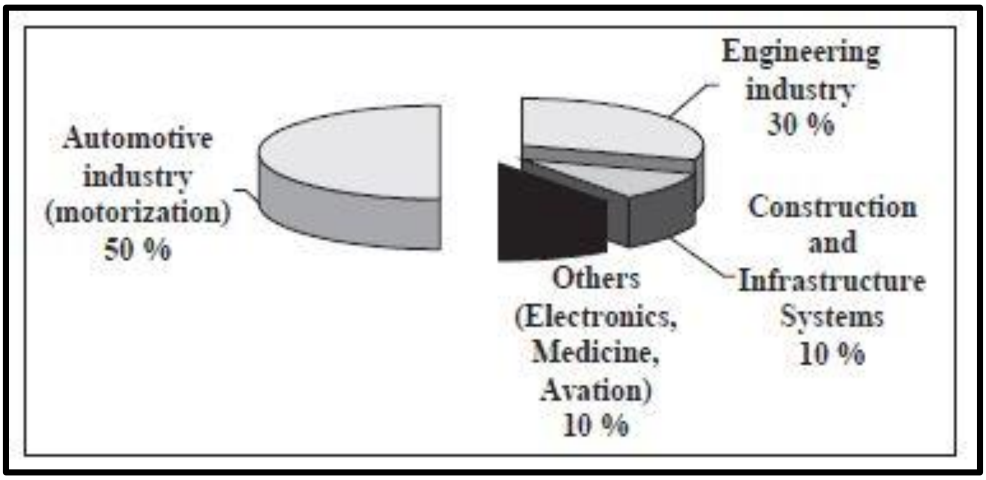


Figure 2.6: Global consumption of foundry products by industry (Holtzer, Zymankowska-Kumon & Danko (2012))

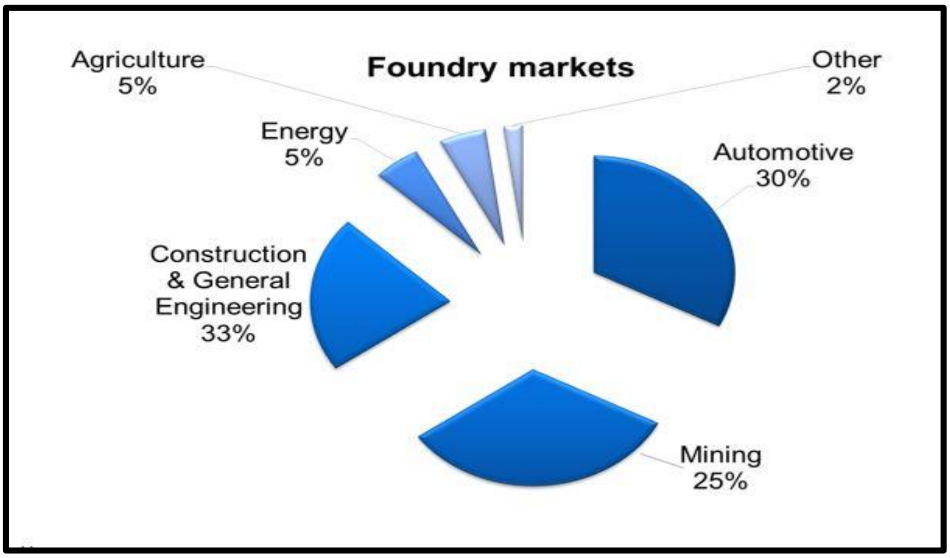


Figure 2.7: Consumption of foundry products by industry in SA (Davies, 2015)

On the economic front, Davies (2015) further reported that in 2014 the South African foundry industry consisted of an estimated 10285 employees, compared to 2011, this was a reduction of 10%. Furthermore, the foundry industry contributed 34.7% to Gauteng’s GDP in 2015. This downward trend is closely aligned with the economic downturn South Africa experienced after 2009. A characteristic the South African industry shares with its global counterparts. A closer consideration of the South African market suggests that the local market is particularly vulnerable to economic downturns. Davies (2015) reported a significant decrease (about 56%) in the number of foundries between 2007 and 2015. The trend is shown in table 2.3. A period characterized by the global market collapse of 2008 and slower recovery of emerging markets like South Africa, thereafter.

Table 2.3: Number of foundries in SA in 2003, 2007 and 2015 (Davies, 2015)

Province	Number of foundries '03	Number of foundries '07	Number of foundries '15	% of total foundries '15
Gauteng	143	141	114	66
KZN	26	25	20	12
Western Cape	33	32	14	8
Eastern Cape	20	20	8	5
Free State	13	13	5	3
North West	13	13	4	3
Northern Cape	7	6	3	2
Mpumalanga	15	15	2	1
Total	270	265	170	

It is therefore evident that foundries around the world share more similarities than differences. This was important because it had implications on the usability of the model that was to be developed. If foundries everywhere behave the same, intuitively, a model developed in one foundry can be easily tailored for another. However, such remain intuitive speculation. The review then moved into the different types of costing methods that foundries employed.

2.3 Foundry costing methods

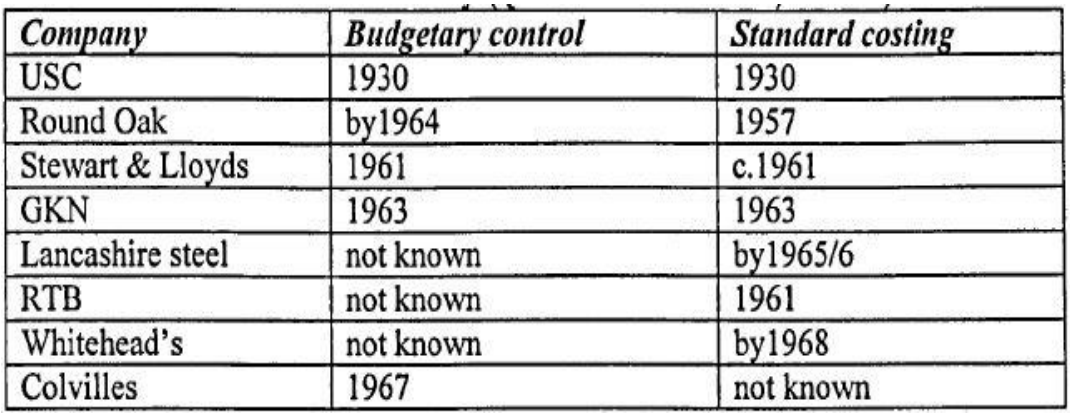
2.3.1 Standard Costing

The research work was to develop a costing model within a standard costing environment. A review of standard costing, as a costing method, was therefore warranted. Firstly, the theoretical underpinnings were discussed. These were followed by an analysis of research work pertinent to the applicability of standard costing in a foundry or similar environments. Lastly, strengths and shortcomings of the method were analysed. This then laid the ground for the next section, where a review of alternative costing methods occurred.

According to Drury (2015), standard costing is a costing method that assigns product costs based on engineering/scientific standards of performance. Historically, the earliest form of standard costing was employed by F. Talyor in the 19th Century (Ibrahim, 2007). Cunningham (1911) describes how F. Taylor wanted to systematically organize labour and manage the floor at the Midvaal Steel Company. Importantly, Cunningham described how F. Taylor conducted time studies to ascertain how long certain tasks take. The establishment of scientific standards is at the core of standard costing. Ibrahim (2007) goes on to further note that Alexander Hamilton Church in 1901 also pioneered the idea of standardized rates to allocate indirect costs. For further historical context, Ibrahim (2007) provides a more detailed account of the development of standard costing systems.

It is now apparent from the evidence above that standard costing systems were developed for use in manufacturing environments, similar to this research work's environment of interest. The 20th century was characterised by the second industrial revolution, where mass manufacturing was prominent. Edwards, Boyns and Matthews (2002) reported the use of standard costing by iron and steel industries in the UK in the 20th century. This is shown in table 2.4. Hergeth (1996) also described elements of standard costing in the textiles industry, dating back to the early 1900s. This suggests that different manufacturing establishments in the early 20th century used standard costing.

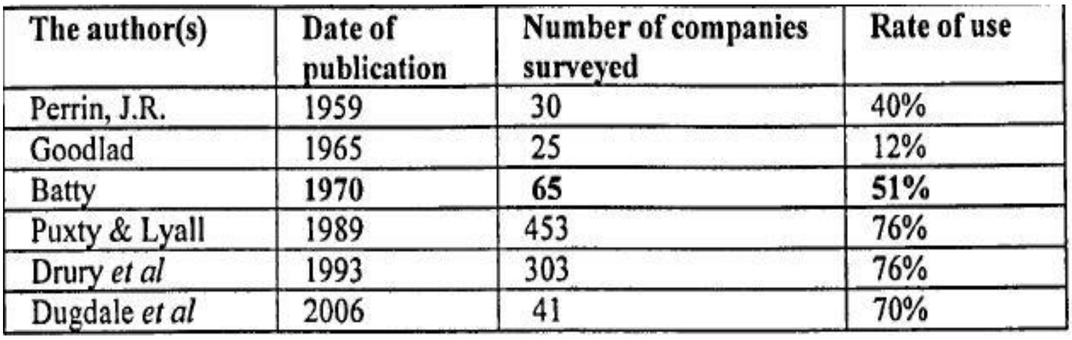
Table 2.4: Use of standard costing by iron and steel industries in the UK in the 20th century (Edwards, Boyns & Matthews, 2002)



Company	*Budgetary control*	*Standard costing*
USC	1930	1930
Round Oak	by1964	1957
Stewart & Lloyds	1961	c.1961
GKN	1963	1963
Lancashire steel	not known	by1965/6
RTB	not known	1961
Whitehead's	not known	by1968
Colvilles	1967	not known

Ibrahim (2007) summarized surveys that had been done by multiple authors on the use of standard costing by manufacturing firms in the past 60 years. The summary is shown in table 2.5. The evidence suggests that there has been an increase in the rate of use of standard costing amongst manufacturing firms. Worth noting however, is the apparent decrease in the rate of use after the 90s. The number of companies surveyed in the 1993 study and the 2006 study might be suspect (86% difference in sample size). However, a deeper view into the evolution of costing systems in manufacturing reveals another possible explanation for the decrease in popularity of standard costing systems.

Table 2.5: Use of standard costing by manufacturing firms (Ibrahim, 2007)



The author(s)	**Date of publication**	**Number of companies surveyed**	**Rate of use**
Perrin, J.R.	1959	30	40%
Goodlad	1965	25	12%
Batty	**1970**	**65**	**51%**
Puxty & Lyall	1989	453	76%
Drury *et al*	1993	303	76%
Dugdale *et al*	2006	41	70%

Khan, Rizwan, Islam and Ul Aabdeen (2006) posited that standard costing is more suitable in an environment of repetitive operations. That is why it is prominently used in manufacturing environments, as is in this research work.

Since the early 1980's, multiple criticisms have emerged against standard costing. An analysis of these criticisms suggests that advanced manufacturing methods and the need to be competitive on a global scale, are the main reasons why these criticisms have been put forth. In their analysis of the role of standard costing in the manufacturing environment, Lucas (1997) noted that manufacturing was not as labour intensive as it was decades before, this can be attributed to advancing manufacturing methods. De Zoysa and Herath (2016) noted that one of the key characteristics of a standard costing system is how it treats direct labour costs as the main control object.

Drury (1999) suggested that manufacturing companies looking for global competitive edge could use techniques such as Just In Time (JIT). Authors such as Kaplan (1983) advocated for the use of Activity Based Costing (ABC) in order to better trace and assign costs. ABC as an alternative method is discussed in section 2.3.2.

Despite all this criticism, there exist multiple sources from literature that suggest that manufacturing companies still use standard costing systems.

- Lyall and Graham (1993) conducted a survey of manager's attitudes to the cost information provided by a standard costing system and found that, contrary to the views of academic experts, the managers were satisfied by the standard costing system.

- Sulaiman , Nazli, Ahmad and Alwi (2005) conducted a survey to ascertain the level of use of standard costing systems in Malaysia. They found that 76% of Malaysian firms used standard costing. They also found that 70% of the surveyed companies that are based in Malaysia but are of Japanese origin also used standard costing.

- Joshi (2001) studied the diffusion of new management accounting practises in India. The author found that Indian companies still employed traditional management accounting techniques and the diffusion of newly developed techniques (such as JIT) were very low.

One of the attractive qualities of standard costing systems, was the relative ease of use such systems afford users. This was perhaps the main reason why standard costing systems still enjoyed so much favour. Variance analyses allow companies to spot potential inefficiencies and wastages.

Similarly, there are a number of authors who have evaluated the foundry industry specifically, in light of these reported shifts in management accounting thinking in the manufacturing space. Al-Tahat and Abbas (2012) pointed out that foundries had traditionally used direct labour as the basis of assigning overhead costs. The authors go on to argue that because of the manual labour that was traditionally involved, there was a strong correlation between direct labour and overhead costs in foundries. However, due to increased automation in foundries, the correlation has grown weaker. This is consistent with the general view that advancing technology will make standard costing obsolete.

Eric, Petri, Tanja and Castillon-Solano (2006) made the point that the cost structure in most foundries had evolved from a 70/30 direct/indirect cost to a 30/70 direct/indirect cost structure. They claimed that this is due to the increased need for adaptability and flexibility. Again, it was evident that the trends in the general manufacturing space were also reflected in the foundry industry. The need for adaptability and flexibility was further echoed by Holtzer, Zymankowska-Kumon and Danko (2012) in their assessment of current and future developments in the foundry industry. Furthermore, this is consistent with the general business conditions of the 21st century: adapt or die. It was clear therefore that the state of technology and the strategic ambitions of a foundry were key factors in determining the appropriate costing system.

TE’s KDS foundry was semi-automated, had repetitive operations and still required considerable manual labour. This was indicative of the old technology employed. A standard costing system therefore, was expected to still be relevant, particularly if the cost structure leaned towards a 70/30 direct/indirect costs split. This expectation is further compounded by the planning requirements (budgets, etc.) that TE’s KDS foundry had to meet as an internal support business.

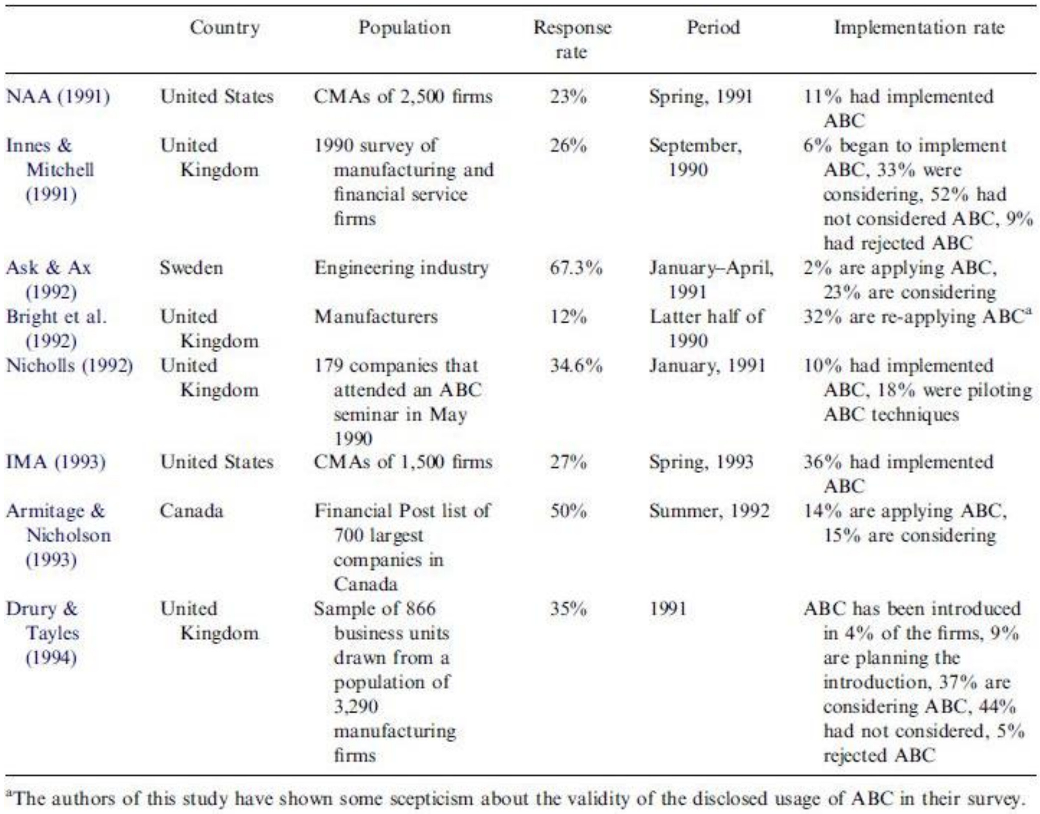
2.3.2 Activity-based Costing

As mentioned in section 2.3.1, one of the alternative costing methods to standard costing is ABC. A review of ABC is therefore necessary, to contextualize and give meaning to the use of standard costing in this research work.

According to Gosselin (2007) ABC is ‘‘*a two-stage cost accounting technique that assigns indirect costs to products, services or any other cost objects*’’. The need to relook overhead costs allocation got more urgent as manufacturing technology advanced. ABC therefore gained prominence due to its promised ability to accurately assign overhead costs. This accuracy in assigning overhead costs had been sighted as one of the shortcoming of standard costing systems. Miller and Vollman (1985) noted that manufacturing managers at the time believed that they are ill equipped to deal with the high manufacturing overheads. The authors further noted that these manufacturing overheads were affecting profit and competitiveness. This very sentiment catapulted ABC to the fore.

Gosselin (2007) conducted a comprehensive review of ABC, where the author looked at the technique, implementation and consequences thereof. Found in the review is a list of published surveys about the diffusion rate of ABC from 1995-2000 in multiple industries.

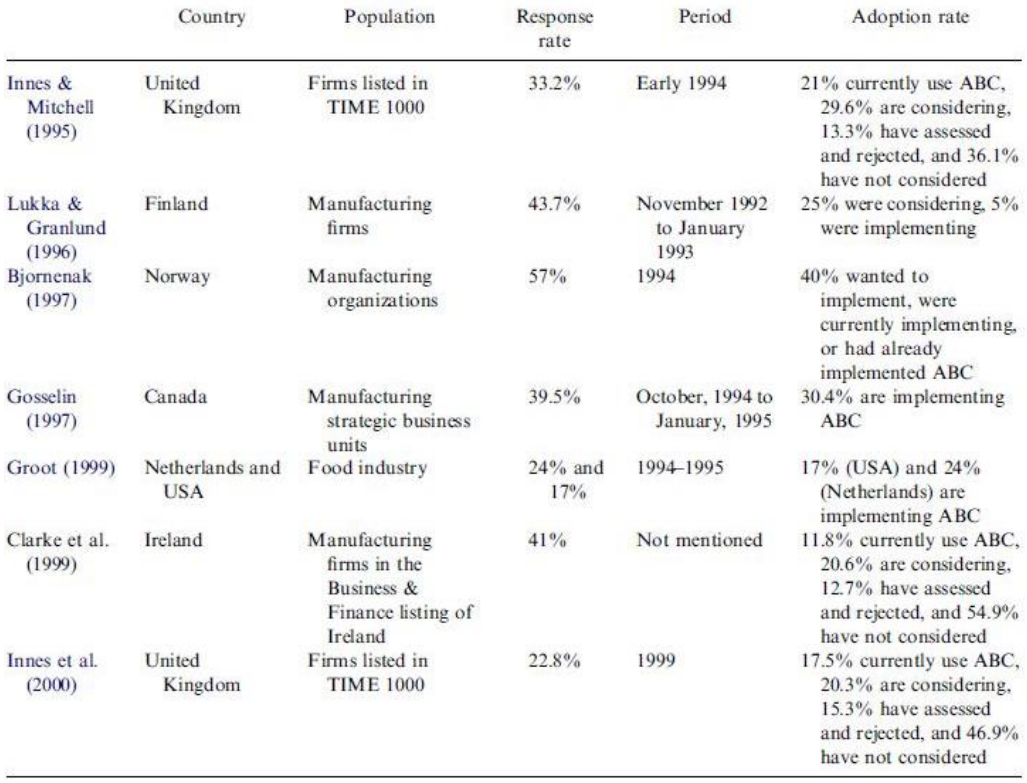
Table 2.6: Surveys on the diffusion of ABC from 1990 to 1994 (Gosselin (2007))



	Country	Population	Response rate	Period	Implementation rate
NAA (1991)	United States	CMAs of 2,500 firms	23%	Spring, 1991	11% had implemented ABC
Innes & Mitchell (1991)	United Kingdom	1990 survey of manufacturing and financial service firms	26%	September, 1990	6% began to implement ABC, 33% were considering, 52% had not considered ABC, 9% had rejected ABC
Ask & Ax (1992)	Sweden	Engineering industry	67.3%	January–April, 1991	2% are applying ABC, 23% are considering
Bright et al. (1992)	United Kingdom	Manufacturers	12%	Latter half of 1990	32% are re-applying ABC[a]
Nicholls (1992)	United Kingdom	179 companies that attended an ABC seminar in May 1990	34.6%	January, 1991	10% had implemented ABC, 18% were piloting ABC techniques
IMA (1993)	United States	CMAs of 1,500 firms	27%	Spring, 1993	36% had implemented ABC
Armitage & Nicholson (1993)	Canada	Financial Post list of 700 largest companies in Canada	50%	Summer, 1992	14% are applying ABC, 15% are considering
Drury & Tayles (1994)	United Kingdom	Sample of 866 business units drawn from a population of 3,290 manufacturing firms	35%	1991	ABC has been introduced in 4% of the firms, 9% are planning the introduction, 37% are considering ABC, 44% had not considered, 5% rejected ABC

[a] The authors of this study have shown some scepticism about the validity of the disclosed usage of ABC in their survey.

Table 2.7: Surveys on the diffusion of ABC from 1995 to 2005 (Gosselin (2007))



	Country	Population	Response rate	Period	Adoption rate
Innes & Mitchell (1995)	United Kingdom	Firms listed in TIME 1000	33.2%	Early 1994	21% currently use ABC, 29.6% are considering, 13.3% have assessed and rejected, and 36.1% have not considered
Lukka & Granlund (1996)	Finland	Manufacturing firms	43.7%	November 1992 to January 1993	25% were considering, 5% were implementing
Bjornenak (1997)	Norway	Manufacturing organizations	57%	1994	40% wanted to implement, were currently implementing, or had already implemented ABC
Gosselin (1997)	Canada	Manufacturing strategic business units	39.5%	October, 1994 to January, 1995	30.4% are implementing ABC
Groot (1999)	Netherlands and USA	Food industry	24% and 17%	1994–1995	17% (USA) and 24% (Netherlands) are implementing ABC
Clarke et al. (1999)	Ireland	Manufacturing firms in the Business & Finance listing of Ireland	41%	Not mentioned	11.8% currently use ABC, 20.6% are considering, 12.7% have assessed and rejected, and 54.9% have not considered
Innes et al. (2000)	United Kingdom	Firms listed in TIME 1000	22.8%	1999	17.5% currently use ABC, 20.3% are considering, 15.3% have assessed and rejected, and 46.9% have not considered

Evident from table 2.6 and table 2.7, the diffusion rates of ABC were very low. This led to what Gosselin (2007) termed the ABC paradox – theoretical superiority of ABC over traditional costing systems, but less reported usage in industry. There were various explanations to the paradox. In a case study to examine why ABC systems fail in organizations, Malmi (1997) examined resistance to change to a new systems as a principal source of why ABC systems seem to fail. The author found that organizational culture was one of the factors that may negatively impact on the success of an ABC system. Kaplan and Anderson (2004) also noted employee irritation and high implementation costs as one of the reasons some organizations abandoned ABC.

Despite what seemed like difficulties in industrial application of ABC systems, there are reported uses of ABC systems in foundries. Al-Tahat and Abbas (2012) developed a cost estimating model for a steel foundry, using an ABC framework. The authors found that ABC systems can effectively be used for cost reduction exercises. The authors modelled a production run, in one scenario ABC was used to allocate overheads and traditional costing (standard costing is a form of traditional costing) was used in the other. The ABC framework was a better reflection of true costs than the traditional costing system. However, the authors also shared the same reservation about the general implementation of ABC systems: Implementation of ABC was a costly exercise.

2.4 Cost estimating approaches in manufacturing

2.4.1 Introduction

There exists quantitative and qualitative methods for estimating costs in the manufacturing sector (Sajid, Wasim, Hussain and Jahanzaib (2018). However, there is no general consensus on the most appropriate way to classify the methods. Niazi, Dai, Balabani and Seneviratne (2006) suggested the classification shown in figure 2.8. Layer, Ten Brinke, Van Houten, Kals and Haasis (2010) suggest the classification shown in figure 2.9. Nonetheless, the differences in classification are due to differences in the choice of criteria.

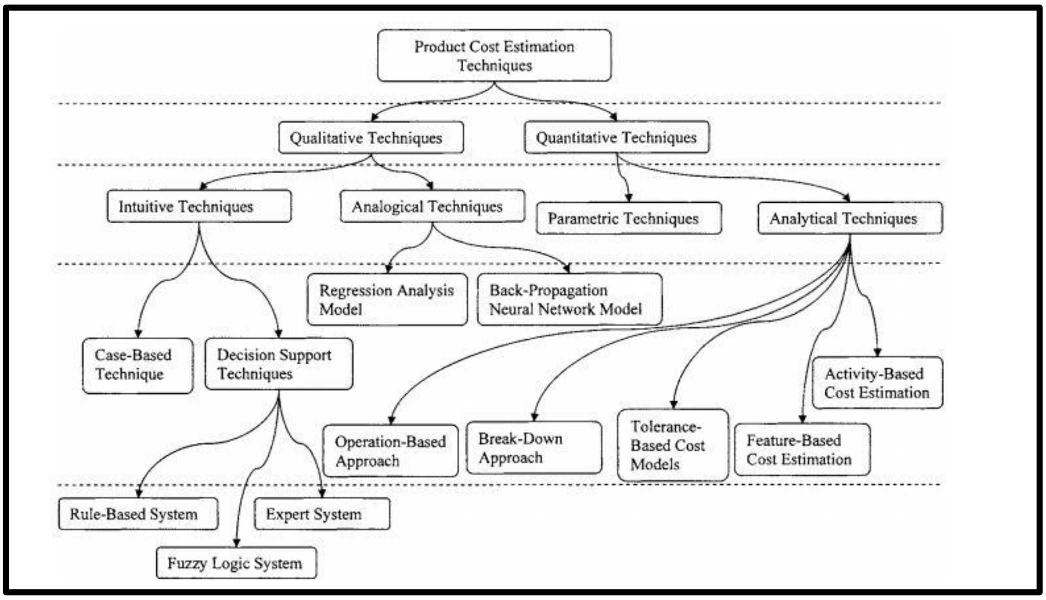


Figure 2.8: Classification of cost estimating methods (Niazi, Dai, Balabani & Seneviratne (2006))

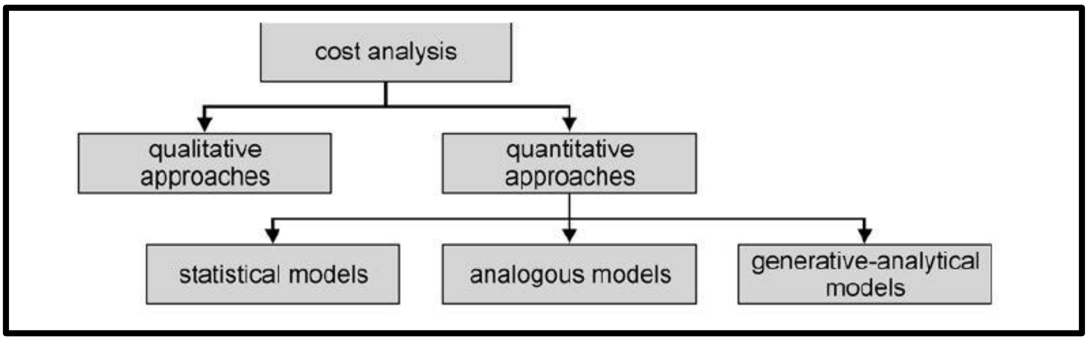


Figure 2.9: Classification of cost estimating methods (Layer et al. (2010))

The purpose of this section therefore, was to critically analyse cost estimating approaches in manufacturing. Specifically, parametric methods – the dominant form of quantitative approaches, analogical techniques and case-based techniques. These approaches had been selected because they were the most widely used and they provide a fair representation of quantitative and qualitative methods.

2.4.2 Parametric/Statistical methods

As per the theoretical frameworks presented in figure 2.8 and figure 2.9, one of the types of quantitative approaches was parametric/statistical approaches. This method was analysed first and in depth because this research work was to make use of a parametric framework.

According to Layer et al. (2010) in their study of recent and future trends in estimation, statistical methods employ historical data with empirical examinations to establish the causal link between product characteristics and costs. See figure 2.10. The authors suggested that the 'product model' was a set of characteristics that describe the product/component to be manufactured. An inherent implication was that these characteristics needed to be accessible/known before manufacturing. These characteristics then acted as the input in the costing model. In the context of this research work, this characteristics was the design mass.

Furthermore, the authors suggested that there are then two ways that this input is converted into a cost estimate/information. Algorithms and neurones. The latter was described as a neural network system, with interconnected nodes that were partitioned into input and output layers. According to Sohl and Venkatachalam (1995) back-propagation was the most popular form of training neural networks. Each node in a layer processed a certain data value, because one node from a single layer connected to multiple nodes below and above it, each connection had a weighting. By training the neural networks, it was these weightings that are fine-tuned till they reach a designated error level. However, Sohl and Venkatachalam (1995) pointed out that using neural networks was suitable when qualitative reasoning was needed or when the solution needed had interdependent variables that could not be easily quantified. In this research context, there was no qualitative reasoning required and the solution (cost estimate) was to come from interdependent variables that could be quantified.

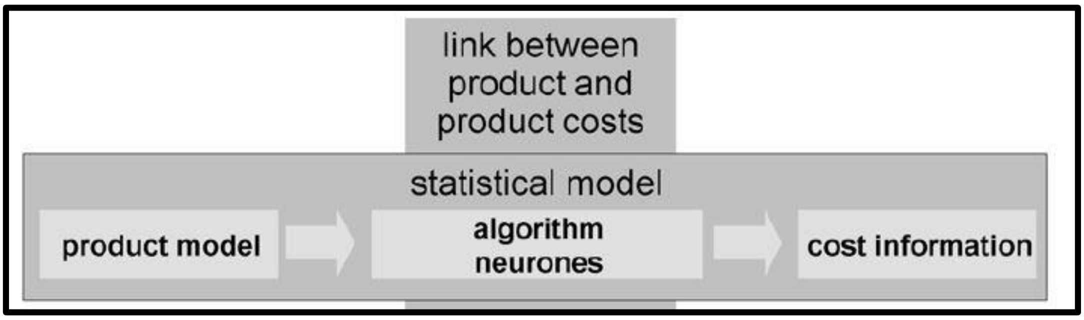


Figure 2.10: Parametric methods (Layer et al. (2010))

Algorithms described in figure 2.10 are best illustrated by Hueber, Horejsi and Schledjewski (2016) in their review of cost estimation methods and models for aerospace composite manufacturing (figure 2.11). These algorithms were simply mathematical equations that linked the input (product characteristics) to the output (cost estimate/information) using regression analysis or optimization techniques. The first important characteristic of parametric cost estimations that use algorithms was the dependence on historic data. Usually, this historic data was some characteristic of the products (part size and wall thickness in the example used in figure 2.11). This had a two-fold implication. One, estimating the cost of a similar product that fell outside the historic range used to compute the mathematical expression invited potential errors because this was now extrapolation territory. Secondly, a product whose cost needed to be estimated had to have the same characteristics that were used to compute the mathematical expressions. For example, in figure 2.11 part size (diameter) and wall thickness are the input characteristics chosen to compute the cost estimating relationship. The cost of another product that is not expressed in the equivalent (cube versus cylinder) input characteristics, cannot be estimated.

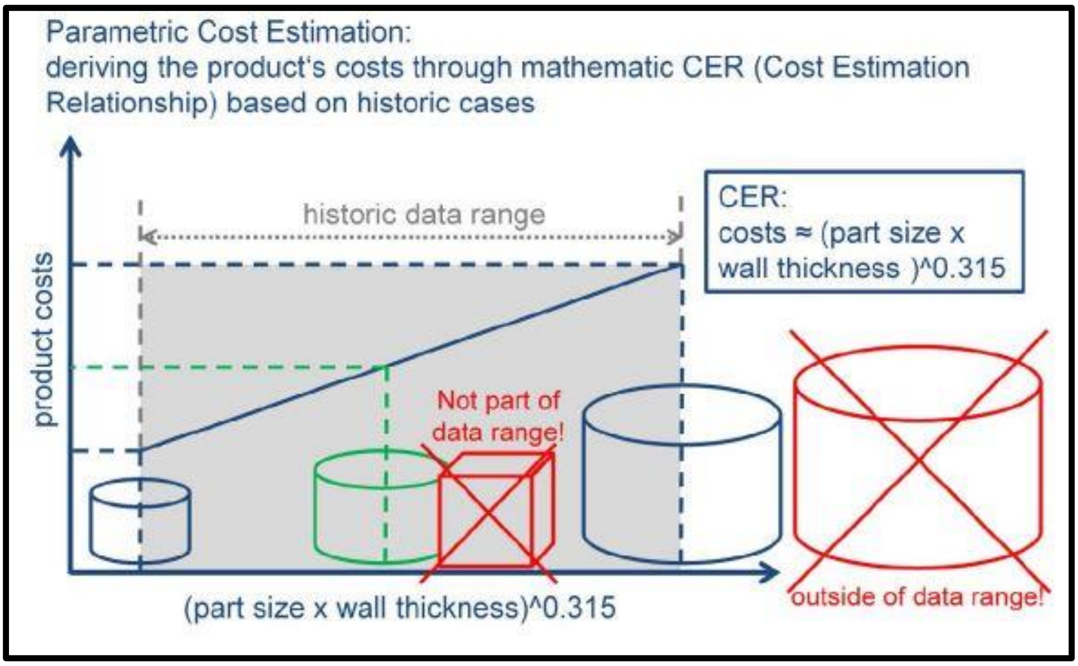


Figure 2.11: Parametric methods (Hueber, Horejsi & Schledjewski (2016))

Curran, Raghunathan and Price (2004) in assessing the state of engineering cost modelling in the aerospace industry, reported on a methodology to develop a parametric cost model, similar to what this research work intended to do(figure 2.12). This methodology broke down the principles and frameworks described above for parametric methods that employed regression equations to link product characteristic(s) to manufacturing cost. Linking product defining characteristics to the manufacturing cost was and remains the essence of developing cost estimating models. Methodology described in figure 2.12 was relevant to this research work from the 'Selection of Variables' stage. Data collection and normalization could follow once the product defining variable(s) has/have been selected. The methodology goes on to describe analysis and packaging of this historic data. Upon analysis, regression and curve fitting occurs, to link the selected product characteristic(s) (variable X and y) using past cases, to the manufacturing cost (C). Upon testing the best form of the relationship, the most appropriate (depending on the purpose of the CER) could be selected, validated, approved and catalogued. This methodology could be suited to addressing the CRQ, as described by this research work.

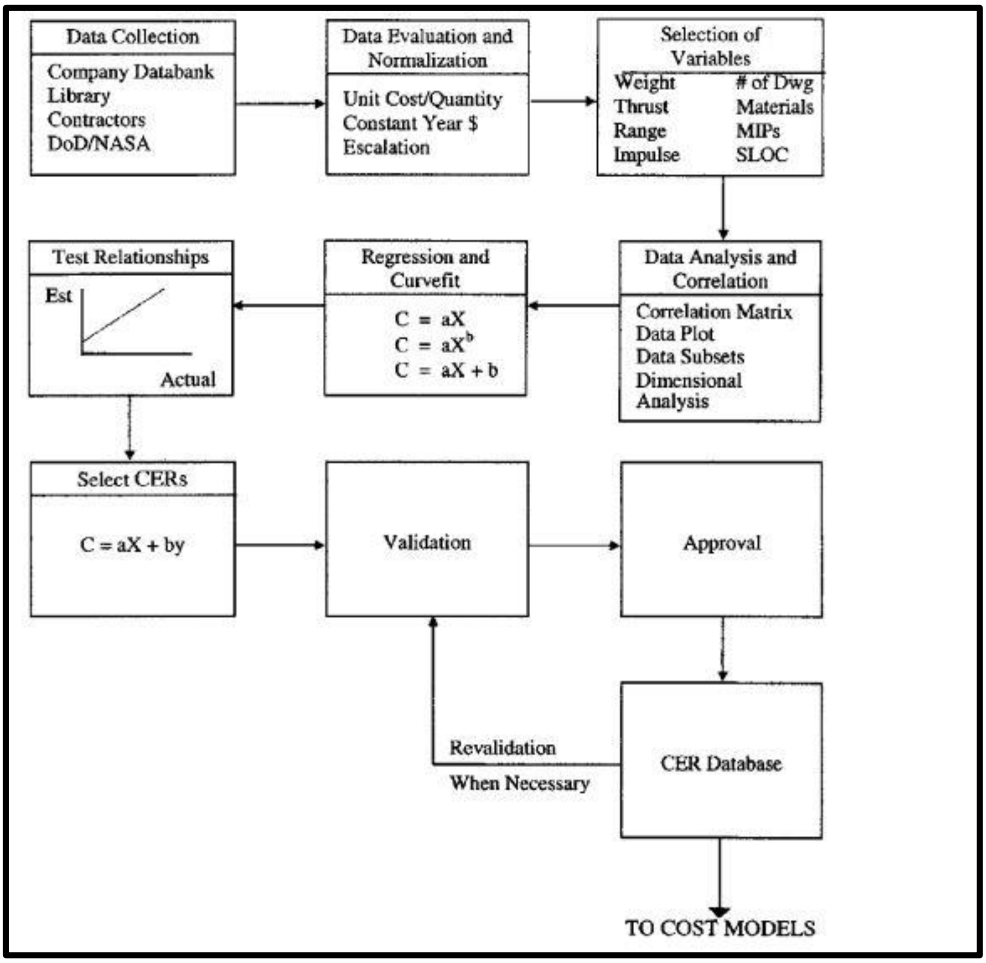


Figure 2.12: Development of cost models (Curran, Raghunathan & Price (2004))

Chougule and Ravi (2010) used a form of statistical estimation methods to predict cast product costs in an integrated product-process design environment. Shreve, Schuster and Basson (1999) also used a statistical estimation method to predict manufacturing cost during tack-welding of steel parts. Even though the two studies were dealing with different manufacturing processes (fabrications vs casting), the desire remained to know the manufacturing cost beforehand. What these two studies revealed was that the manufacturing price was sought for different purposes. This research work aimed to develop a costing model for preliminary quote processes, whilst in both studies the preliminary cost was for design decision making purposes. However, the requirements, for both design-decisions and preliminary quotes, were accuracy and ease of use. Watson & Kwak (2004) reaffirmed that parametric estimation models were most useful in a bidding process because they generated an estimate quickly. That is precisely what this research work sought to do: Develop a tool that can estimate product costs at TE’s KDS foundry for preliminary quote purposes, using known variables.

Chougule and Ravi (2010) asserted that over 70% of a product’s cost were locked in during the design phase. Hence, a lot of research effort had gone into trying to work out preliminary costs for design purposes than for quotation purposes. In a parametric approach to cost estimating at the conceptual stage of design, Mileham, Currie, Miles and Bradford (1993) identified three key system characteristics that allowed the use of a parametric estimating model. One, the availability of basic information in the conceptual stages. Two, the presence of process specific, component information database that links cost to a certain variable. Thirdly, that there be a set of generic component parameters that described the characteristics. Mileham et al. (1993) went on to develop a mass-cost relationship for injection mould cast components and upon the addition of another known process parameter, improved the accuracy of the estimate. A similar approach could be considered for this research work.

According to Toth (2006), the drawbacks of parametric methods included difficulty in developing the model and the availability of relevant historic data. Additionally, the presence of cost drivers outside the model system boundary could have been of concern. Curran, Raghunathan and Price (2004) also noted the lack of direct cause-effect relationships as a drawback of parametric methods. All these drawbacks were associated with an individual process step in the methodology described in figure 2.12. Intuitively, this was consistent with how any system works: There are associated weaknesses with each step. The effect of these associated weaknesses on the overall system was not in the scope of this research work.

Hueber, Horejsi and Schledjewski (2016) provided a summary of the advantages and disadvantages of parametric methods. See table 2.8. It was evident that a lot of considerations and assumptions had to be made and documented in order to be able to understand and interpret the model results. Furthermore, it was clear that validation was an important element of interpreting results generated using parametric methods. See figure 2.12 also.

Table 2.8: A summary of the advantages and disadvantages of parametric methods (Hueber, Horejsi & Schledjewski (2016))

Method	Advantages	Disadvantages
Parametric Cost Estimation	-Easy to implement -Excellecnt for "what-if" analysis -Non-technical experts can apply method -Allows scope for quantifying risk	-Difficult to develop at times -No clear direct cause-and-effect relationships -Requires validation of conclusions, raw data and development of equations -Loses predictive credibility outside relevant data range

2.4.3 Analogous methods

According to Curran, Raghunathan and Price (2004) analogous costing uses the cost of a similar product to generate a baseline estimate. Hueber, Horejsi and Schledjewski (2016) further noted that the method relied on the assumption that similar products had similar costs. See figure 2.13.

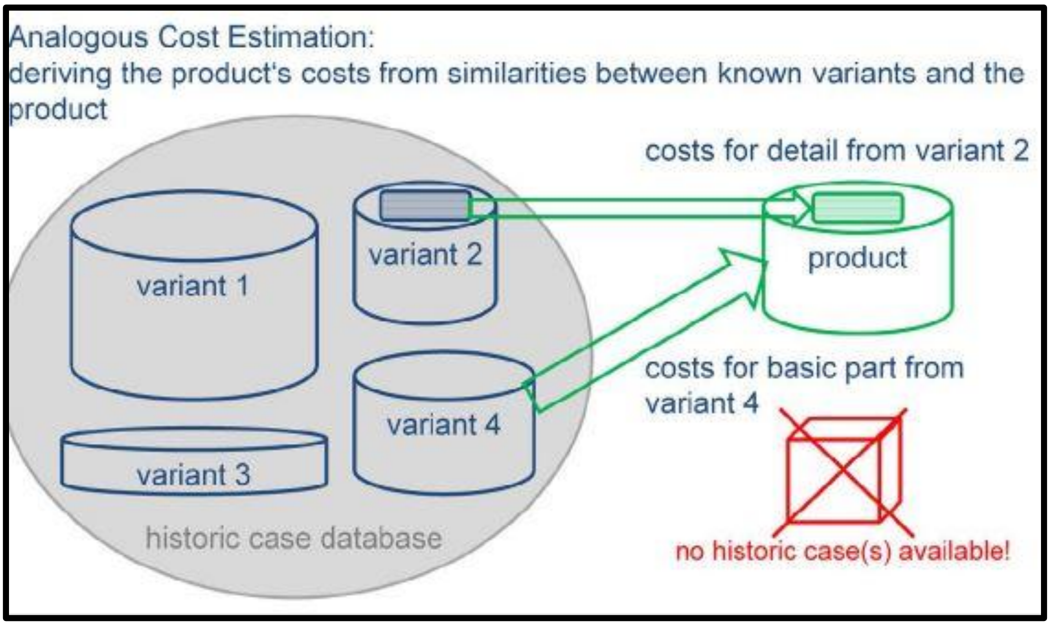


Figure 2.13: Analogous cost estimation (Hueber, Horejsi & Schledjewski (2016))

Niazi, Dai, Balabani and Seneviratne (2006) went on to classify analogous methods into two types. Ones that relied on regression analysis models that establish linear relationships between product costs and product characteristics. Back-Propagation Neural-Network models that were better suited to non-linear relationships. This was similar to the parametric methods outlined in section 2.4.3 and figure 2.10. The difference being an analogy was being made to estimate the new product's cost, using similar variants whose detailed costs were available. Intuitively analogous costing methods could be used to generate the first rough estimates in a foundry environment, in the absence of data and pressures of time. However, Curran, Raghunathan and Price (2004) in their review of cost modelling in the aerospace industry took an excerpt from literature to demonstrate the predictive power of regression analysis models and the power of adding more data to the estimating model. The authors described the task as that of predicting costs for an airplane component whose costs was dependent on its diameter. Ultimately, they were able to show that a modified regression analysis model that incorporates both the component diameter and the complexity of the component reduced the average absolute error from 14% to 10%. Therefore, there was value in incorporating more data.

According to Hueber, Horejsi and Schledjewski (2016) some of the disadvantages associated with analogous methods is identifying the appropriate analog and the availability of detailed data. Specific to this research work, it would not be appropriate to use an analogous estimating model when detailed data was available. Furthermore, there were many characteristics that could be considered comparable between a new product and a historic product. These characteristics could be coming from different process stages and they could yield different cost estimates when used. Therefore, the task of identifying the appropriate analog could be difficult.

2.4.4 Case-Based Reasoning

Evident from the classification in figure 2.8 , case-based reasoning is a form of qualitative cost estimation. According to Zima (2015) case-based reasoning can be described as using similar cases once solved, to solve new similar cases. This is under the assumption that similar cases have similar solutions. Furthermore, case-based reasoning systems are characterized by the system ‘learning’.

Chougule and Ravi (2003) developed an approach to casting process planning using case-based reasoning. The authors used the methodology shown in figure 2.14. Ultimately, they used the four Rs method (Retrieve, Reuse, Revise and Retain) also described by Zima (2015). In their undertakings, Chougule and Ravi (2003) noted that the retrieval of the most appropriate case was one of the difficulties associated with case-based reasoning. This suggested that expert involvement was key.

However, the applicability of a case-based reasoning in this research context was limited. Primarily, the method was applied for process planning and evaluation of alternative steps for processing. This research work intended on using a fixed foundry process route and modelling the cost at the most basic level of the TE KDS foundry process route.

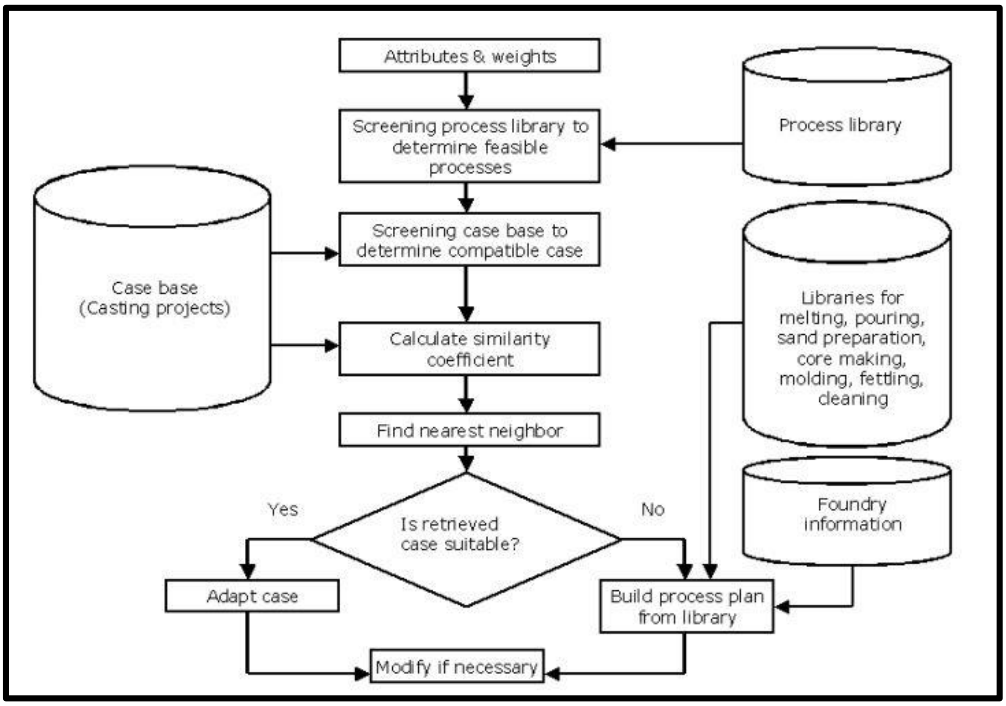


Figure 2.14: Case based reasoning approach in a foundry (Chougule & Ravi (2003))

2.5 Cost model development in manufacturing

2.5.1 Introduction

At the heart of this research effort was the development of a simulation model. All the theoretical frameworks underpinning the environment to be simulated had been discussed. A review of model building (simulation) literature as it relates to manufacturing was now necessary.

2.5.2 Simulation models

According Banks, Carson, Nelson and Nicol (2005) a simulation was "the imitation of the operation of a real-world process or system over time". This research work intended to build a model that simulated TE's KDS foundry costing methodology. The authors went on to describe a simulation development model for discrete systems that was relevant to this research work. See figure 2.15. The 'Experimental design' design stage was described as being concerned with deciding how many alternatives are going to be simulated. 'Production runs and Analyses' was concerned with measuring how well the model performs in relation to the simulated alternatives.

Apparent from the model presented by Banks et al. for discrete models, was the iterative nature of model development. This was an important consideration because it required a research method that was centered around patience and attention to detail. Otherwise, there was going to be a lot of unnecessary back and fro. Documenting and reporting was also another aspect of simulation model development that was often underestimated or not given the required attention. Often, the limitations and drawbacks of the simulation model are overlooked or overshadowed by the task of completing the model. Additionally, implementation is often viewed as the most important task, particularly in a business environment. Therefore, documentation of model characteristics and proper reporting of model capabilities was considered important in order to avoid a disastrous/stressful implementation phase.

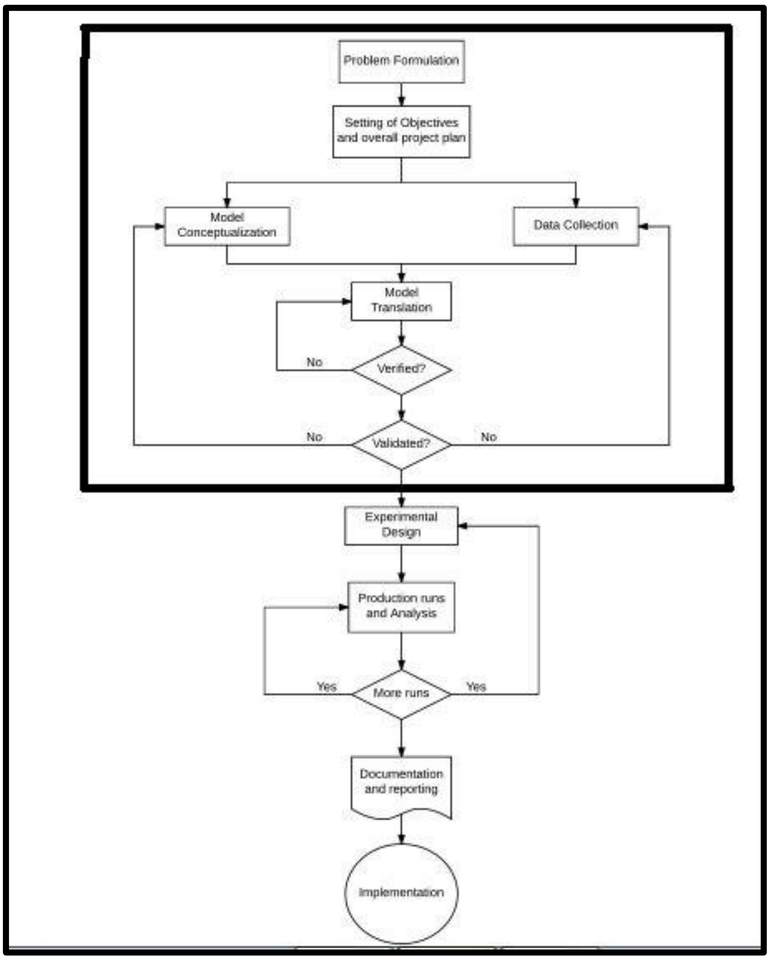


Figure 2.15: Simulation development model for discrete systems (Banks et al. (2005))

Law (2009) suggested the seven steps outlined in figure 2.16 in order to build a successful and valid simulation model. As can be seen, the models presented in figure 2.15 and figure 2.16 share more similarities than differences. It is also evident, as discussed in Section 2.4.2, that model validation is an important part of model development.

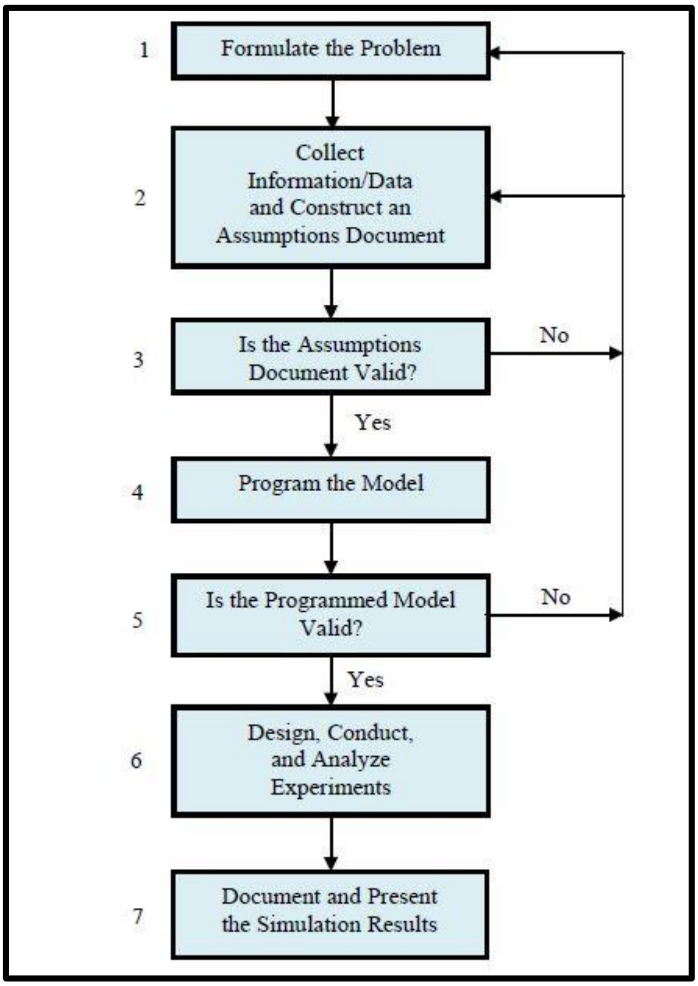


Figure 2.16: Steps to build a successful and valid model (Law (2009))

The limitations of simulation models can be anticipated from the individual process steps involved. For example, if the problem is not formulated properly, the simulation results can easily be misinterpreted. Of special interest however, were the limitations related to the data collection process. Fundamentally, if the incorrect data is used, the entire model is questionable. Secondly, limitations associated with the data used would be difficult to spot and timeous to correct. This is particularly of great concern in relation to this research work due to the financial and economic implications of the model involved. Therefore, it was important that these limitations are outlined, understood and actively minimized at each step of the research method. Additionally, the interpretation of the cost estimate upon completion and applicability of the model in general, needed to be done through the lens of these limitations.

2.5.3 Cost simulation models

The traditional model of cost model development as presented by Busch (1994) was considered, figure 2.17. It was evident that in modelling costs, the same important themes from general simulation modelling still hold: formulation of the problem, collection of the data and testing validity. Notably, in relation to cost model development, as can be seen on figure 2.17, the importance of data collection and treatment was amplified.

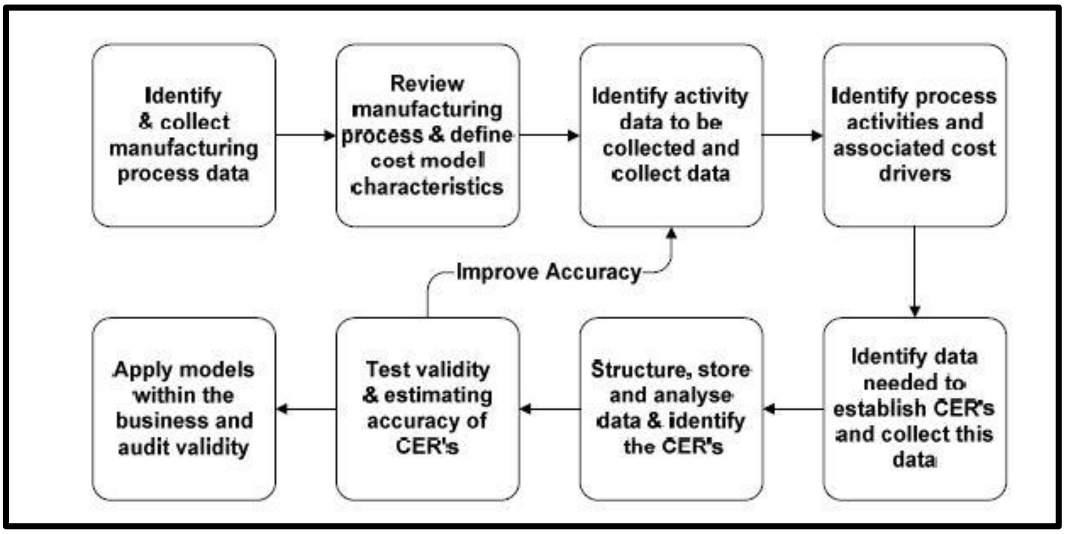


Figure 2.17: The traditional model of cost model development (Busch (1994))

Delgado-Arvelo (2012) conducted an investigation into the data collection process for the development of cost models. The author identified concerns related to each step of the cost model development process. Related to the data, the author identified potential issues with availability, sources and handling thereof. On data availability, missing data and inaccurate data were a major concern. That is why this research work, in its research design, would have to have safeguards against this potential problem (such as have independent experts review model input-output relationships). In reference to data sources, accessibility and the overlooking of data were identified as a potential concern. Therefore, safeguards such as ensuring company consent is received would potentially alleviate accessibility issues. Nonetheless, with these safeguards in place, this research work was not immune to these potential errors.

2.6 Summary

The aim of this section was to survey and understand work that had already been done in relation to developing cost estimating models in foundries and similar environments. This was done to relate (compare and contrast) that previous work to the current work. General status and management practises of the foundry industry, locally and internationally were analysed and commented on first. It was found that the foundry industry's fortunes are heavily tied to the general economic climate.

Building upon that, the focus of the review moved to the costing regimes employed by foundries. It was found that standard costing and ABC are the two most prominent methods that foundries use. The intended standard costing method was found to be appropriate for the proposed study's context. The review then moved to cost estimating methods in manufacturing and the frameworks involved in the development of cost estimating models. Of the multiple cost estimating methods, it was found that the proposed study ought to use a parametric method. A comprehensive summary is shown in Table 2.9.

Table 2.9: Summary of key literal themes

Concept	Themes	Source(s)
Foundry industry and current management practises	• Performance found to be reliant on general economy, locally and globally. • South African industry found to lack strategic competitive approaches at times.	• Holtzer, Zymankowska-Kumon and Danko (2012) • Krieg and Cunningham (2014)

	• Automotive and mining industry, biggest consumers of foundry products in SA.	• Davies (2015)
Foundry costing methods	• Standard costing and ABC are predominantly used • Standard costing suitable for environments where direct labour is a huge factor and basis of assigning overheads. • Standard costing is subject of much criticism but it is still widely used • ABC is theoretically superior to standard costing but there are reported low diffusion rates	• Drury (1999) • Lyall and Graham (1993) • Al-Tahat and Abbas (2012) • Sulaiman et al. (2005) • Joshi (2001) • Gosselin (2007)
Cost estimating approaches in manufacturing	• There exist qualitative and quantitative methods • Parametric methods suitable for research work of this nature	• Layer et al. (2010) • Hueber, Horejsi and Schledjewski (2016)

Cost model development in manufacturing	• Formulation of the problem, collection of the data and testing validity are the key themes.	• Busch (1994) and Law (2009)

3. Research Method

3.1 Introduction

Section 3 of this research work describes what was done in an attempt to answer the CRQ: *Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product?*

The research philosophy that underpinned the entire research method that was used, will be addressed in this introductory section. The framework developed by Saunders, Lewis and Thornhill (2015) was used. Figure 3.1 shows a summary of their developed framework, the ‘research onion’. The authors argued that the assumptions that underpin every research method need to be made explicit upfront. The first aspect to consider is the overall philosophy. The authors defined this as the beliefs and assumptions that underpin the development of knowledge. This research work adopted a positivism philosophy. Meaning the basis of this research was scientific, observable, the researcher remained objective and sought to develop a predictive model.

Since the goal was to develop a predictive model, according to Saunders, Lewis and Thornhill (2015), deduction as an approach to theory development was consistent with a positivism philosophy. Deduction, according to the authors, was anchored on true premises necessitating true conclusions, generalizing from the general to the specific and testing established theory. This was consistent with the intentions of this research work, therefore the approach to theory development was categorized as deductive. The next layer that was considered was the methodological choice. The research questions needed a predictive model (quantitative) and expert validation (qualitative). Therefore, a simple mixed method approach was adopted. The next layer to be considered was the strategy. According to the framework, the strategy is how the research questions will be answered. This research work adopted a mixture of archival research (the data was already available but used for different purposes) and survey research for validation and verification purposes. This strategy, according to Saunders, Lewis and Thornhill (2015) is consistent with deductive approaches to theory development.

The last two layers that were considered are the time horizon of the research and the actual collection and analysis of the data needed to address the research questions. A cross sectional time horizon was found to be the most appropriate. According to Saunders, Lewis and Thornhill (2015), the key characteristic of this time frame is that it considers a single moment in time. The cost estimating model to be developed, validated and verified will be considered for a single moment in time. The collection and analysis of the data is dealt with in depth from section 3.2 onwards.

A summary of the adopted philosophy, approach, strategy, choice of method and the time horizon, is shown in table 3.1.

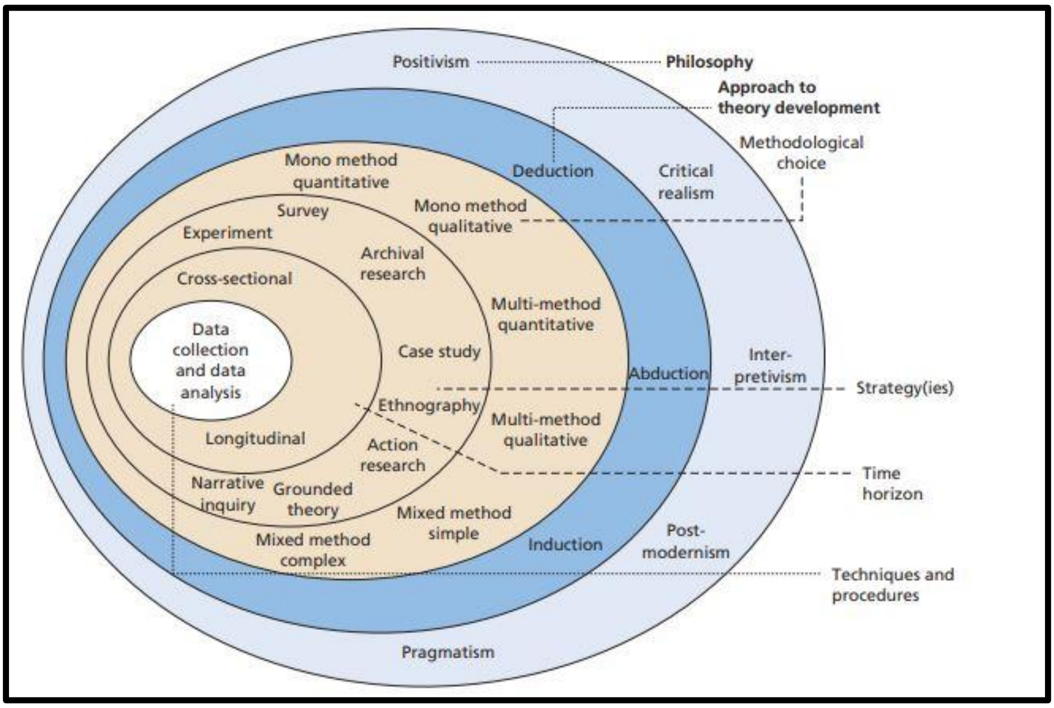


Figure 3.1: The research onion (Saunders, Lewis & Thornhill (2015))

Table 3.1: Adopted philosophy, approach, strategy, choice of method and the time horizon

Aspect/Layer	**This research work**
Philosophy	Positivism
Approach	Deduction
Choice of Method	Mixed method simple
Strategies	Archival research and survey
Time Horizon	Cross-sectional

The rest of the chapter details data collection and analysis and is schematically presented in figure 3.2. Section 3.3 intended to give an overview of the methods that were followed and give an in-depth description of what motivated the chosen research design (choice of method per table 3.1). Sampling, Instrumentation, Verification & Validation and Ethical Clearance were all important sub-elements and expansions of the chosen research design.

Section 3.3 described the sample population that was the subject of this research work. Rational and theoretical justification thereof, and a detailed description of the samples chosen, were given. The next section, section 3.4, gave a description of all the instrumentation that was used to collect, document and process the data. Section 3.5 was a culmination of the expansion of Section 3.3 and Section 3.4. Data collection, pertinent to the subject sample population, was described, followed by a description and justification of the methods/instruments of analysing the data.

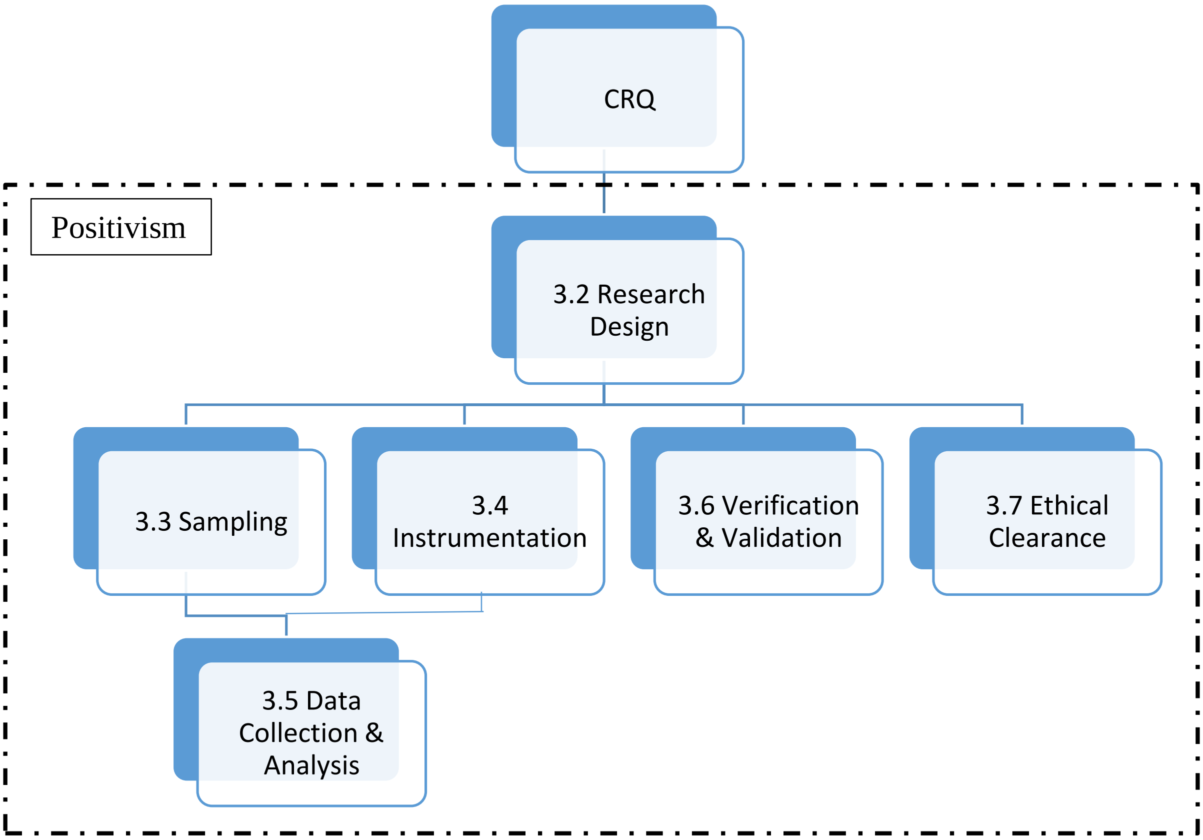


Figure 3.2: Outline of the Research Methods section

3.2 Research design

The choice of method employed by this research work was a combination of complementary quantitative and qualitative methods to address the CRQ. Specifically, a quantitative cost model was developed and validated, and expert judgement used to establish the level of reliability. Figure 3.3 below shows the overall research design. Step 1, 2, 6 and 8 were discussed in this section. The remaining steps were treated individually in subsequent sections.

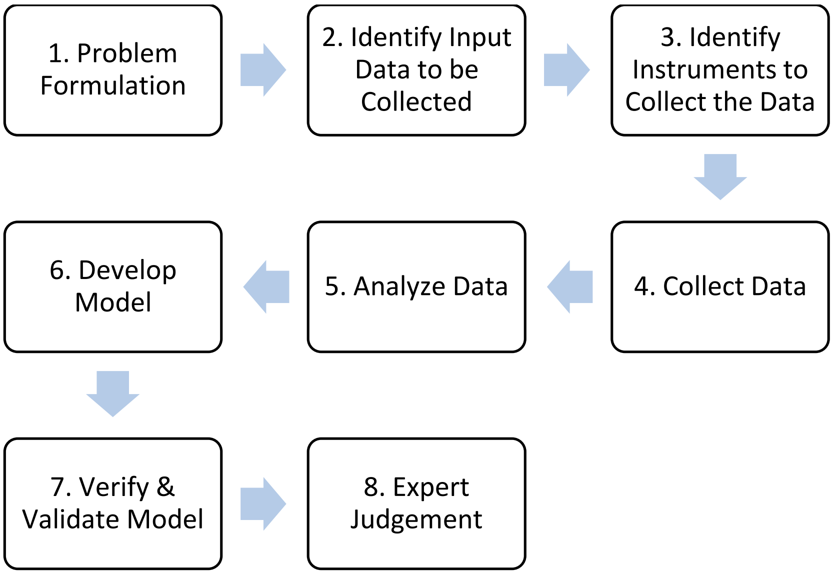


Figure 3.3: Overall research design

The Critical Research Question (CRQ) is repeated here for clarity: *Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product?*

Based on the CRQ, this research aimed to answer the following:

(a) What is the relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost?

(b) How accurate would a model, using the design mass of a cast component be in predicting the final cast product's manufacturing cost?

(c) Can the developed CER be reliably used in practise?

The objectives therefore of this research were to:

a) Establish a relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost.

b) Develop a costing model with cast component design mass and final product cost as the output for Transnet's KDS foundry.

(c) Develop a questionnaire for expert judgement on the usability of the developed model for validity and reliability purposes.

The outlined research design was adopted from cost modelling literature (see section 2.5 in the literature review section). The adopted research design incorporates elements of the models proposed by Busch (1994), Law (2009) and Banks, Carson, Nelson and Nicol (2005) for the development of simulation models. The next consideration is how to validate a model and establish reliability. Siriram (2018) and Beecham, Hall, Britton, Cottee and Rainer (2005) used expert judgements to critique and improve a developed numerical model. This research work therefore intended to do the same as reliability was one of the critical requirements of the CRQ.

Furthermore, one of the specific research questions emanating from the CRQ was '*What is the relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost*? Mileham et al. (1993) used a research design similar to the one adopted, in a similar research environment, to try and establish a CER using mass as the basis. Therefore, the chosen research design could potentially address the CRQ.

3.2.1 Problem formulation

Formally, this research work stated the problem as follows:

The derivation, testing and validation of a cost estimating model for new products at a steel foundry.

The problem statement was borne of the research motivation (section 1.3) and research background (section 1.2). It was meant to be a succinct summary of what this research effort was about. It was from the problem statement that the CRQ and the research objectives emanated.

3.2.2 Identification of input data

The CER had two distinct types of input data that were required:

- Product features – The identified and chosen product feature was the design mass of the cast components. Therefore, all the design masses of all the TE KDS Foundry components were collected. Furthermore, the mass of the moulds and mass of the casting with risers needed were collected as per research objective (a) in section 1.6.

- Material Costs – As per research objectives (a) and (b) in section 1.6, manufacturing cost were to be calculated. In order to calculate manufacturing cost, material costs needed to be known. Material cost in question was the material needed to manufacture the product. Included in this list was the cost of sand, sleeves, chemical additives (binders, resin and bentonite), mild-steel scrap, alloy additives (ferromanganese, ferrosilicate), slag coagulant, hot topping and other direct material that goes into manufacturing the product. The total material costs for each TE KDS foundry section were collected from the annual budgets (2012/13 FY and 2016/17 FY).

- Labour Cost – This was the second element needed in calculating manufacturing cost. The number and rank of people in each section of the foundry were ascertained. The labour rate for each rank was to be calculated. The total labour costs for each TE KDS foundry section were collected from the annual budgets (2012/13 FY and 2016/17 FY).

- Manufacturing Overheads – The last element of manufacturing cost. All the indirect costs that cannot be traced to an individual unit manufactured needed to be known. This included support service costs, electricity, depreciation, etc. The total manufacturing overhead costs for each TE KDS foundry section were collected from the annual budgets (2012/13 FY and 2016/17 FY).

The identified input data was consistent with what authors such as Wang, Stockton and Baguley (2000) identified as key input data in their research work related to developing cost models.

3.2.3 Develop model

At the core of this research effort was the development of a CER for TE's KDS foundry. The process is usually initiated by a potential customer looking for a quote, for a given cast component. Design mass was then made the input for the model. Manufacturing cost was the output. A cost report would then be generated and TE's KDS foundry business would quote the potential customer. The quote would include a profit margin in the instance of an external customer, which is beyond the scope of this research work. This is the process environment that the model simulated. This process environment was shown in figure 3.

The development of the model began with the establishment of the statistical relationship between the design mass, mass with risers, mould mass and the manufacturing cost. Mould mass and mass with risers were the variables that were used to establish regression equation 1 and regression equation 2. Normality of the sample data using the Shapiro-Wilk test was done for all four of the variables. Additionally, Q-Q plots for the main variables of interest (design mass and manufacturing cost) were generated. Upon establishing normality for the main variables of interest, the Pearson correlation coefficient was calculated. Finally, the parametric relationship between the design mass and the mould mass was calculated (regression equation 1 in figure 3.3). The parametric equation (regression equation 2 in figure 3.3) between the design mass and the mass with risers was computed.

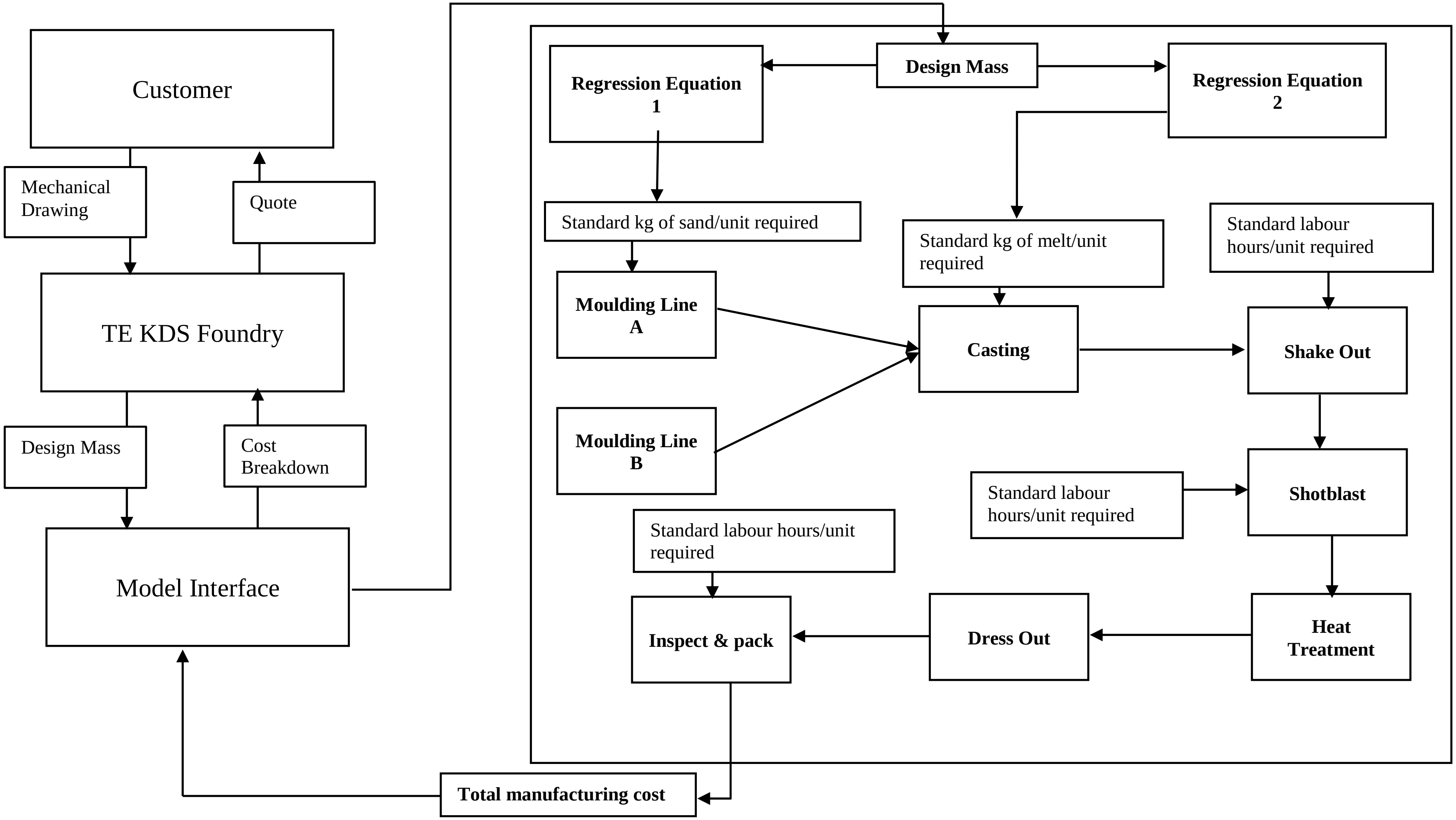


Figure 3.4: Cost model development process

The user interface of choice was Microsoft Excel. One of the core themes of this research effort was developing a model that can easily be used. That is what therefore informed the use of a more commonly understood software interface. As interactive and as simple Microsoft Excel is, it was still a capable and suitable tool nonetheless.

All the mathematical relationships between the identified input data in section 3.2.2 were mapped out according to standard costing principles. For each section (moulding, melting, shakeout, shotblasting, cut and fettle, dressing and final inspection) in the foundry, a breakdown of the standard cost was mathematically done. For each section, the intention was to calculate the tariff associated with having a product pass through that section. The sections were ordered in the manufacturing sequence for all the cast products. The sum of these sectional model outputs was the total manufacturing cost. The use of models for each different section was done in line with verification principles (see section 3.6) that advocated for the interrogation of the conceptual background of the model. In this form, the model could be easily troubleshot and verified. The full mathematical logic for the melting and casting sections was shown in Appendix A.

Regression equation 1, as per figure 3.3, was to estimate the standard amount of sand required for a given cast component. This figure is the same as the mould mass of the component, upon completion of technical compliance. Standard costing in the moulding section required this value. Regression equation 2, was to estimate the standard amount of molten melt required to cast a given component. This figure was important in order to calculate the standard cost of having a component pass through the casting section. The finishing sections standard inputs (labour hours required) were assumed to be the same as the ones TE’s KDS foundry already used.

The sensitivity of the manufacturing cost to the labour, material and overhead cost was also done, to demonstrate the practicality of the developed model. The percentage contribution according to the model, of each cost element was first calculated. The sensitivity was calculated by increasing each element by 10% whilst keeping the other two fixed. The effect on manufacturing cost was then plotted. This was consistent with research objective (c) that was concerned with the usability of the model. Cost optimisation exercises were also an important consideration made for TE's KDS foundry. Further demonstrations of practical usability were documented in the questionnaire pack (Appendix C) that was sent out to the experts.

3.2.4 Expert judgement of the developed model

Upon assessing the importance of verification and validation of the developed model, in section 3.6, the chosen validation techniques were discussed in this section. It is worth noting again that at the core of the CRQ, is whether a CER based on the design mass of the component can be reliably used. Additionally, all the reviewed literature (see Section 2.5.3) on model development highlighted the need for model validation.

As discussed in section 3.6, the use of people outside the model development team provides external validity to the model. Furthermore, external assessment affords the developed model a better chance at reliability than the potentially subjective assessment of only those who developed the model. This was consistent with research objective (c), which had asked, *Can the developed CER be reliably used in practise?* Delgado-Arvelo (2012) made a similar point in that confidence in a cost estimating model could be established using expert judgement satisfaction, amongst other things.

Similarly, Beecham et al. (2005) used an expert panel to validate a requirements process improvement model. The authors stated that one of the primary reasons why they undertook the validation exercise, was to illicit independent feedback. This was the same reason that this research study undertook to validate the developed model. Furthermore, De Jongh, Larney, Mare, Van Vuuren and Verster (2017) presented work for best validation practises for banks. One of the proposed steps in validating models in the financial sector, was independent review. In the financial sector, the need for independent review could possibly have stemmed from the financial and reputational risks associated with using statistical models. The same risks were also present in the context of this research work. Foundries are competitive businesses and there were financial risks associated with use of the developed model.

A list of potential foundry experts at TE was drawn and they were approached for possible participation in the validation exercise. A questionnaire was developed (see section 3.4 for the rationale) to illicit expert opinion. An information pack about the model and the purpose of the study was prepared. How the model was developed, all the underlying theories and assumptions, how the model worked, the user interface and the predictive accuracy were briefly described in the information pack. Additionally, the purpose, duration of the study and the role the participant was going to play was sent out. Each of the experts were given the information pack and the questionnaire to complete.

3.3 Sampling

This section detailed how the sample population of products to be studied was selected. Additionally, key characteristics of the sample population were discussed. The rationale behind the number and type of experts selected for evaluating the model was also discussed. Lastly, the rationale for the chosen evaluation criteria of the model was given.

The population that was considered was Transnet Engineering KDS foundry's range of cast products that the foundry business manufactured for TE's customer facing businesses. The cast components under consideration had a mass in the range of 12kg-850kg. The components had varied use, some were used for their wear properties, whilst others were used for their material toughness. The components were used in new-build programmes and some were used for maintenance purposes. All the components were transported to be used at various TE locations (Durban, Uitenhage, Bloemfontein, Salt River and Koedoespoort) across South Africa and the African continent. A total of 25 components were sampled from the past 25 years of manufacturing. Four of the components were left out of the modelling and used for testing the predictive accuracy of the model.

In selecting a panel of experts, four experts were approached. Three of the experts responded. Ma (2011) in validating a cost model for manufacturing composites for work of similar scope, used four experts. Zamanzadeh et al. (2015) noted however, that the number of experts for such exercises had always been partly arbitrary. Therefore, three was deemed acceptable. No scientific sampling method was used. Beecham et al. (2005) also did not use any scientific sampling method in selecting experts to review their model. Consequently, a list of accessible potential participants was drawn and the potential participants were petitioned by email to participate. The background of each expert that responded is shown in table 3.2. The criteria for expert was 7 and more years of experience in the foundry and manufacturing field of any age or sex.

Table 3.2: Expert information

Expert	**Field of Expertise**	**Experience**	**Highest Qualification**
1	-Modelling, foundry management & metallurgy	10 years	PhD
2	-Foundry management & operations	15 years	Honours
3	-Foundry operations & metallurgy	7 years	Honours

In developing the evaluation criteria for expert panel evaluation, five critical success factors of a good predicting model were considered. The success factors were identified from literature. In their study of using an expert panel to validate a model, Beecham et al. (2005) used 7 criterion (verifiability, tailorability, ease of use, understandable, consistency, limited scope and adherence to model characteristics). Andrews (2017) noted that accuracy, repeatability and flexibility are some of the key characteristics that a cost estimating model ought to have.

Therefore, the evaluation criteria in the questionnaire for this research work was centered around the following themes:

- Consistency
- Ease of use
- Accuracy
- Flexibility
- Scope

3.4 Instrumentation

The type, choice and rational of instruments used in this research work was discussed in this section. First, all the tools used in developing the model were discussed. Lastly, the questionnaire used to elicit expert opinion in the qualitative section of the research report, was discussed.

The quantitative portion of the research study undertaken was in the form of a simulation, the data was of archival nature and correlations between certain variables were established. Ventresca and Mohr (2002) described archival research methods as those that are involved with the study of historical documents by and about an organization. Therefore, there was no manipulation of variables in the experimental sense. Data of interest was retrieved by going through Transnet KDS foundry's financial and operational records. Calibrated scales were also used to weigh and verify component mould masses and mass with risers. Microsoft Excel was used to store the collated data and to build the simulation model. Statistical treatment of the data and correlations were conducted on SPSS version 2.3 (2019).

Rowley (2014) defined questionnaires as documents with open and closed questions that invite a respondent to provide answers. The author noted that one of the requirements for using a questionnaire was the availability of respondents who could provide meaningful data. This is true in this research work's context because the research questions demanded a level of external validation and the literature reviewed (section 2.5) suggested the same. Rowley (2014) further noted the relevance of questionnaires to predictive and analytical research. Therefore as instruments, questionnaires were found fit for purpose. According to Eckerdal & Hagstrom (2017) it was good practise to look at a previous questionnaire of similar purpose, when developing a new one. This is particularly intuitive if the previous questionnaire has been verified and validated. Bolarinwa (2015) noted how important it was for a researcher to ascertain that the measurement tool was actually measuring what it intended to measure. Therefore, this research work sought to base its questionnaire on a validated questionnaire that had already been developed.

Beecham et al. (2005) developed a questionnaire to elicit expert opinion for a process improvement model. The first principle employed was identifying the success criteria for the model. Questions in the questionnaire were then framed around the identified success criteria. This research work first identified five (scope, accuracy, consistent, flexibility and ease of use) critical success criteria for a cost development model (see section 3.3). Scope was defined as what the model includes and excludes. Consistency was framed to address the correctness of the conceptual description. Flexibility was tailored to probe the usability and practicality of the model to aid decision making. Ease of use dealt with how appropriate the model interface will be and what this meant for end users.

Consequently, a questionnaire based on accuracy, scope, ease of use, flexibility and consistency of the model was developed. To ascertain the expert's opinion on the model accuracy, the level of accuracy and the usefulness of the attained level of accuracy, were the core themes. In terms of the scope, the questionnaire was formulated to ascertain whether the model does what it was intended for. Secondly, the appropriateness of the level of detail offered by the model. Lastly, the appropriateness of the use of design mass as a key variable. The consistency portion of the questionnaire was designed to establish, from an expert's perspective, the reasonability of the model outputs, compared to the model inputs. Additionally, the consistency portion was framed to ascertain the correctness of the mathematical logic of the developed model. Flexibility was framed to establish whether the experts thought that the model could be used in any foundry environment, whether it could allow the user a sufficient view to make informed decisions about material usage and labour related decisions. All this, as the decisions relate to manufacturing cost. The ease of use facet was formulated to ascertain from the experts, whether they thought the model would be user-friendly and easy to understand for a non-technical user.

3.5 Data collection and analysis

This section described the type of data, where it was collected, where and how it was analysed. Lastly, it highlighted some important considerations about the data collection process in the development of CERs.

The design mass of the sample cast components was collected from TE’s product development department, the manufacturing costs and mould sizes were collected from the logistics department of TE’s KDS foundry. Missing information, such as cast component mould mass or mass with risers for any of the component currently in production, was collected. This was done by weighing the components on a calibrated scale at TE’s KDS foundry. The information was collated and sorted on Microsoft Excel, then transferred to IBM’s SPSS package for analysis. Linear regression, one-way ANOVA and MAPE were conducted on Microsoft Excel. Normality and correlations were computed on SPSS version 2.3 (2019).

On Microsoft Excel, for each of the 21 components, the design mass, mass with risers, mould mass and the component manufacturing cost were recorded. The data was then transferred to IBM’s SPSS for calculating the normality and correlation. The variables ‘manufacturing cost’, ‘design mass’, ‘mass with risers’ and ‘mould mass’ were firstly stored as numeric and scale values. Descriptive statistics, tests of normality and Q-Q plot of the data were then generated. Similarly, the 2-tailed Pearson correlation between the ‘manufacturing cost’ and the ‘design mass’ were computed using the bivariate correlations option on SPSS. In order to compute the one-way ANOVA on Excel, the actual manufacturing cost of the sample components and the predicted manufacturing cost of the sample components were used. The ‘Analysis Toolpak’ add-in was loaded and ‘Anova: Single Factor’ was selected.

Inputs for the numerical model, related to standard costing (labour, material and overhead costs), were collected from TE’s Koedoespoort foundry’s finance and logistics department. The production and cost budget for the 2012/13 and 2016/17 FY were used to source data related to cost structure and activity. Once the data had been consolidated, it was digitally stored. This was to help mitigate any errors relating to poor handling of data. Data limitations and cell instructions were fitted onto the model interface. The rest of the tabs were locked and set to display only. The only cell that could accept values was the ‘design mass’ cell. This was to safeguard against any confusion related to the model output and general interface.

The expert judgement sessions occurred individually with the three experts. This was to ensure that each experts gets a chance to liberally ask about the model, without any reservations. Each expert was presented with the research results (model accuracy and how this compares to the current model) and the assumptions underlying development of the model. The presentation sessions, on average, lasted for 30 minutes. Feedback from the questionnaire was then grouped per critical success criteria, and each expert’s opinion was documented. Questionnaire data from the expert feedback was collected and stored in a locked container. After interpretation and analysis, digital copies of the raw data were made and stored in a locked hard drive for further reference.

Delgado-Arvelo (2012) in their work (figure 3.5) on the data collection process in the development of CERs highlighted the causes of ineffective input data. Pertinent to this section was data availability, data sources and data handling. The author noted that ineffective input data may be due to missing data, particularly if the cost model requires a high degree of accuracy. Inaccuracy of the data was also of concern. The data sources may also be a source of inaccurate data. Cost model development involves multiple disciplines as was shown in figure 1.2. Indirect and numerous sources of data may lead to input data being ineffective because as the data moved along, portions could be added and removed as per the needs of each user. Having too many data sources, inaccurate data and poor handling thereafter, were some of this research work's considerations.

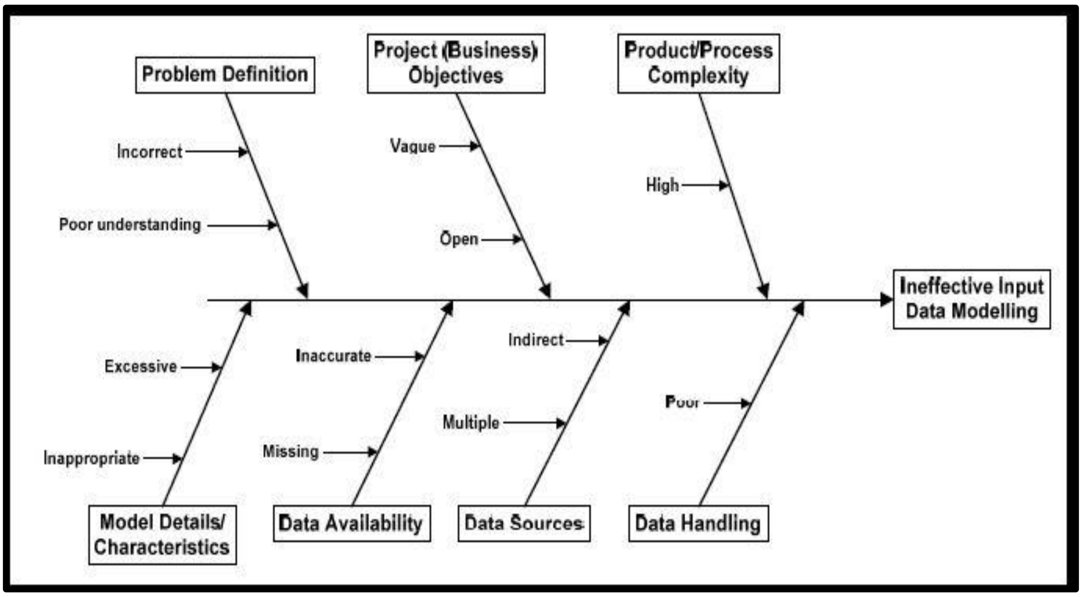


Figure 3.5: Causes of ineffective input data (Delgado-Arvelo (2012))

3.6 Verification & validation

Evident from the adopted research design, model validation and verification were an integral part of simulation model development. This section dealt with the importance of validation and verification, how it related to answering the CRQ and a brief description of the chosen techniques.

According to Thacker et al. (2004), verification is the process of determining that a model accurately implements its conceptual description. Golafshani (2003) asserted that in a quantitative context, validity was an indication of whether the means of measurement were measuring what they intended. Thacker et al. (2004) went on to suggest that verification and validation processes provided evidence to sufficiently judge if a model was appropriate for its intended use. These assertions were adopted by this research work.

Sargent (2011) presented a simplified version of this verification and validation paradigm, shown in figure 3.6. According to this model, the ‘Problem Entity’ was the system to be modelled, the ‘Conceptual Model’ was the mathematical representation of the ‘Problem Entity’. Lastly, the ‘Computerized Model’ was a translation of the ‘Conceptual Model’ into a computer language. Characteristics of the ‘Problem Entity’ are then inferred from experiments in the computer model. This model was consistent with this work’s research design. Therefore, as per the definitions presented above and figure 3.6, there were three important steps that were to be followed. One, the conceptual model was to correctly describe the problem entity (i.e does the math correctly describe the system). Two, was the math translated correctly onto the computing language. Three, were the results of the model a good description of the problem entity. Evidently, the entire paradigm was valuable and appropriate in addressing this research work’s CRQ (*Can the final product manufacturing cost be reliably predicted using the design mass of the product?*).

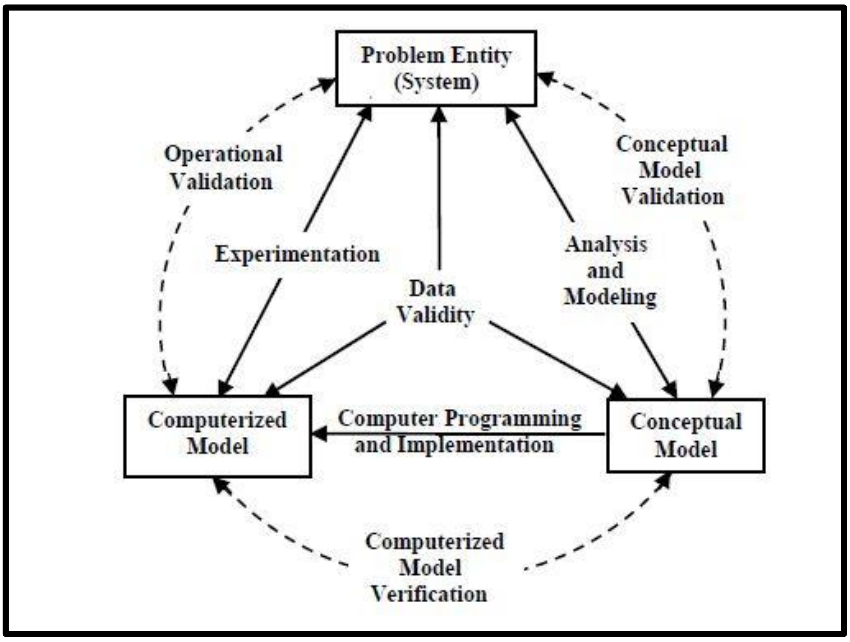


Figure 3.6: Verification and validation paradigm (Sargent (2011))

Sargent (2011) went on to describe techniques that could be used to execute validation exercises. Pertinent to this research work was face validity and historical data validity. These were described as using experts on the system to ascertain whether the model was behaving reasonably and setting some of the data aside to use for comparison with the model outputs, respectively. As described in the research design, a group of experts were approached to validate the model. Furthermore, it was also noted in the Sampling section (section 3.3) that some products were not included in the sample population, so that they may be used to test the predictive accuracy of the model.

Lastly, in line with the identified validation techniques, the developed model was compared to the current model setup that TE's KDS foundry used. Three aspects of the identified critical success criteria in section 3.3 were used. This was done as a benchmark to the expert's judgement of the model that followed after. Comparison on the basis of the other identified success criteria, accuracy and consistency were left to the external experts for comment. It was believed an internal comment on the two aspects would be of no value. Assessment of the current model that TE's KDS foundry uses, was based on experience using the system. As mentioned above, the predictive accuracy of the model was tested using four components that were left out of the model, that are of known manufacturing cost. The Mean Absolute Percentage Error (MAPE) was also computed to ascertain a standardized measure of model predictive accuracy. An analysis of variance in means of the manufacturing cost as predicted by the developed model and the actual cost for the components was done. A one-way ANOVA test using the sample components discussed in section 3.3 was done. Lastly, the behaviour of the developed model versus the current across a design mass range of 21kg-550kg was plotted.

3.7 Ethical clearance

-Transnet Engineering was approached to grant permission for the use of company-specific information. The authorisation was attached as Appendix D.

- An application for ethical clearance to conduct the research was made to the University of the Witwatersrand before the commencement of any research work.

-Ethics clearance was granted: MIAEC 001/20. Proof is attached as Appendix E.

4. Results

The following chapter contained all the resultant data and information collected, as a result of all that was done in section 3. Figure 4.1 shows the chapter outline.

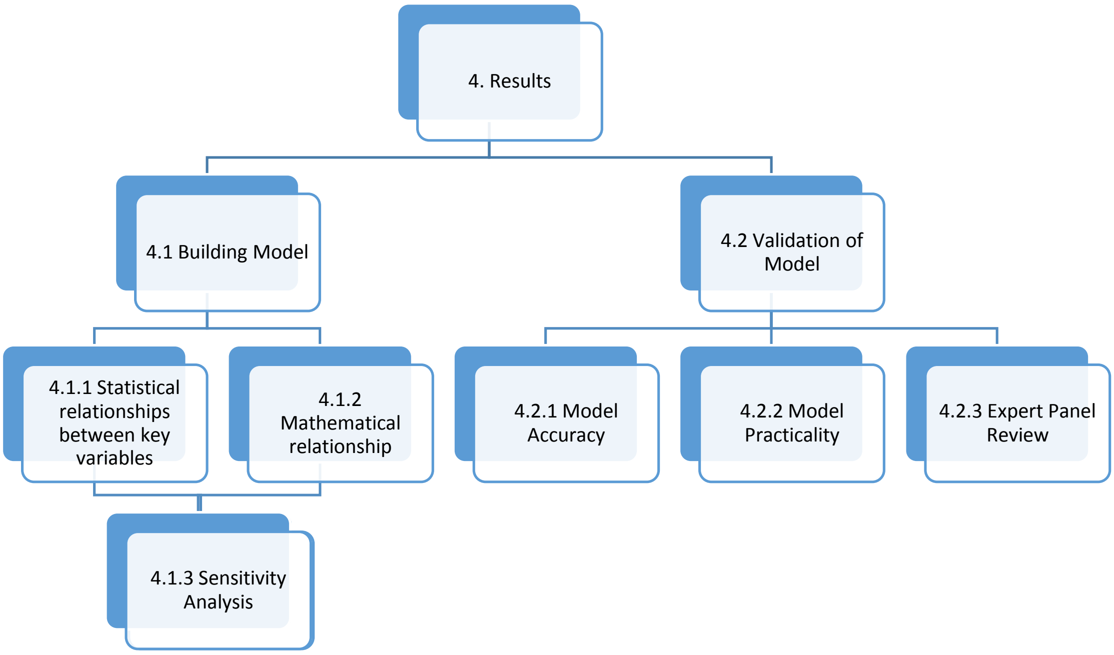


Figure 4.1: Section 4 outline

Section 4.1 detailed all the results pertinent to building of the cost estimating model. The results shown were as a consequence of what was described in section 3.2.3 in the Research Method section. This was consistent with research objective (a) and (b), which stated that a relationship between the various variables and the final manufacturing cost were to be established. Additionally, the resultant parametric relationship between the chosen design parameter (mass of the component) and the final manufacturing cost was shown. Upon establishing the parametric relation (4.1.2) and relationship between the input variables (4.1.1), the results of the sensitivity analysis (4.1.3) described in section 3.2.3 of the research design were shown.

Section 4.2 showed the internal and external validation results of the cost estimating model built in section 4.1. It was the result of what was described in section 3.6 of the method section. The model accuracy was tested using four different products that were produced at TE’s KDS foundry, whose costs were already known. The results are shown in section 4.2.1. Additionally, results for the side by side comparison of the predictive model setup and the current TE KDS foundry model were shown in section 4.2.2, as described in the research design. An expert panel was used for validation purposes as per the research design. The questionnaire responses were shown in section 4.2.3.

4.1 Building the model

Figure 4.2 schematically represents the flow logic and where the various variables fit in, for section 4.1. It was adopted from figure 3.3 in the Research Method section.

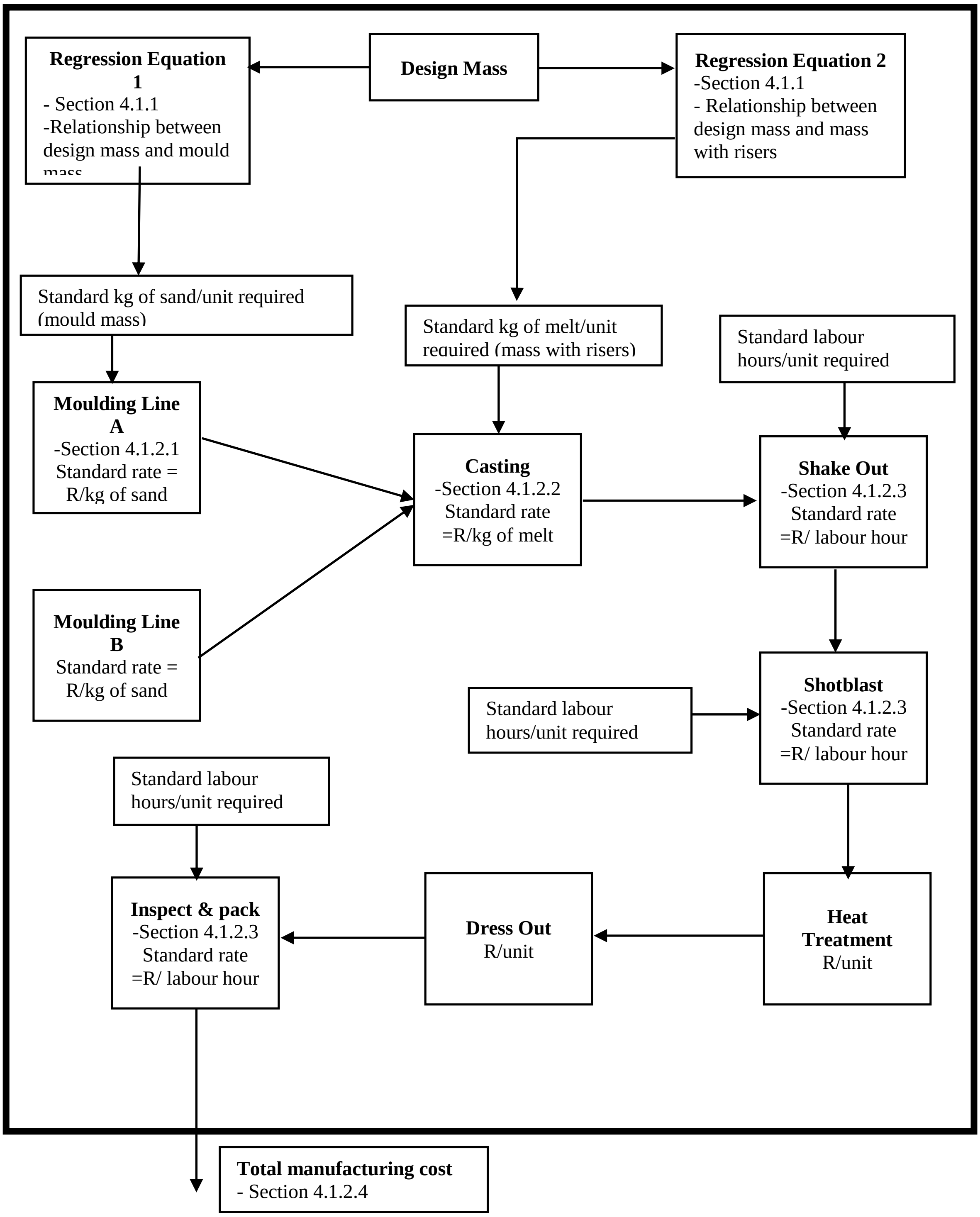


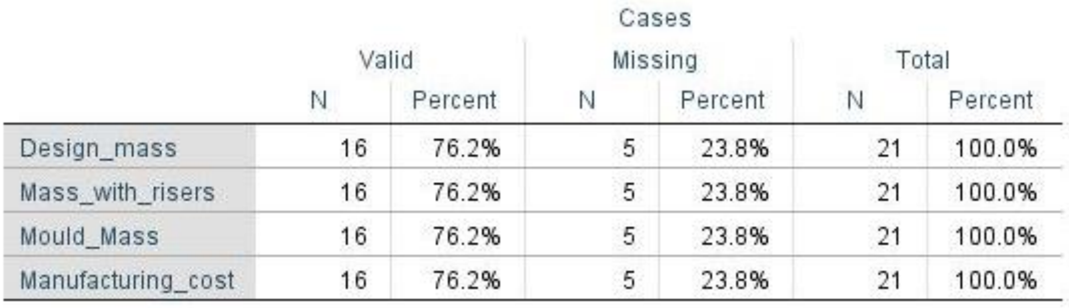
Figure 4.2: Outline of section 4.1 showing how the various variables link

4.1.1 Relationship between design parameters and final manufacturing cost

4.1.1.1 Normality

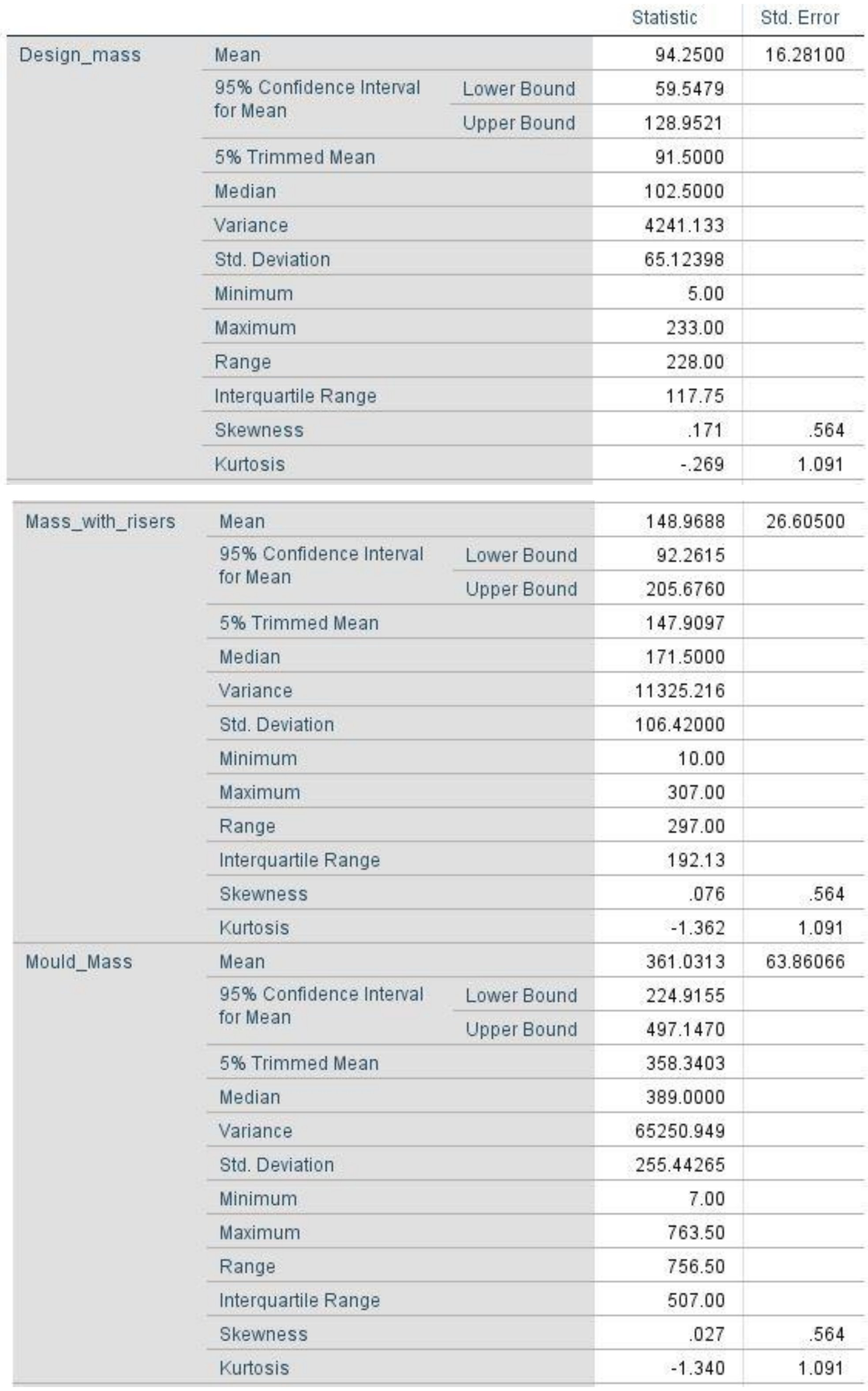
Results for the tests of normality described in section 3.2.3 were shown below. 21 different components were used for the design mass, mass with risers, mould mass and manufacturing cost. This data is shown in Appendix B. Table 4.1 shows the number of valid data points (N) used to compute normality statistics. Table 4.2 shows the descriptive statistics for mass of the moulds, mass of the components with risers and the manufacturing cost. Lastly, the summary of the Shapiro-Wilk and Kolmogorov-Smirnov tests of normality statistics are shown in table 4.3. The quantile-quantile (Q-Q) plots for design mass and manufacturing cost are shown in Figures 4.3-4.4.

Table 4.1: Summary of design mass, mass with risers, mould mass and manufacturing cost data

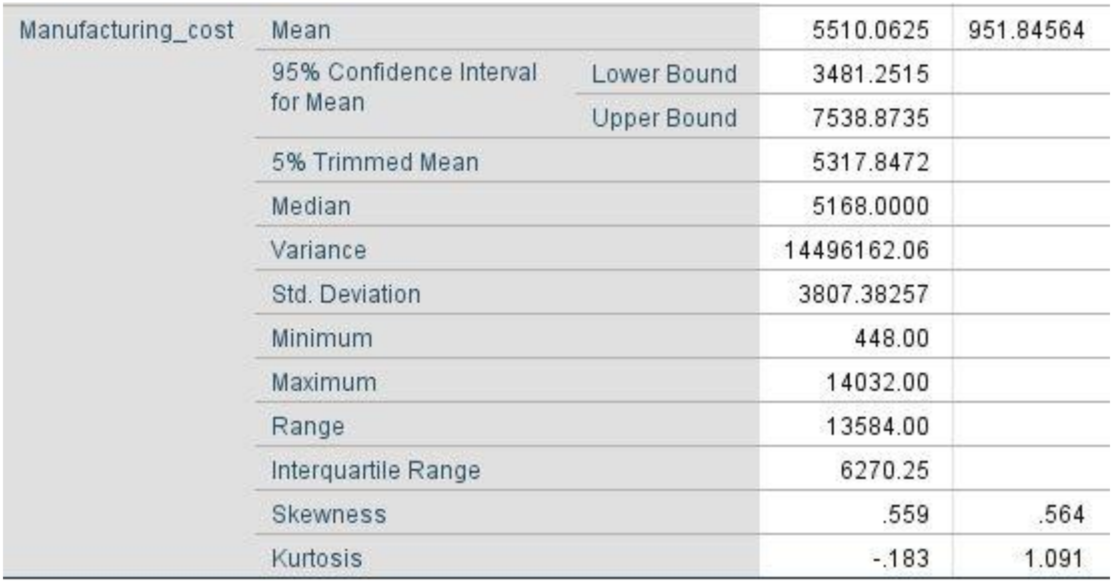


	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Design_mass	16	76.2%	5	23.8%	21	100.0%
Mass_with_risers	16	76.2%	5	23.8%	21	100.0%
Mould_Mass	16	76.2%	5	23.8%	21	100.0%
Manufacturing_cost	16	76.2%	5	23.8%	21	100.0%

Table 4.2: Descriptive statistics for design mass, mass of the moulds, mass of the components with risers and the manufacturing cost

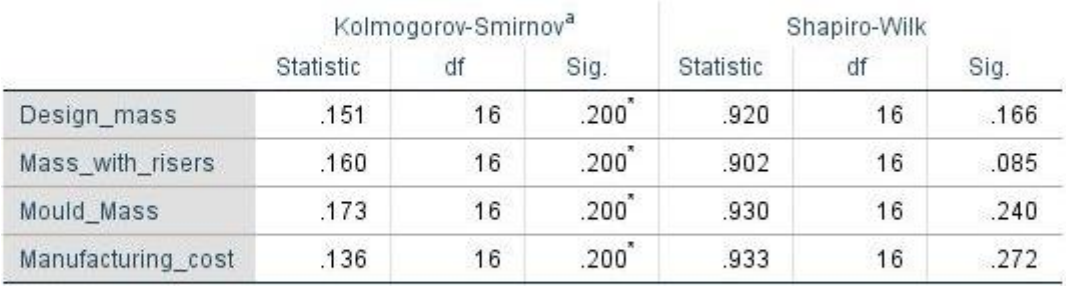


			Statistic	Std. Error
Design_mass	Mean		94.2500	16.28100
	95% Confidence Interval for Mean	Lower Bound	59.5479	
		Upper Bound	128.9521	
	5% Trimmed Mean		91.5000	
	Median		102.5000	
	Variance		4241.133	
	Std. Deviation		65.12398	
	Minimum		5.00	
	Maximum		233.00	
	Range		228.00	
	Interquartile Range		117.75	
	Skewness		.171	.564
	Kurtosis		-.269	1.091
Mass_with_risers	Mean		148.9688	26.60500
	95% Confidence Interval for Mean	Lower Bound	92.2615	
		Upper Bound	205.6760	
	5% Trimmed Mean		147.9097	
	Median		171.5000	
	Variance		11325.216	
	Std. Deviation		106.42000	
	Minimum		10.00	
	Maximum		307.00	
	Range		297.00	
	Interquartile Range		192.13	
	Skewness		.076	.564
	Kurtosis		-1.362	1.091
Mould_Mass	Mean		361.0313	63.86066
	95% Confidence Interval for Mean	Lower Bound	224.9155	
		Upper Bound	497.1470	
	5% Trimmed Mean		358.3403	
	Median		389.0000	
	Variance		65250.949	
	Std. Deviation		255.44265	
	Minimum		7.00	
	Maximum		763.50	
	Range		756.50	
	Interquartile Range		507.00	
	Skewness		.027	.564
	Kurtosis		-1.340	1.091



Manufacturing_cost	Mean		5510.0625	951.84564
	95% Confidence Interval for Mean	Lower Bound	3481.2515	
		Upper Bound	7538.8735	
	5% Trimmed Mean		5317.8472	
	Median		5168.0000	
	Variance		14496162.06	
	Std. Deviation		3807.38257	
	Minimum		448.00	
	Maximum		14032.00	
	Range		13584.00	
	Interquartile Range		6270.25	
	Skewness		.559	.564
	Kurtosis		-.183	1.091

Table 4.3: Summary of tests of normality



	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Design_mass	.151	16	.200*	.920	16	.166
Mass_with_risers	.160	16	.200*	.902	16	.085
Mould_Mass	.173	16	.200*	.930	16	.240
Manufacturing_cost	.136	16	.200*	.933	16	.272

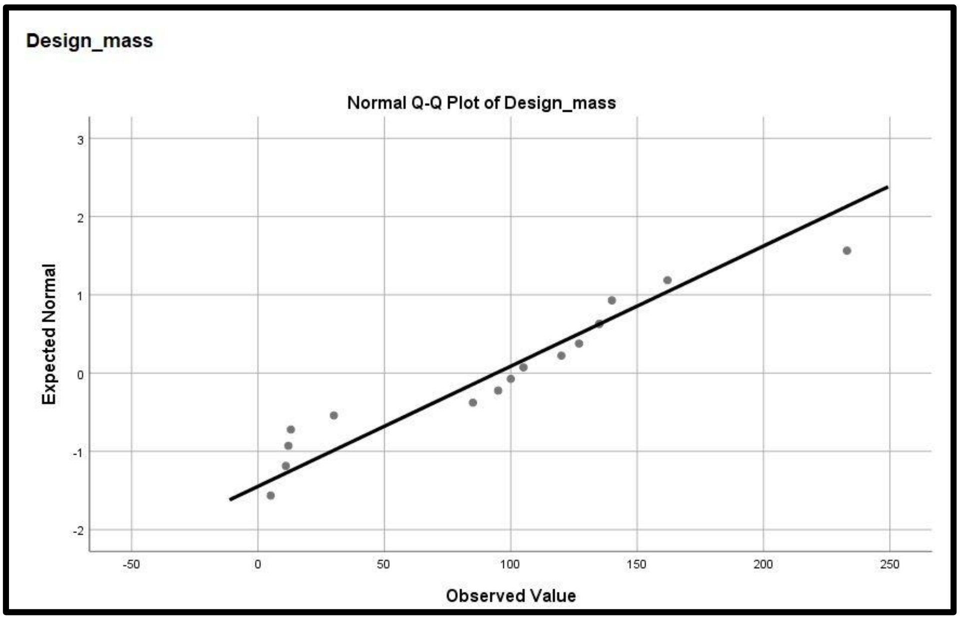


Figure 4.3: Q-Q plot of design mass

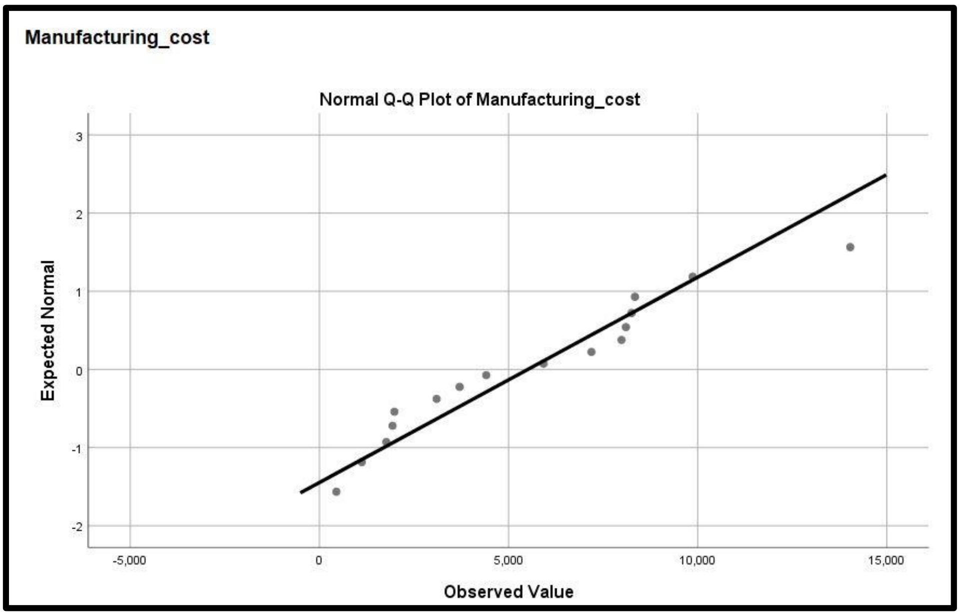


Figure 4.4: Q-Q plot of manufacturing cost

4.1.1.2 Correlation

Upon establishing normality of the data, the correlation was calculated as described in section 3.2.3. The results of the correlation between design and manufacturing cost were shown below. A scatter plot of the data was shown in figure 4.5. The Pearson correlation coefficient was shown in table 4.4.

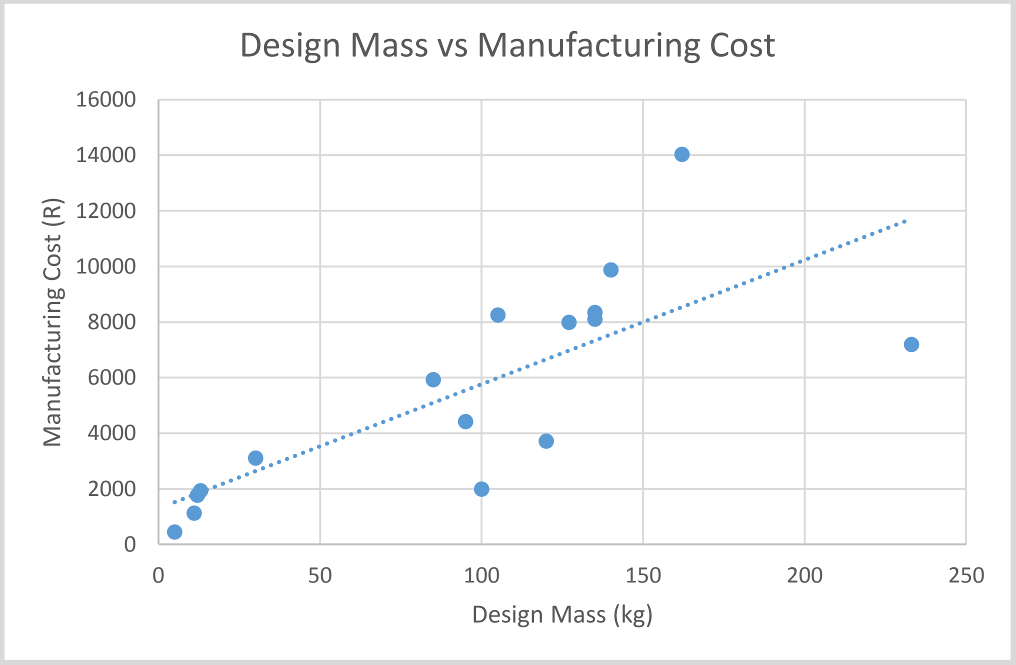
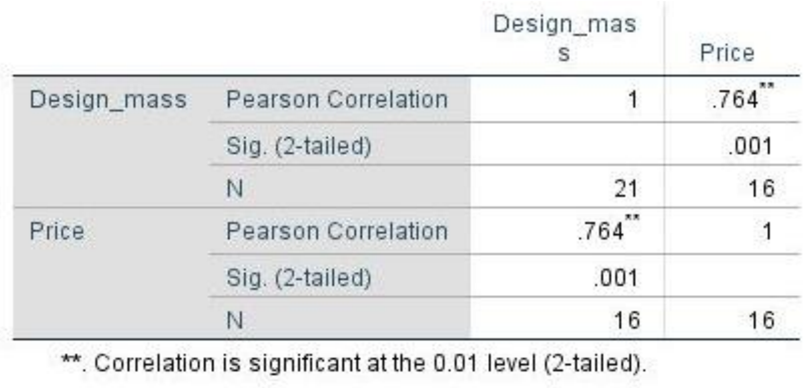


Figure 4.5: Manufacturing cost as a function of design mass

Table 4.4: Pearson correlation coeffiecient for design mass and manufacturing cost.



		Design_mass	Price
Design_mass	Pearson Correlation	1	.764**
	Sig. (2-tailed)		.001
	N	21	16
Price	Pearson Correlation	.764**	1
	Sig. (2-tailed)	.001	
	N	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

4.1.1.3 Parametric relationship between design mass and standard amount of sand required

Figure 4.6 shows the mould mass of the sample components as a function of the design mass.

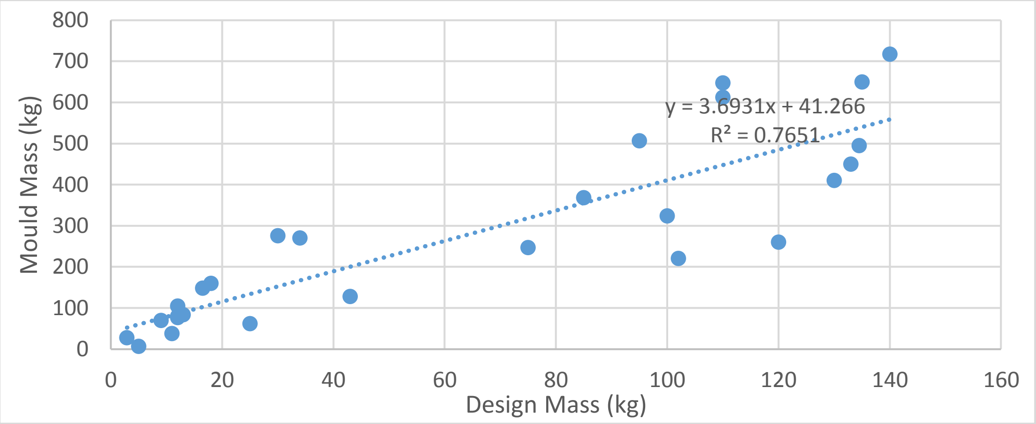


Figure 4.6: Mould mass as a function of design mass

$D_m=3.6931x_1 + 41.266$ ……………………………………………………………1

Where D_m = Standard mould mass of the component

x_1 = design mass of the component

4.1.1.4 Parametric relationship between design mass and standard amount of melt required

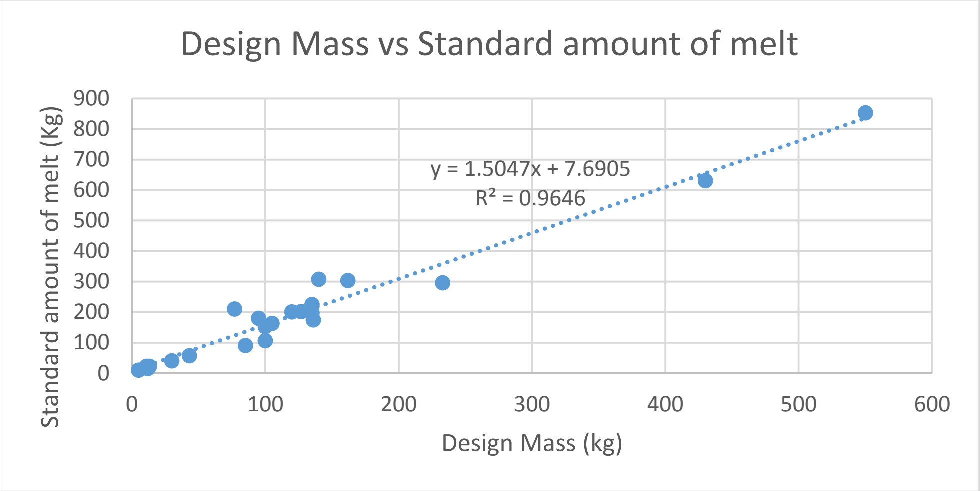


Figure 4.7: Mass with risers as a function of design mass

M_Z=1.5047x_2 + 7.6905 ………………………………………………………2

Where M_z = Standard amount of melt required (kg)

x_2 = design mass of the component (kg)

4.1.2 Conceptual Description

A summary of the parametric relationships as a function of the major cost drivers for each section was shown below. Particular attention was given to the moulding and melting section, as per section 3.2.3 of the method section.

4.1.2.1 Moulding section

P_1=6.1515y_1 …………………..……………………………………….3

Where P_1 = Cost of the product when it has passed through the moulding section

y_1 = standard amount of sand required by the product

4.1.2.2 Melting section

P_2 =6.15y_1 + 10.13y_2………………………………………..………………..4

Where P_2 = Cost of the product when it has passed through the melting section

y_2 = standard amount of melt required by the product

4.1.2.3 Finishing section

P_3 = 6.15y_1 + 10.13y_2 + 1189w_1 ………………………………………………5

Where P_2 = Cost of the product when it has passed through the melting section

w_1 = standard amount of time required to shakeout, shotblast, inspect & pack the product (hours)

4.1.2.4 Total manufacturing cost

P_{MC} = 6.15y_1 + 10.13y_2 + 1189w_1 + F + H ……………………………………...6

Where P_{MC} = Total manufacturing cost (R)

w_1 = standard amount of time required to shakeout, shotblast, inspect & pack the product (hours)

F =Cost to Cut and Fettle (R)

H = Heat Treatment cost (R)

The conceptual basis of equation 6 is shown schematically in Figure 4.8.

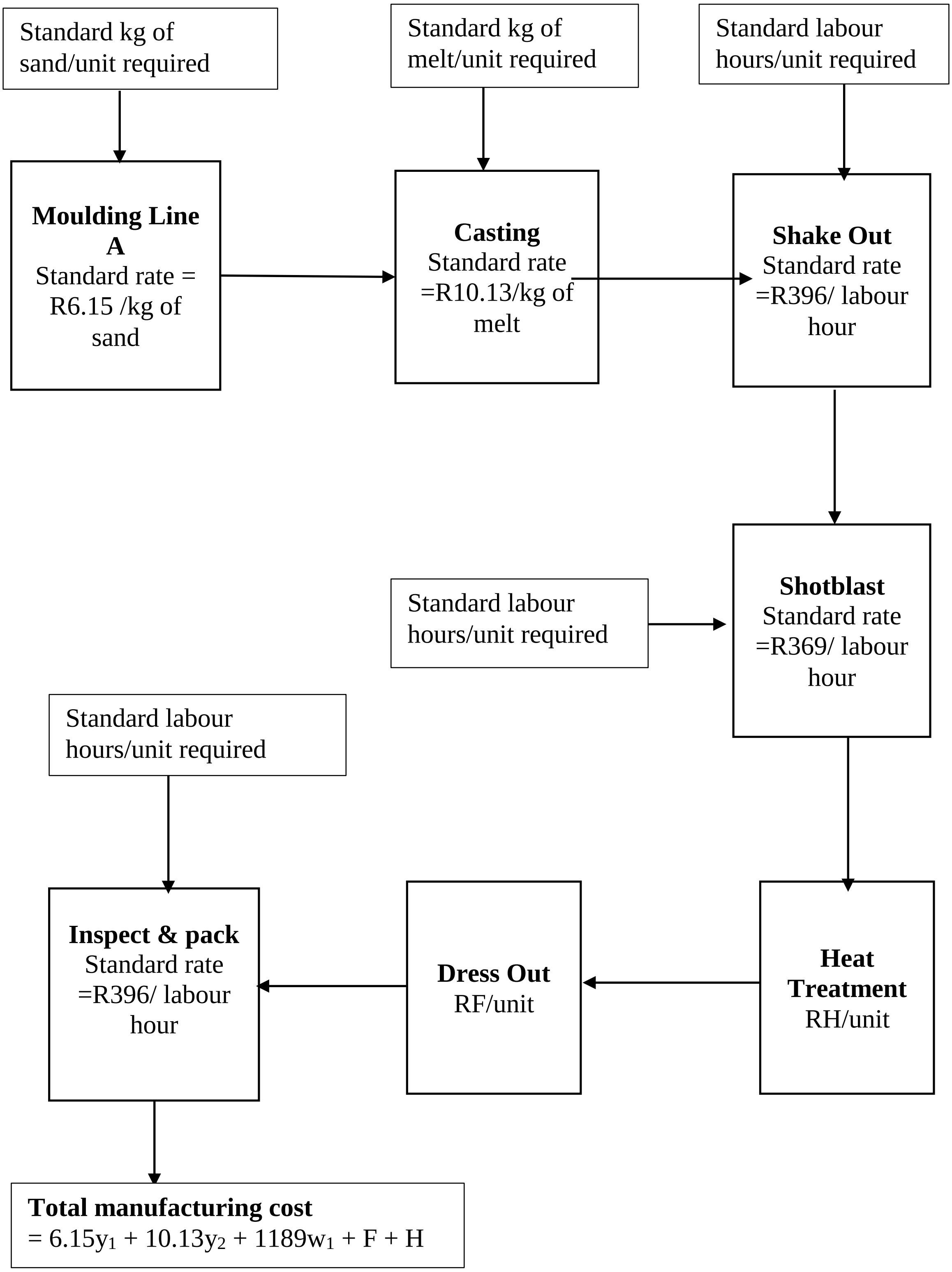


Figure 4.8: Conceptual basis of equation 6

4.1.3 Sensitivity of manufacturing cost to different cost elements

The percentage contribution of each element to the total manufacturing cost at TE's KDS foundry is shown in Figure 4.9. Figure 4.10 shows the sensitivity of the manufacturing cost to total labour costs, total material costs and total overheads. The analysis is based on the characteristics of product A, table 4.5, as predicted by the model.

Table 4.5: Characteristics of product A used for the sensitivity analysis

Product A	
Design mass (kg)	250
Standard mould mass (kg)	965
Mass with risers (kg)	384

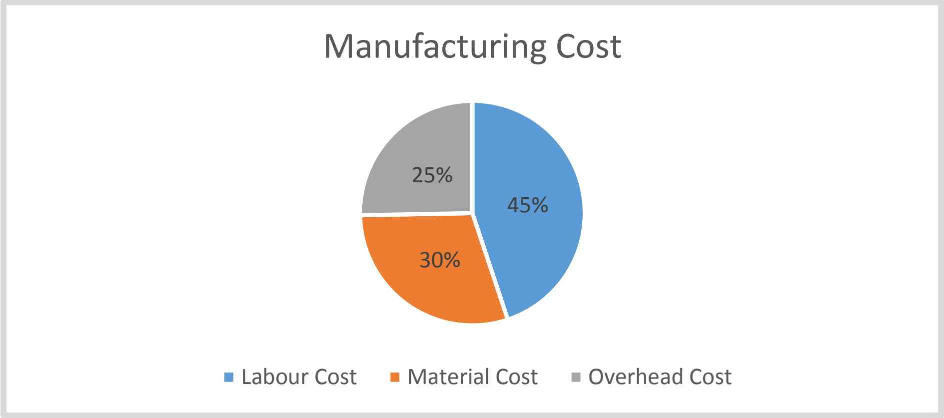


Figure 4.9: Percentage contribution of each element to the total manufacturing cost

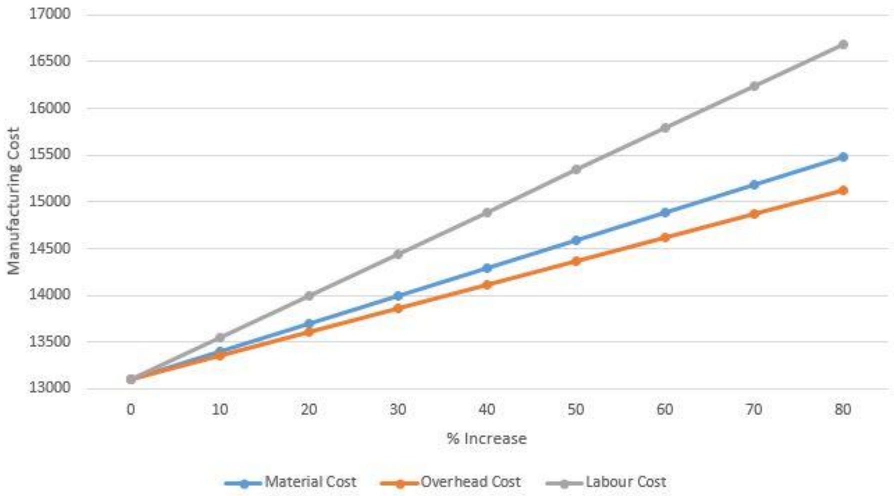


Figure 4.10: Sensitivity of the manufacturing cost

4.2 Validation of the model

The model was validated in two phases as described in section 3.6. Section 4.2.1 showed how the developed model compared to the current model that TE's KDS foundry uses, on accuracy. Results of the comparison done for four products that were left out of the modelling data, currently in production at TE's KDS foundry were shown. Furthermore, results of the one-way ANOVA test were shown. Section 4.2.2 showed the results of the comparison between the developed model and the current model, based on three critical success factors, as described in section 3.6 of the methods section. Section 4.2.3 showed the results for the validation exercise carried out with the external experts.

4.2.1 Model accuracy

Table 4.6 showed the Mean Absolute Percentage Error (MAPE), a standardized measure of model accuracy. Table 4.7 showed the one-way ANOVA for manufacturing cost as predicted by the developed model and according to TE's KDS foundry model. Figure 4.11 graphically showed how the developed cost compared to the current TE KDS foundry model over a design mass range for products similar to products A-D.

Table 4.6: Accuracy of the developed model versus the current TE KDS foundry

Product	**Characteristics**	**Model Cost**	**Actual Cost**	**% Difference**	**MAPE (%)**
A	Design mass of 550kg	R24489	R28945	15.4%	9.23
B	Design mass of 53 kg	R5621	R5972	5.88%	
C	Design mass of 48 kg	R5431	R5596	2.95%	
D	Design Mass of 21 kg	R4406	R3989	-10.45%	

$$\% \text{ Difference} = \frac{Actual\ Cost - Model\ Cost}{Actual\ cost} \text{x}100$$

$$\text{Mean Absolute Percentage Error} = \frac{\sum_{n=1}^{n}\left|\frac{Actual\ cost - Model\ cost}{Actual\ cost}\right|}{n} \text{x}100 \text{ (Lewis, 1982)}$$

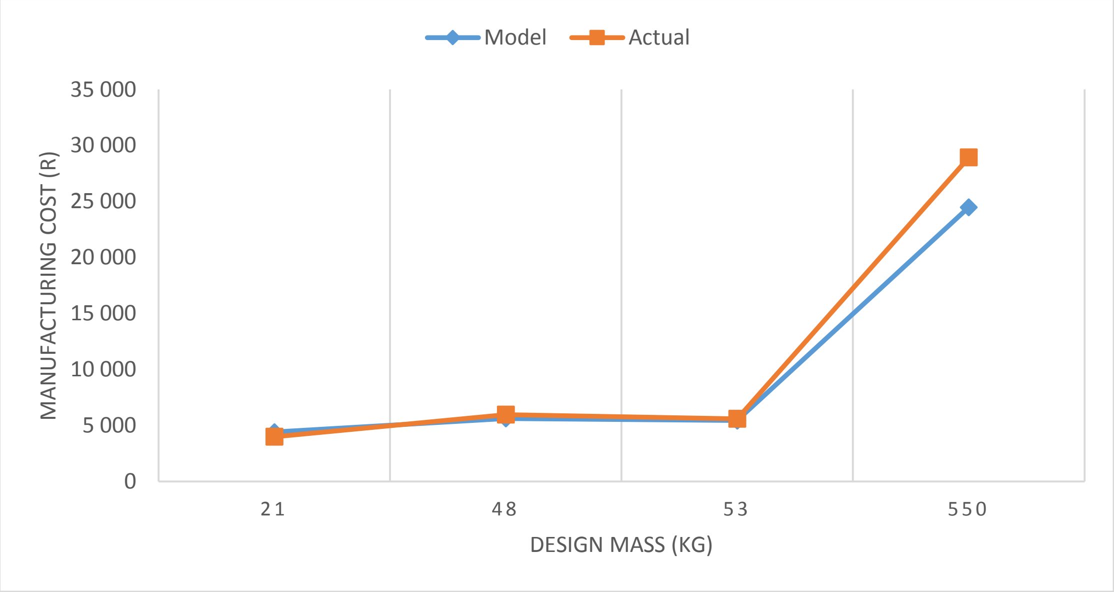


Figure 4.11: Developed model versus TE's KDS foundry model

Table 4.7: One-way ANOVA for manufacturing cost as predicted by the developed model and according to TE's KDS foundry model.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1905696.1	1	1905696.1	0.21068	0.64965	4.18296
Within Groups	262310007.3	29	9045172.667			

4.2.2 Model practicality

The results in this section are for the second aspect of the internal validation of the developed model. As already stated, three critical success factors (ease of use, flexibility and scope) of any model were used a criteria for the comparison of the developed model and the current model.

The theme of research objective (c) was assessing the usability of the model in practise. Therefore, it was deemed appropriate that the model be compared with what is already in use. Table 4.8 shows the comparison between the developed model and the current TE KDS foundry model as described in section 3.6 of the method section.

Table 4.8: Model practicality versus current TE KDS foundry model

Characteristic	**Developed Model**	**Current Model**
Ease of use	(a) Model inputs and outputs all on Microsoft Excel (b) Any user competent in Microsoft packages can use and understand model (c) Requires little to no training (d) Can generate a preliminary quote immediately	(a) Cannot generate a quote (b) Model inputs and outputs are housed in different departments (c) Model inputs only accessible to users trained on the use of SAP systems
Scope	(a) Allows a customisable view of the entire foundry from a costing perspective (b) Uses a design variable that has the biggest influence on foundry costs (b) Level of detail as a preliminary cost estimator is appropriate.	(a) Not intended to provide quotes

Flexibility	(a) Addition/removal of any aspect to the model can be easily made due to the simplified layout of the mathematical relationships. (a) Provides an immediate view of the effects of the various factors on manufacturing cost.	(a) Routing methodology employed is complex (b) May be victim of process latency (c) Prone to error because of multiple stakeholders involved.

4.2.3 Expert evaluation of the model

The questionnaire seeking expert judgement of the model was partitioned into five success criteria, scope, ease of use, flexibility, accuracy and consistency. The success criteria identified were aligned to deal with the CRQ, which stated '*Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product'*. All five critical success criteria were deemed to be the core themes of 'reliability' in the CER context. A summary of the results is shown in table 4.9.

Table 4.9: Summary of expert opinions on the model

Critical success criteria	**Expert 1**	**Expert 2**	**Expert 3**
Ease of use	• Believes the model should be easy to use for a foundry based individual • There is no installation or maintenance costs associated. A huge positive.	• Believes the model can be easily used	• Believes Microsoft Excel is appropriate as it doesn't require rigorous training compared to traditional simulation packages
Consistency	• Major parts of standard costing in a foundry context in place. Some parts however, could have benefitted from a lengthier focus. • Believes outputs are satisfactorily consistent with inputs • To improve consistency, perhaps have different regression models for the size ranges, instead of one equation across the design mass range	• Use of actual budget and figures suggests inherent value • Believes outputs are consistent with inputs except for Product A.	• Standard costing elements presented cover all the important foundry variables. • Consistency can be improved by testing model over a uniform design mass range

Flexibility	• Believes that the model can be applied in any steel foundry environment • Provides a reasonable view of material usage effects on product cost. However, the model could have benefitted from focusing on the energy usage effects also. • The model is sufficiently flexible.	• The model can be used in a different foundry. • Believes the model does not provide a detailed enough view of labour-related decisions because labour cost is lumped. • Model can be improved further	• Foundry setups are similar. Therefore model can be used in any foundry. • Does not believe the effects of material usage is detailed and apparent enough
Scope	• The model can give a satisfactory preliminary quote with the underlying assumptions • Level of details is sufficient and covers all the major foundry aspects • Design mass is the most appropriate variable	• The model can give a satisfactory preliminary quote • The information behind the model suggests it covers the necessary aspects • Addition of another variable could maybe improve accuracy.	• Believes design mass is the most appropriate variable • Study can be improved by including other alloys except steel

Accuracy	• Believes the model is a sufficient tool for competitive bidding, albeit it can be still improved. • The model is excellent for internal budgeting and management, especially for small-medium sized components.	• Satisfied that the model provides competitive accuracy • Believes the model could be adopted as is for internal budgeting and planning.	• Model can be used for competitive bidding

5. Discussion of Results

5.1 Introduction

The following chapter sought to interpret the meaning of the results presented in section 7. Interpretation was done relative to the research questions, literature review and what other researchers had found. The research questions are again shown again in figure 5.1.

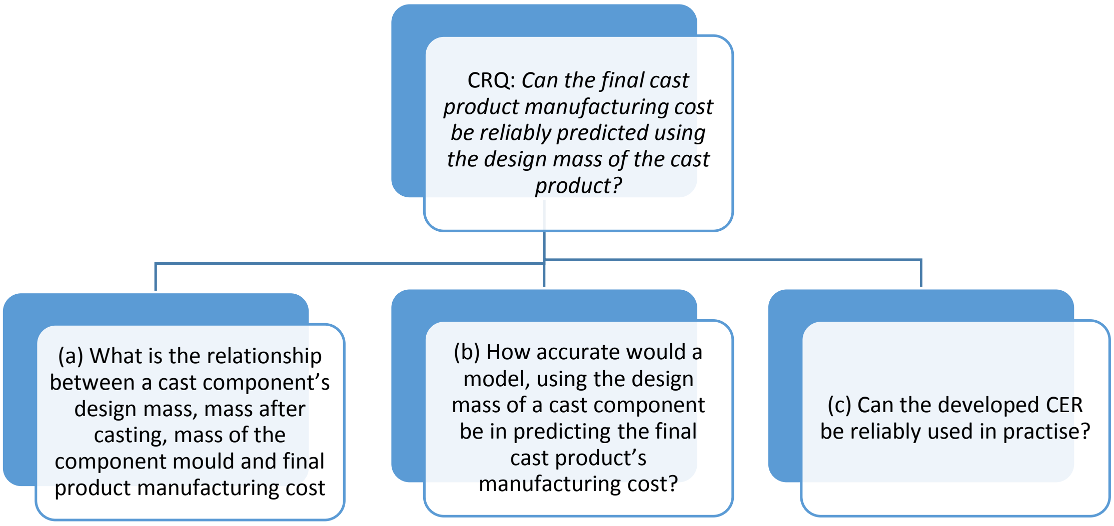


Figure 5.1: Research questions

5.2 Relationships between the variables used as input data of the model

Section 5.2 detailed how research question (a) from figure 5.1 was addressed. The results in question are found in section 4.1.1. The purpose behind the formulation of research question (a) was to gauge how the major variables related to one another. Ultimately, this was to also give an indication of what to expect when addressing research question (b).

The ultimate metric that was chosen as a measure of how the major variables relate to one another was Pearson's correlation. Mohapatra and Weisshaar (2018) asserted that Pearson's correlation is a commonly used statistical metric to measure linear correlation between two variables. In this research work, the two major variables of interest were the design mass of a cast component and the manufacturing cost of the cast component. However, Schober, Boer and Schwarte (2018) noted that two assumptions have to be met before Pearson's correlation can be used. Firstly, the data comes from a random, representative sample. Secondly, both variables are continuous and normally distributed. Consequently, tests of normality were first conducted on all the variables before the strength of association between the design mass of a cast component and the manufacturing cost of the cast component was assessed.

A sample size of 21 data points, with 5 missing cases of component design mass, component mould mass, component mass with risers and component prices was used. According to Yap and Sim (2011), the Shapiro-Wilk test of normality was the most appropriate for samples sizes less than 50. As shown in table 4.3 , the test statistic of the design mass of a cast components, the manufacturing cost of the cast components, the cast component's mass with risers and the cast component's mould mass were all found to be greater than 0.05. According to Mishra et al. (2019) if the test statistic was greater than 0.05, normality could be assumed. However, Ghasemi and Zahediasl (2012) pointed out that small sample sizes were likely to pass the Shapiro-Wilk normality test. This was due to the test's sensitivity to sample size. Visual methods to ascertain normal distribution were then considered. According to Oztuna, Elhan and Tuccar (2006), Q-Q plots were a valuable visual aid to ascertain normality. Figures 4.3-4.4 showed the Q-Q plots for the design mass and the manufacturing cost respectively. It was found that the points on the Q-Q plot lie, more or less on the straight line for both the design mass and the manufacturing cost. According to, Ghasemi and Zahediasl (2012), in order for normality to be assumed, the points had to lie on the straight line in a Q-Q plot. However, Mishra et al. (2019) made the point that one of the drawbacks of visual methods is that they require experience to interpret. It is therefore possible for one worker to claim normality and for another to interpret the same visual aid differently. Hence, both statistical and visual methods were used.

Upon establishing the normality of the variables, the correlation between the design mass of a cast component and the manufacturing cost of the cast component was calculated. First, a scatter plot of the data was generated, figure 4.5. It can be seen that there exists a somewhat linear relationship between the design mass of a cast component and the manufacturing cost of the cast component. This was an expected result because of the nature of the casting process. However, it was necessary to assess the strength of association using a standardized metric. The Pearson correlation between the design mass of a cast component and the manufacturing cost of the cast component was found to be 0.764 and significant at a 0.01 level.

According to Schober, Boer and Schwarte (2018), a Pearson correlation between 0.70-0.89 could be interpreted as a strong positive correlation. There were however, different cut-offs from different researchers. In this context, it was believed ‘significant correlation’ was appropriate. This belief was anchored in the intuitive understanding of how a foundry works. The bigger the component, the more material and time it takes to produce. Costs are a strong function of material and time taken. One of the confirmations of this belief was found in Al-Tahat and Abbas (2012), where the authors found that 61% of the total cost of a component in a steel foundry can be attributed to direct material and labour costs.

It was however worth noting that the use of correlation coefficients, such as Pearson's correlation coefficient have come under a lot of criticism. Asuero, Sayago, Gonsalez (2006) in their review of the correlation coefficient made the argument that the correlation coefficient had limited value because correlation coefficient values could not be meaningfully compared. Perhaps a potential weakness, in this research work, relating to the use of the correlation coefficient was the fact that the design mass of a cast component and the manufacturing cost of the cast component have a functional relationship. However, Asuero, Sayago, Gonsalez (2006) did point out that calculating the correlation coefficient for variables with a functional relationship, "adds an aura of respectability, but not much else". The purpose of assessing relationships amongst the various variables was not the ultimate goal. It was to build a base to tackle research questions (b).

5.3 Parametric form of the model

The following section built on the work from the previous section. Having assessed and established the kind of relationship between the various foundry variables, mathematical conceptualization of the model began. Research question (b) spoke to the accuracy of a model, built on the various foundry variables found in section 4.1.1. The first step in dealing with this research question was conceptualization of the model itself.

Figure 4.6 showed a linear relationship that was found to exist between the design mass of a cast component and the resultant mould mass of the cast component. In a foundry, the mould mass is dependent on the size of the component which then dictates the feeding system and general architecture of the pattern box. Al-Tahat (2010) described the manufacture of a pattern box as a process of translating a design drawing into a physical component, on a 1:1 scale, on a plate of wood. This was thoroughly discussed in section 2.2.2 ('what is a foundry' in the literature review). However, different materials, depending on the use, could be used. Intuitively therefore, the result that was found was consistent with foundry practise. The bigger the component, the bigger the pattern box ought to be. Why then was design mass and resultant mould mass relationship not exactly linear? The other component size characteristics, such as component dimensions play a role in the final design of a pattern box. Additionally, component features (such as the requirement of a core) also influence the component mould mass.

The linear relationship found between the design mass of the component and the resultant mass of the component with risers was shown in figure 4.7. As can be seen, the relationship is almost exactly linear. R^2 value is equal to 0.96. This result was to be expected. According to Darwish (1995), risering of cast components is meant to eliminate shrinkage defects. As commonly understood, steel shrinks when it solidifies. Risering is done by placing a metal reservoir to provide molten metal upon solidification. Therefore, the bigger the component, the bigger the metal reservoir to combat shrinkage defects ought to be. Similar to the relationship between design mass and resultant mould mass, the relationship between the design mass of the component and the mass of the component with risers was not perfectly linear. Eliminating shrinkage defects is not only done through volumetric considerations, but by considering where the riser is to be placed on the component. The latter is solely dependent on the designer.

The parametric model that describes how the total cost builds up through the various TE KDS foundry sections was expressed as equation 3. However, the model was broken up into three sections: the moulding section, the melting section and the finishing sections. Equation 1 described the cost of having a component pass through the moulding section at TE KDS foundry. Standard costing principles were applied. According to Drury (2015), a standard cost card for a component is a summation of the direct material costs, direct labour costs and the factory overhead costs. This can be expressed per section. Consequently, a standard cost tariff was developed for the moulding section, melting section and the finishing sections. The tariff for the moulding section was expressed per unit of planned moulding activity. The planned activity for the moulding section was drawn from the sales budget for the year. The sales budget used was shown in Appendix B. The standard cost tariff for all the various sections were determined from the sales budget.

Mileham et al. (1993) developed a cost estimating relationship for injection moulding, using component mass. The authors found a similar form of the parametric equation relating a cast component manufacturing cost and the cast component mass. However, the model was developed for the injection moulding process. Nonetheless, functional and material similarities can be drawn between injection moulding and metal casting. Both process make use of a mould that is a replica of the actual component. Material fills the mould to make the component. Therefore, for both processes, material consumption is heavily reliant on the initial design. That then acts as a basis and justification for comparison.

5.4 Sensitivity of manufacturing cost to different cost elements

The following sub-section acted as a bridge between research question (b) and research question (c). Accuracy of the model in describing the cost structure of a steel foundry was explored. There are multiple uses of a sensitivity analysis. Heiselberg et al. (2009) used a sensitivity analysis to identify the most impactful variable so as to bring the focus to that variable. In this section, the sensitivity of manufacturing cost to the various cost elements at TE’s KDS foundry was assessed, relative to how these cost elements were known to affect other foundries. This was done to establish a level of reliability on the model.

Firstly, figure 4.9 showed the assumed cost breakdown used in the model. This breakdown was based on the actual 2017/18 FY for TE’s KDS foundry. According to the developed model, the labour cost was the biggest cost item followed by the material cost. This was in agreement with what Rapoza (2013) reported, that labour costs and material costs are one of the biggest cost item in most foundries. The breakdown in figure 4.9 therefore, was used because it is representative of most foundries. In addition to the model using representative data, the primary focus was the individual effect of increasing input costs on the final manufacturing cost.

Figure 4.10 showed the individual effect of a gradual increase in material, labour and overhead costs on total manufacturing cost, as predicted by the model. The graph showed what happens to the manufacturing cost when one of the individual cost elements was increased. For example, at ‘20%’ increase, the graph showed what the manufacturing cost would be if labour cost had increased by 20 percent, whilst material and overhead cost had remained the same. At the same ‘20%’ point, the curve showed what the manufacturing cost would be if material costs increased by 20 percent whilst labour and overheads remained the same. The same applied to overheads. In essence, what this sensitivity analysis aimed to bring forth, was the understanding of, relative to one another, which cost element affects manufacturing cost more. This allowed for informed management decisions at strategic level to be made. Furthermore, this exercise was done to demonstrate the usability of the model to assist in making management decisions, per research question (c). The curve did not only have the potential to show the effects of an increase in one element, instances could occur where two or all of the individual cost elements increased in a foundry. For instance, in the beginning of the new financial year, trade unions could negotiate wage increases (increasing labour rates), suppliers of raw material would make inflationary adjustments to prices (affecting material cost). Energy prices are likely to change also (overheads). The model was able to show the immediate effect of all those scenarios on product prices.

The developed model suggested that manufacturing cost was more sensitive to labour costs at TE’s KDS foundry, as compared to the other cost elements. What this communicates to management was that if all costs are to increase, more effort should be made to curb labour cost increases. This result was to be expected. As much as the cost breakdown (figure 4.9) already showed labour cost as the biggest cost contributor, sensitivity could not be assumed. As a possible explanation to this in the South African context, Davies (2015) reported low labour productivity as one of the challenges facing foundries in South Africa. Furthermore, it has been noted (South African Institute of Foundrymen, 2014) that the skills and qualification pipeline in the South African foundry industry is poor relative to peer countries. Couple this with the highly unionized labour market (Wood and Dibben (2008) noted the South African trade unions as the strongest in Africa) in South Africa. As mentioned in the literature review section (2.3.1), Eric, Petri, Tanja and Castillon-Solano (2006) made the point that foundries, because of technology, are going from a 70/30 direct/indirect cost structure to a 30/70 direct/indirect cost structure. It is evident that at TE’s KDS foundry, direct costs (material and labour) are still relatively higher (75%) than indirect costs (25%). The reason for this is simple. TE’s KDS foundry is semi-automated, therefore considerable human effort was still required. Union activity was also very strong, because the company is State owned.

Additionally, figure 4.10 was not only useful in its ability to identify the most sensitive cost element. It allowed the immediate understanding of the effects of increases other cost elements, on manufacturing cost. One of which was of relevance in the South African market, is energy costs. The National Foundry Technology Network (NFTN) in South Africa made representations to the Portfolio Committee on Trade and Industry, in Parliament to highlight the perilous effects of rising energy costs in South Africa. It was reported (South Africa. Parliamentary Monitoring Group, 2012) that electricity tariff increases directly resulted in scale downs and closures in the foundry industry. It is therefore clear that it is of paramount importance that a foundry keeps precise track of the effects of major variables on manufacturing cost.

As shown in figure 5.1, research question (c) spoke to the reliable and practical use of the model. This section, as a precursor, demonstrated that the model, functionally, can potential inform management on practical, strategic issues related to the continuous management of the foundry. Functionally, the model seemed to demonstrate a fair representation of the general conditions of a South African steel foundry.

5.5 Internal validation of the model

The following section dealt with the model accuracy and model practicality analysis, presented in section 4.2 and tables 4.6-4.7. Research question (b) and (c) spoke about the accuracy and usability of the developed model. These two core themes were explored by assessing the developed model versus the current model that TE’s KDS foundry uses. Four different components, per table 4.6, were discussed. Lastly, the one-way ANOVA results, per table 4.7, was also discussed.

A cast component of design mass 550kg, that is in production at TE’s KDS foundry was used to test the model accuracy. The manufacturing cost of the component, as priced by TE KDS foundry was known. The results were shown in table 4.6. As can be seen, there was a 15% difference between the predicted cost and the current cost being charged. There were two possible explanations to these observed results. Firstly, the design mass range used to develop the regression model for predicting mould mass was 12kg-140kg. Hahn (1977) warned against simply extrapolating in linear regression and notes that extrapolations need to be supported by physical considerations. Fortunately, the model outlined the predicted cost per section. According to the developed model the predicted moulding costs constituted 52% of the total costs, whilst the melting costs constituted 34.5% and finishing costs 13.5%. The current TE KDS foundry model had 15% of the total costs attributable to the moulding section, 44% to the melting section and 41% to finishing. The huge discrepancies therefore, were found within the moulding sections and the finishing sections.

A closer analysis of the moulding section revealed that the actual mould mass of this particular component is 870kg. With the current data, the model predicted that a component of this design mass would have a mould mass of approximately 2000kg. Physically, this bordered on the improbable. However, the result is to be expected and was one of the weakness areas of the developed model. Firstly, the R^2 value of the regression analysis for design mass and mould mass was found to be 0.77. The design mass of the component was 550kg, the range of the data was 12kg-140kg. Why then was a component outside the data range used? This was done in response to what would happen in reality. Potential customers will come with various components that are outside the 12kg-140kg design mass range. The relative similarities in how the proposed model and the current foundry model assign costs to the melting section is a positive for the developed model. This means that potential customers, looking to have their own moulds casted by TE's KDS foundry, could be assisted.

The huge discrepancy between the developed model and the current foundry model, in the finishing sections was unexpected. However, a closer look at the routing methodology employed by TE's KDS foundry provided possible explanations. Heat treatment was one of the costly sections in the finishing stage. The cast component in question undergoes a normalizing heat treatment in a top hat furnace.

Operationally, the top hat furnace is operated whenever the section supervisor deems the number of castings inside to be strategically (downstream turnaround times are an important consideration) 'sufficient'. This poses a costing challenge. Heat treatment costs cannot be assigned per product because the product mix inside the furnace can vary depending on operational needs. TE's KDS foundry model used rates based on mass of the component which is how the heat treatment cost was assigned to the component in question. The TE KDS foundry method is clearly inaccurate, albeit a decent approximation. The developed model used a more conservative approach to assign heat treatment costs by assuming that a single component can be heat treated at a time. The cycle time, top hat furnace power rating and the applicable Eskom tariff were used to estimate the cost.

Evident from table 4.6, two components of 48kg and 53kg design masses, of known manufacturing cost were used to test the model accuracy. These two components were within the 12-140kg design mass range that characterized the regression equations. It was found that there was a 5.9% difference between the developed model cost and the current TE KDS foundry model cost, for component B of 53kg design mass. A percentage difference of 2.95% was found for component C, of 48kg design mass. As mentioned in the discussion of component A above, the developed model and TE's KDS model differed on the allocation of standard amount of sand required for a component. The model used a regression equation with an R^2 value of 0.77. In the case of component of B, the model predicted the standard amount of sand required to be 237kg and the actual standard amount of sand required was 326 kg. The finishing costs, albeit structured with different philosophies, were also found to be comparable between the developed model and the current model. This therefore explains the relatively small difference between the predicted cost and the current (actual) cost.

The same was believed to be true for component C. Due to the design mass of 48 kg being within the regression equation 1 range, the difference between the predicted cost and the current (actual) cost was relatively small. However, for component D, of design mass 21 kg, which was within regression equation 1 data range, the predicted cost was higher than the current TE KDS foundry model cost. This suggests that there is a point on figure 4.11, below which the developed model predicts higher manufacturing costs than the current TE KDS model. It was therefore apparent that across a 21-550 kg design mass range, the developed model and the current TE KDS foundry model behaved differently. However, the reality of the matter was that a potential client could come request a quotation for a component as small as 21kg or as big as 550 kg. It was upon those grounds that a standardized measure of model predictive accuracy was employed across a 21kg-550kg range. Table 4.6 shows the MAPE for the developed model across the four instances of a 21 kg component, 48 kg component, 54 kg component and 550 kg. The MAPE was found to be 9.23%. According to Lewis (1982), a model with a MAPE value below 10% is a highly accurate forecasting model.

Perhaps were the developed model shined the more, was on the aspect envisaged by research question (c), the usability of the model. Three critical success factors that were identified from literature were used to assess the practical usability of the developed model compared to the current TE KDS foundry model. Table 4.7 summarized the assessment. The findings were not unexpected. Primarily, the TE KDS foundry model was not designed to handle preliminary quotations due to the current strategic trajectory of the business. A strategy of supporting internal Transnet Engineering businesses. However, a comparison is still warranted because internal potential customers still do approach the business for indicative pricing for their own budgetary purposes.

Beecham et al. (2005) identified ease of use, scope and flexibility as important success factors in model development. In terms of ease of use, the developed model was considered superior to the current model. All the input data used for the modelled was collected and stored on one Microsoft Excel file. The TE KDS foundry model inputs are littered across various internal departments, across different geographic locations. The developed model was also packaged on a commonly used software package. The current model inputs are mined from various data banks that are administered and managed by different departments. This posed a challenge of access and rendered TE’s KDS foundry model prone to organizational latency issues.

Scope referred to what the model covers in terms of what it intended to do. As already stated, the current TE KDS foundry model was only designed to provide the manufacturing cost upon completion of the first compliant prototype. The model provided no immediate view of the manufacturing cost implications around changing inputs to assist in decision making. The developed model on the one hand, provided a more informed view because it is done by the ‘design’ department of the foundry business. This was especially critical in a manufacturing environment. Chougule & Ravi (2010) asserted that over 70% of a product’s cost are locked in during the design phase. Flexibility was the last critical success factor that the two models were compared on.

Most of the inflexibility of the current TE KDS foundry model lied within the fact that input data was scattered and the output was not generated by the user of the information. This meant that the user could not easily run simulations to assess the potential impact of business decisions. As already seen in this chapter, the South African foundry industry is dynamic and relentless. Competitive edge can easily be lost and closures are a real threat. The developed method therefore, would practically allow TE’s KDS foundry to have a better understanding of how critical factors such as staffing decisions, material price increases and rising energy costs could affect competitiveness.

Table 4.7 showed the one-way ANOVA test for manufacturing cost as predicted by the developed model and according to TE’s KDS foundry model. The objective of the test was to ascertain if there exists statistically significant differences in the means of the manufacturing cost as predicted by developed model and TE’s KDS foundry. It was found that the p-value (0.65) is greater than the set significance level of 0.05. Therefore, the null hypothesis of the one-way ANOVA test cannot be rejected (Kim, 2017). This means that we can conclude that there are no statistically significant differences between the mean of the manufacturing cost as predicted by the developed model and the mean of the manufacturing cost as predicted by TE KDS foundry’s model.

5.6 Expert judgement of the model

This section discussed the results of the expert judgement of the model, presented in section 4.2.3. The results were discussed per critical success criteria, within the parameters of the internal evaluation and what literature said.

According to all the experts that were engaged, the accuracy provided by the model was excellent for internal budgeting and planning. One of the observations in the literature review (section 2.3.1) was the issue of manager's attitude towards costing systems. Lyall and Graham (1993) conducted a survey to ascertain manager's attitudes towards costing information and systems. One of the findings they made was on the importance placed on budgets. They observed that budgets in manufacturing tend to be considered targets by managers. TE was no different. Therefore, the model's ability to execute the budgeting and planning function made it appealing to the experts, who are industrial practitioners.

Pertinent to accuracy, it was also found that all the experts agree that the model can produce competitive quotes. The experts' view was believed to be based on the MAPE that was found to be 9.23%. This finding by the experts was consistent with what literature (Lewis (1982)) considered to be reasonable estimating power. As mentioned in the Research Motivation (section 1.3), at the core of this research work was developing a tool to allow TE's KDS foundry to potentially respond to market quickly. Maciol (2017) highlighted the importance of providing quick responses to the market, to stay competitive. The model therefore, from the expert's perspective, provided this functionality, as intended by the research objectives.

In this research context, scope was defined as what the model includes and excludes in its functionality. The questionnaire was formulated to ascertain whether the experts think the model does what it was intended for. Secondly, the appropriateness of the level of detail offered by the model. It was found that all the experts agree that the model can provide the necessary information to generate a satisfactory preliminary quote. Sargent (2011) in their discussion of verification and validation of simulation models, emphasized the importance of a model being developed for a specific purposes and validity established for that same purpose. Research objective (c) stated '*Develop a questionnaire for expert judgement on the* *usability of the developed model for validity and reliability purposes'*. Therefore, the model, from the expert's perspective does what it was intended to do. However, Expert 3 believed that the model could benefit from including other alloys except steel. As outlined in section 2.2.3 of the literature review, the majority of foundry activities is in other alloys of iron, except steel. Therefore, Expert 3's recommendation was justified and welcomed, although it could not be possibly addressed now in this research work's current scope.

Furthermore, it was found that Expert 1 and Expert 3 were satisfied with the use of design mass, as a key variable, whilst Expert 2 advocated for the addition of another design variable. The suggestion from Expert 2 is consistent with what Mileham et al. (1993) did. The researchers used design mass to generate the initial quote, then added cycle time as another design variable to improve the costing model accuracy. Sajid, Wasim, Hussain and Jahanzaib (2018) also developed a feature based model that estimates manufacturing cost for sand casted components. The model featured cost, design, and process data bases. To generate a quote, a casting process is selected, then casting material, casting design features (pouring basin , sprue, runner, number and type of risers) and then process features. Furthermore, the model required the user to enter cost related information (labour rate, number of workers and other related expenses). The model then generated a quote with a 14.3% difference in predicted versus actual value. The developed model in this research work only requires the user to input the design mass, and the model produces an estimate with a MAPE of 9.23%.

Ease of use was one of the most under-appreciated critical success criteria of any cost estimating model. Often times, it is easier to sacrifice ease of use for aspects such as accuracy. It was found that all the experts believe that the model is easy to use. The same was found to be true when internal evaluation of the model was conducted. Expert 1 in particular, commended the fact that there are no implementation costs associated with using the model. Beecham et al. (2005) also noted how overly complex models are unlikely to be used because of the associated costs (such as training costs) of using them. Again, consistent with research objective (c), the model allows ease of use, which is an important aspect of any simulation model, particularly in cost estimating.

Consistency was framed to address the correctness of the conceptual description and the appropriateness of the resultant input-output relationship. As discussed in section 3.6 (Verification and Validation), Sargent (2011) defined conceptual model verification as making sure that the underlying assumptions and theories are correct and represent the system to be modelled, reasonably well. All experts that were surveyed, generally believed that standard costing principles were applied correctly in the research context. The experts also believed that the model outputs and inputs are consistent, with the exception of Product A. Expert 3 took exception to large design mass range of the products used to test the accuracy (figure 4.11). Unfortunately, this could not be avoided as these were the only components of known design mass and manufacturing cost, outside the regression data. This was to be expected, as discussed in section 5.5. Expert 1 believed that the model would benefit from partitioning the regression equations into different design mass size ranges. This was to be expected, as discussed in section 5.5, the source of inconsistency in the model is regression equation 1. The suggestion from Expert 1 is what Mileham et al. (1993) did for their regression analysis. Due to time constraints and the preliminary nature of this research work, the suggestion from Expert 1 could not be implemented at present. However, it was noted for future work.

The last critical success criteria to be considered was the flexibility of the model. In the research design, flexibility was framed to establish whether the experts think that the model can be used in any foundry environment, whether it can allow the user a sufficient view to make informed decisions about material usage and labour related decisions. It was found that all the experts believe that the model can be used in any foundry environment. This finding was not surprising, considering that one of the themes from literature (section 2.2) was how foundries across the globe share practical and functional similarities. Expert 3 believed that the model wouldn’t allow proper management of material usage as it affects the manufacturing cost. This is believed to have been caused by the blanketed approach to the cost elements. A limitation that could not be avoided. However, Expert 1 & Expert 2 believed that the blanketed view was still sufficient.

6. Conclusion and Recommendations

6.1 Conclusion

The following chapter summarised the key findings of this research work, relative to the CRQ - *Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product?* The findings are presented per research question that emanated from the CRQ.

- Research question (a) stated 'what is the relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost?'. It was found that a linear relationship adequately describes how the cast component's design mass relates to all the other variables (mass after casting, mass of the component mould and final product manufacturing cost).

- Research question (b) asked 'how accurate would a model, using the design mass of a cast component be in predicting the final cast product's manufacturing cost?' It was found that using the design mass of a cast component, a MAPE of 9.23% can be achieved across a design mass range of 21kg-550kg.

- Research question (c) asked 'Can the developed CER be reliably used in practise?' It was found that experts from TE's KDS foundry, who evaluated the model, believe that the model is easy to use, consistent, flexible, accurate and had the appropriate scope.

Therefore, this research work concludes that the final manufacturing cost can be reliably predicted using the design mass of the product.

6.2 Implications of the research work

In relation to the CRQ, the implications for sand casting foundries were that the quotation process for competitive bidding can be accomplished in a short space of time, at minimal effort. Sand casting variables can be modelled using simple regressions. Practically therefore, the internal budgeting, the production planning process and other strategic decisions can be executed more succinctly.

Additionally, the findings in this research work have shown that a foundry that uses standard costing has to ensure that the engineering standards that have been established are truly reflective of the said foundry. The tariffs at each processing stage are a direct function of the planned activity. The planned activity is a function of the perceived engineering capacity of the foundry. It is therefore imperative that the engineering department is involved in the costing of cast products. It can be argued as far as to say, it would be of benefit to a foundry to employ design to cost methodologies and/or target costing. Chougule and Ravi (2010) pointed out that 70% of a product's cost are locked in at the design phase. In a foundry, it is the engineers that design the product.

There are other significant issues that were identified in the literature review, such as the appropriateness of standard costing in modern times. Albeit not in the intended scope of this research work, but this research work supports the other bodies of work that show that there is still a preference and a place for easy to use systems. Particularly in SA, where the underlying assumptions of standard costing systems are still true.

Lastly, this research work adds support to the body of work that suggest a research design with a combination of quantitative and qualitative methods provides a complete and enhanced picture. Particularly in CER development.

6.3 Recommendations

In light of the research findings, the following is recommended:

- TE's KDS foundry to develop and maintain a database of all products that have been developed and produced. This data can be used to improve the accuracy of the cost estimating model over time.

- Develop a cost estimating framework specifically for steel casting, cast iron and test it across different foundries in SA. The framework should include parametric methods in a standard costing setting. Use of expert panels for validation is recommended. The framework can include a bigger expert panel, from different foundries, for validation purposes. The regression equations should be partitioned into different design mass ranges. A variable, in addition to design mass, can be considered, such as the volume of the cast component, to improve accuracy.

- A study to investigate the effectiveness of a design-to-cost approach at TE's KDS foundry, considering that this study has shown a clear relationship between design variables and manufacturing cost.

- A study to compare the gains of implementing an ABC systems versus standard costing in a steel casting foundry in SA considering the state of technology. Literature reviewed (section 2.3.2) highlighted accuracy in tracing cost back to the product as the major advantage ABC might have over traditional costing methods. Ease of use and simplicity is quoted (literature review section 2.3.1) as one of the advantages of traditional costing systems over ABC, a characteristic that was evident in this research work.

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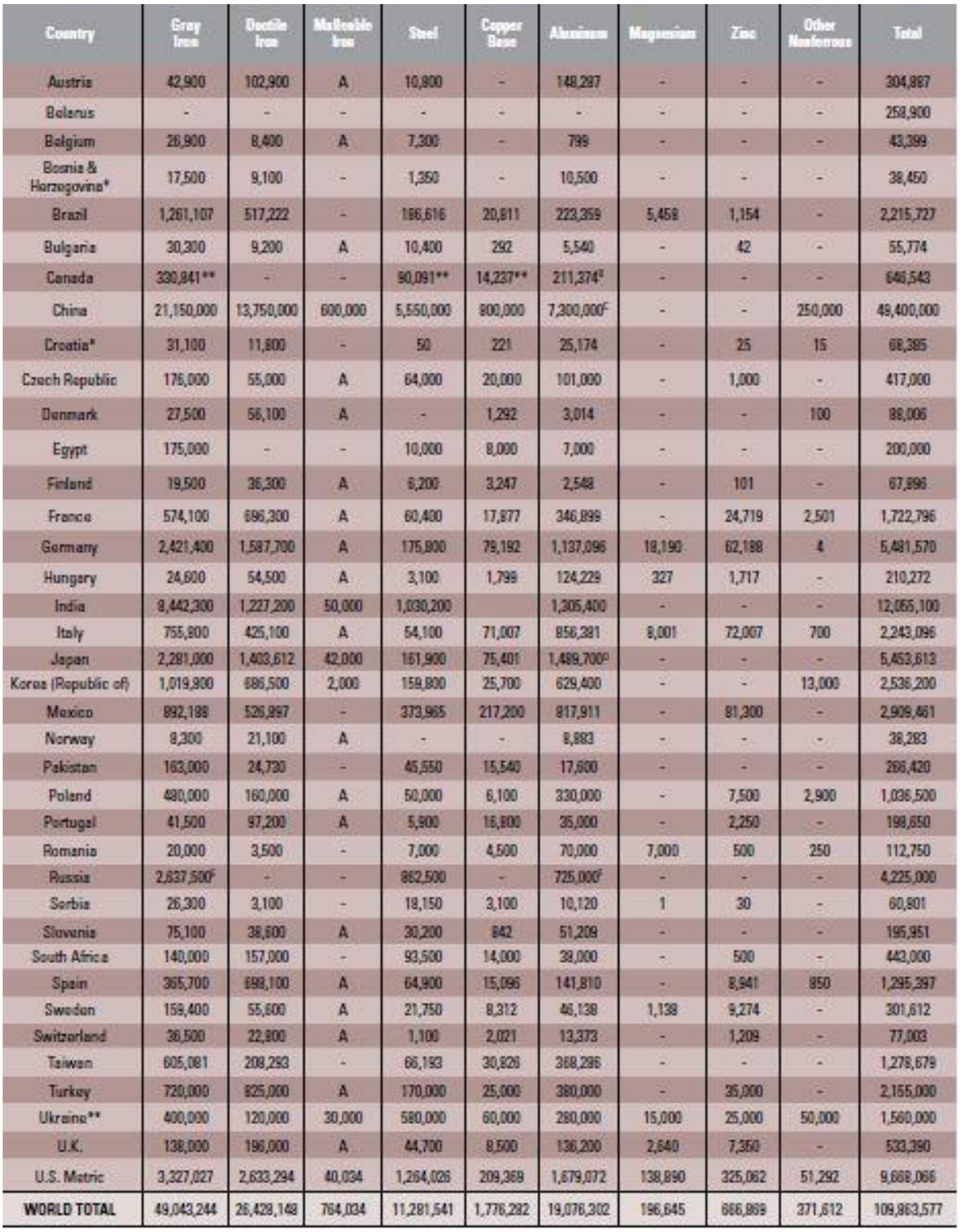
Appendix A

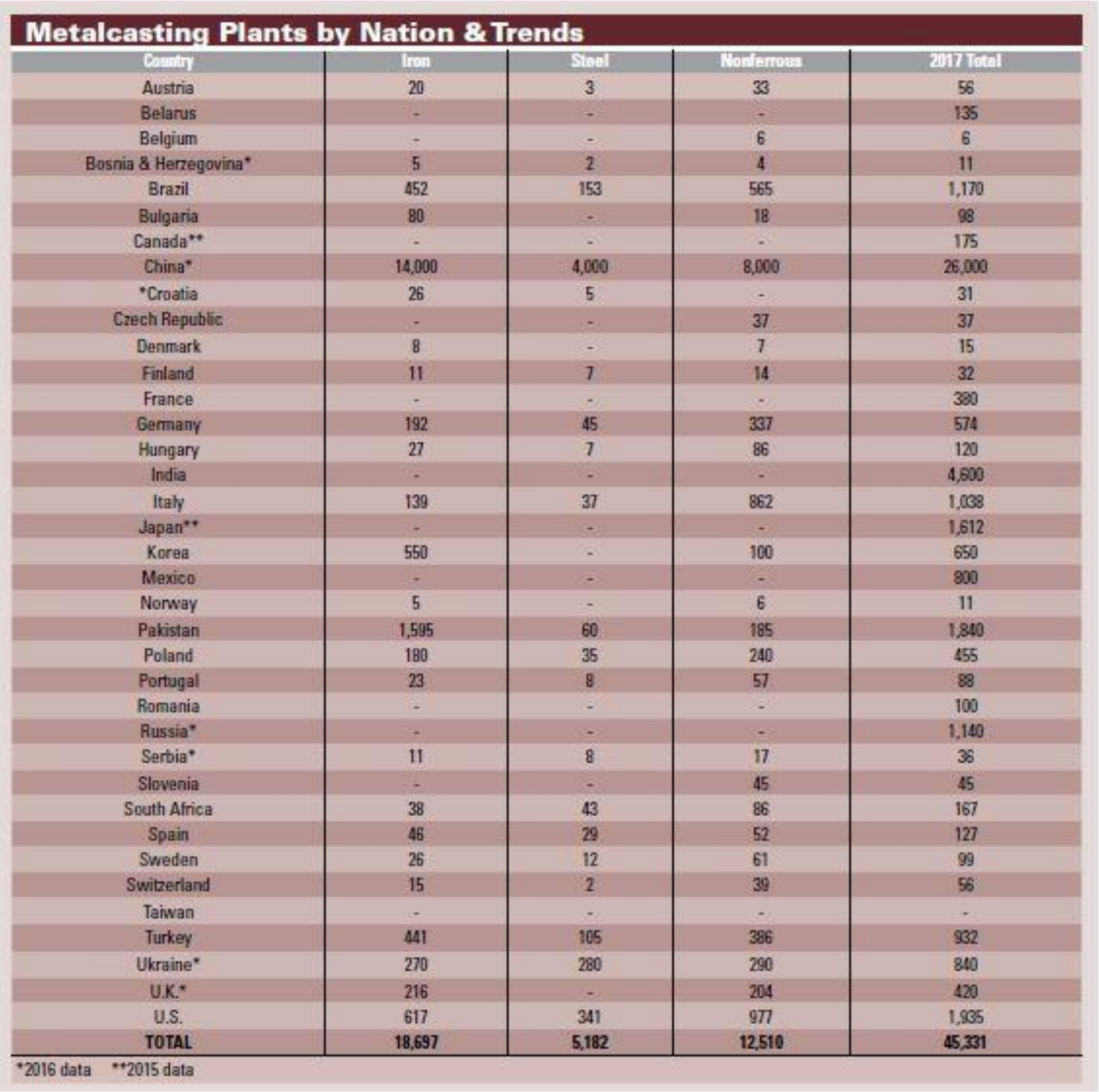
Global foundry outputs

Table A.1: A summary of global industry outputs, per country (“Census of World”, 2018)



Country	Gray Iron	Ductile Iron	Malleable Iron	Steel	Copper Base	Aluminum	Magnesium	Zinc	Other Nonferrous	Total
Austria	42,900	102,900	A	10,800	-	148,297	-	-	-	304,887
Belarus	-	-	-	-	-	-	-	-	-	258,900
Belgium	26,900	8,400	A	7,300	-	799	-	-	-	43,399
Bosnia & Herzegovina*	17,500	9,100	-	1,350	-	10,500	-	-	-	38,450
Brazil	1,261,107	517,222	-	186,616	20,811	223,359	5,458	1,154	-	2,215,727
Bulgaria	30,300	9,200	A	10,400	292	5,540	-	42	-	55,774
Canada	330,841**	-	-	90,091**	14,237**	211,374^{8}	-	-	-	646,543
China	21,150,000	13,750,000	600,000	5,550,000	800,000	7,300,000^{F}	-	-	250,000	49,400,000
Croatia*	31,100	11,800	-	50	221	25,174	-	25	15	68,385
Czech Republic	176,000	55,000	A	64,000	20,000	101,000	-	1,000	-	417,000
Denmark	27,500	56,100	A	-	1,292	3,014	-	-	100	88,006
Egypt	175,000	-	-	10,000	8,000	7,000	-	-	-	200,000
Finland	19,500	36,300	A	6,200	3,247	2,548	-	101	-	67,896
France	574,100	696,300	A	60,400	17,877	346,899	-	24,719	2,501	1,722,796
Germany	2,421,400	1,587,700	A	175,800	79,192	1,137,096	18,190	62,188	4	5,481,570
Hungary	24,600	54,500	A	3,100	1,799	124,229	327	1,717	-	210,272
India	8,442,300	1,227,200	50,000	1,030,200		1,305,400	-	-	-	12,055,100
Italy	755,800	425,100	A	54,100	71,007	856,381	8,001	72,007	700	2,243,096
Japan	2,281,000	1,403,612	42,000	161,900	75,401	1,489,700^{P}	-	-	-	5,453,613
Korea (Republic of)	1,019,800	686,500	2,000	159,800	25,700	629,400	-	-	13,000	2,536,200
Mexico	892,188	526,897	-	373,965	217,200	817,911	-	81,300	-	2,909,461
Norway	8,300	21,100	A	-	-	8,883	-	-	-	38,283
Pakistan	163,000	24,730	-	45,550	15,540	17,600	-	-	-	266,420
Poland	480,000	160,000	A	50,000	6,100	330,000	-	7,500	2,900	1,036,500
Portugal	41,500	97,200	A	5,800	16,800	35,000	-	2,250	-	198,650
Romania	20,000	3,500	-	7,000	4,500	70,000	7,000	500	250	112,750
Russia	2,637,500^{F}	-	-	862,500	-	725,000^{F}	-	-	-	4,225,000
Serbia	26,300	3,100	-	18,150	3,100	10,120	1	30	-	60,801
Slovenia	75,100	38,600	A	30,200	842	51,209	-	-	-	195,951
South Africa	140,000	157,000	-	93,500	14,000	38,000	-	500	-	443,000
Spain	365,700	698,100	A	64,900	15,096	141,810	-	8,941	850	1,295,397
Sweden	159,400	55,600	A	21,750	8,312	46,138	1,138	9,274	-	301,612
Switzerland	36,500	22,800	A	1,100	2,021	13,373	-	1,209	-	77,003
Taiwan	605,081	208,293	-	66,193	30,826	368,286	-	-	-	1,278,679
Turkey	720,000	825,000	A	170,000	25,000	380,000	-	35,000	-	2,155,000
Ukraine**	400,000	120,000	30,000	580,000	60,000	280,000	15,000	25,000	50,000	1,560,000
U.K.	138,000	196,000	A	44,700	8,500	136,200	2,640	7,350	-	533,390
U.S. Metric	3,327,027	2,633,294	40,034	1,264,026	209,369	1,679,072	138,890	325,062	51,292	9,668,066
WORLD TOTAL	49,043,244	26,428,148	764,034	11,281,541	1,776,282	19,076,302	196,645	666,869	371,612	109,863,577

Table A.2: Foundries by country ("Census of World", 2018)



Metalcasting Plants by Nation & Trends

Country	Iron	Steel	Nonferrous	2017 Total
Austria	20	3	33	56
Belarus	-	-	-	135
Belgium	-	-	6	6
Bosnia & Herzegovina*	5	2	4	11
Brazil	452	153	565	1,170
Bulgaria	80	-	18	98
Canada**	-	-	-	175
China*	14,000	4,000	8,000	26,000
*Croatia	26	5	-	31
Czech Republic	-	-	37	37
Denmark	8	-	7	15
Finland	11	7	14	32
France	-	-	-	380
Germany	192	45	337	574
Hungary	27	7	86	120
India	-	-	-	4,600
Italy	139	37	862	1,038
Japan**	-	-	-	1,612
Korea	550	-	100	650
Mexico	-	-	-	800
Norway	5	-	6	11
Pakistan	1,595	60	185	1,840
Poland	180	35	240	455
Portugal	23	8	57	88
Romania	-	-	-	100
Russia*	-	-	-	1,140
Serbia*	11	8	17	36
Slovenia	-	-	45	45
South Africa	38	43	86	167
Spain	46	29	52	127
Sweden	26	12	61	99
Switzerland	15	2	39	56
Taiwan	-	-	-	-
Turkey	441	105	386	932
Ukraine*	270	280	290	840
U.K.*	216	-	204	420
U.S.	617	341	977	1,935
TOTAL	**18,697**	**5,182**	**12,510**	**45,331**

*2016 data **2015 data

KDS Foundry process flow

The following section is a description of the mathematical underpinnings of the model, based on standard costing principles. Figure A.3 shows the KDS foundry process flow.

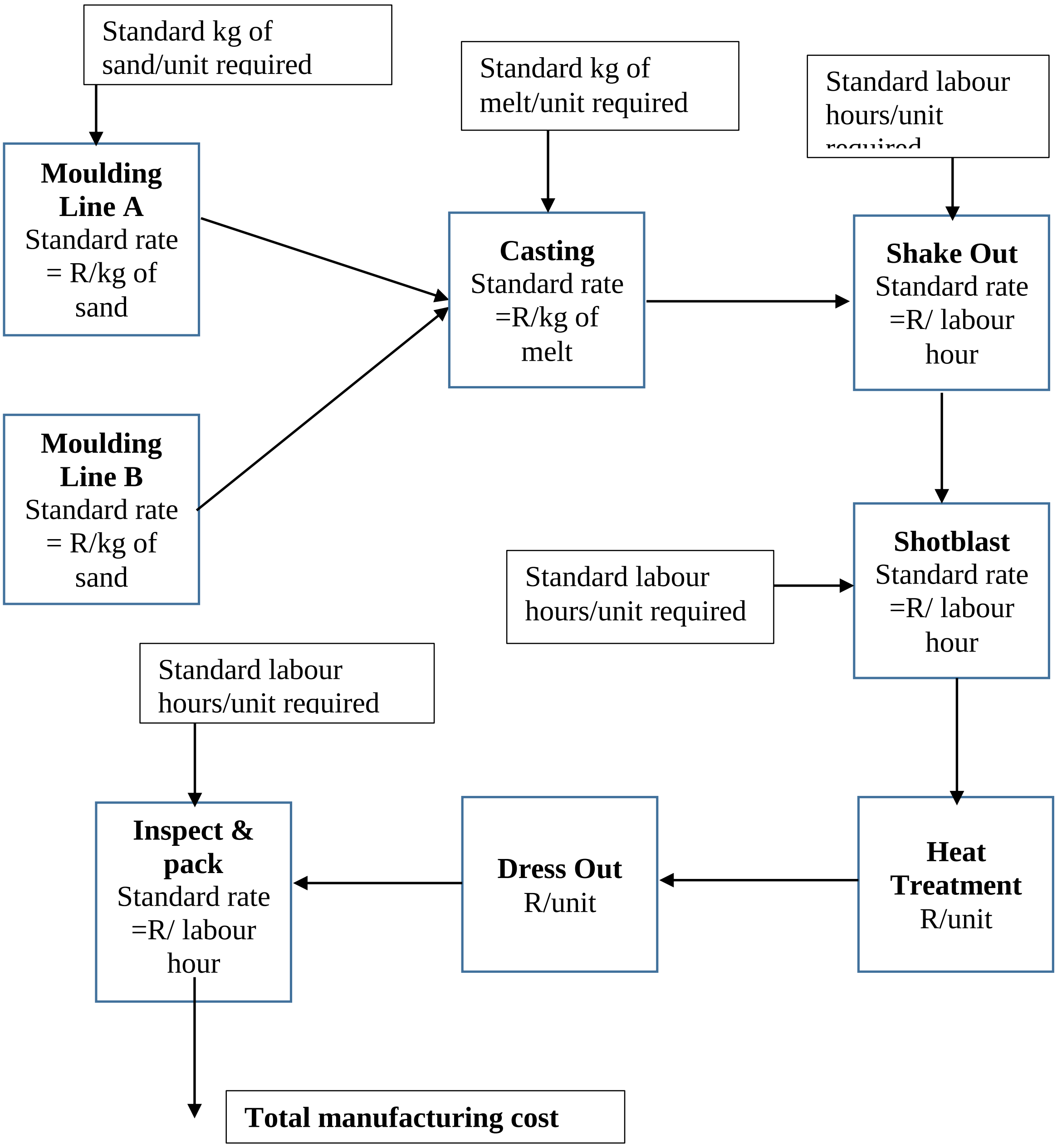


Figure A.3: TE KDS foundry process flow.

Moulding

Standard rate moulding line A (M_{RA}) = $\frac{Total\ Costs\ to\ run\ moulding\ line\ A\ (TCA)}{Planned\ annual\ activity\ on\ moulding\ line\ A(PAA)}$

TCA = Material $Cost_A$ + Labour $Cost_A$ + Overhead $Costs_A$

Material $Cost_A$ = $\sum Number\ of\ units\ of\ material\ i\ x\ unit\ price\ of\ material\ i$

where i = sand, resin, catalyst, zip strip paint, sleeves

Labour $Cost_A$ = $\sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard $Costs_A$ = f(energy, depreciation, support services, overtime and other operating expenses)

PAA = $\sum standard\ amount\ of\ sand\ used\ by\ product\ k1$,

where k1 = all the products for line A in the production plan for the period in review.

Standard rate moulding line B (M_{RB})= $\frac{Total\ Costs\ to\ run\ moulding\ line\ B\ (TCB)}{Planned\ annual\ activity\ on\ moulding\ line\ B(PAB)}$

TCB = Material $Cost_B$ + Labour $Cost_B$ + Overhead $Costs_B$

Material $Cost_B$ = $\sum Number\ of\ units\ of\ material\ l\ x\ unit\ price\ of\ material\ l$
where l = green sand, bentonite, water, starch, cores

Labour $Cost_B$ = $\sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard Costs_B = f(energy, depreciation, support services, overtime and other operating expenses)

$PAB = \sum standard\ amount\ of\ sand\ used\ by\ product\ k2$,

where k2 = all the products for line B in the production plan for the period in review.

<u>Casting</u>

Standard rate casting (C_{RA}) = $\frac{Total\ Costs\ to\ run\ casting\ section\ (TCC)}{Planned\ annual\ activity\ on\ casting\ section (PAC)}$

TCC = Material Cost_C + Labour Cost_C + Overhead Costs_C

Material Cost_C= $\sum Number\ of\ units\ of\ material\ z\ x\ unit\ price\ of\ material\ z$

where z = scrap metal, patching material, additives (ferromanganese, ferrosilicon)

Labour Cost_C = $\sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard Cost_C = f(energy, depreciation, support services, overtime and other operating expenses)

$PAC = \sum standard\ amount\ of\ melt\ used\ by\ product\ k1 + k2$,

<u>Shake Out / Shotblast / Inspect & Pack (Finishing)</u>

Standard rate casting (F_{RA}) = $\frac{Total\ Costs\ to\ run\ casting\ section\ (TCF)}{Planned\ annual\ activity\ at\ finishing\ section (PAF)}$

TCF = Material Cost$_F$ + Labour Cost$_F$ + Overhead Costs$_F$

Material Cost$_F$= $\sum Number\ of\ units\ of\ material\ c\ x\ unit\ price\ of\ material\ c$

where c = scrap metal, patching material, additives (ferromanganese, ferrosilicon)

Labour Cost$_F$ = $\sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard Costs$_F$ = f(energy, depreciation, support services, overtime and other operating expenses)

PAF = $\sum standard\ amount\ of\ labour\ hours\ used\ for\ products\ k1 + k2$,

Appendix B

The following section details the assumptions underlying the development of the model.

Regression data

Table B1: Regression data

Component	**Design Mass (kg)**	**Mould Mass (kg)**	**Mass with risers (kg)**
W	5	-	10
X	12	-	15
Y	12	77	21
Z	13	84	22
E	11	-	22.5
F	30	276	40
G	43	128	56.8
H	85	368	90
I	100	-	106
J	100	324	152
K	105	410	163
L	136	270	174
M	95	507	180
N	135	650	197
O	120	260	200
P	127	450	201
Q	77	247	210
R	135	495	225
S	233	612	296
T	162	764	303
V	140	717	307

Manufacturing cost breakdown

-Foundry sections are divided into the greensand line, chemical bond sand line, melting and finishing sections.

-The percentage contribution of each section to labour cost, material cost and overhead costs is as follows: greensand line contributes 61%, chemical bond sand line 13.5%, melting section is 15.8% and the finishing sections contributes 9.7%. The split is based on the 2012/13 FY.

-The total manufacturing (labour, material and overheads) costs used were extracted from the 2017/18 FY and apportioned to the various foundry sections.

Planned activity breakdown

-The projected quantities to be produced were from the 2017/18 FY.

-The standard amount of sand required and the standard amount of melt required, for the projected components were sourced from were as follows:

Table B2:Planned activity assumed in developing the model

Component	Standard amount of sand required (kg)	Standard amount of melt required (kg)	Projected quantity to be produced
P	450	201	1000
Y	77	21	400
Z	84	22	600
YY	77	21	400
ZZ	84	22	600
V	717	307	800
S	612	296	800
AA	7	10	5000
AB	11	22.5	7000
AC	11	22.5	7000

-222 production days were assumed, with 8 hour shifts.

Appendix C: Permission Letter, Consent Letter & Questionnaire Pack

The following Appendix consists of the following sections:

Permission Letter

-The permission letter from Transnet Engineering management requesting for the collection and use of operational and financial information pertaining to the KDS foundry

-A signed copy was submitted to the School of MIA's ethical committee prior to the granting of the mandatory Ethical Clearance.

Consent Letter

-A copy of the letter given to the expert panel, to capture consent to process information and feedback.

- A copy was submitted to the School of MIA's ethical committee prior to the granting of the mandatory Ethical Clearance.

Questionnaire Information Pack

-A summary of the research report given to the expert panel in order to fill the questionnaire.

-Shows research background and purpose of the study, theoretical motivation, critical research questions, research design and the research results. A demonstration of the developed model's practical capabilities is also included. Capabilities are related to production planning and cost management in the foundry.

Permission Letter

18/11/2019
Dear Manager

PERMISSION TO CONDUCT RESEARCH FOR ACADEMIC PURPOSES

I would like to request your permission to collect and analyze KDS Foundry Business financial and operational data. I am a full-time Transnet Engineering employee at PD Foundry and a part-time Masters student in the School of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand. I am under the supervision and direction of Prof. Raj Siriram. My MSc research project is titled "A cost estimating model for new products at a Transnet Foundry for preliminary quote purposes ".

The information required pertains to product costing at the KDS Foundry. This includes, but not limited to, material costs, labour costs and the overhead costs per section. Furthermore, information pertinent to the production budget and all related planned activities for the 2019/20 financial year. Upon completion, the estimating model will be made available for use by the Foundry Business. The Foundry Business shall indicate all sensitive information that ought to be kept confidential as this research will be in the public domain.

Please contact me or my supervisor if you have any questions regarding the research. Kindly sign below the acknowledging your permission for me to conduct the survey.

Sincerely
M Boyce
Student:0715672600
Email:Mhlangabezi.Boyce@students.wits.ac.za
Supervisor: Cell: 082 894 6253
Email: raj@alpha-concepts.com

Consent letter

Dear participant

Thank you for your participation in this study. Please read and complete the consent form below. By signing this consent letter, you are indicating that you have read and understood the description and purpose of this study. Furthermore, you agree to the terms as described below:

	Mark with X	
	YES	NO
I confirm that I have read and understood the information about this study as provided in the participant's information sheet.		
I understand that my participation is voluntary and that I am free to withdraw at any time without any penalties or negative consequences against me.		
I agree that the information I provide may be treated as strictly confidential and anonymous and only the research team will have access to the questionnaire data.		
I agree that the results of this study may be recorded in academic journals and at conferences.		
I have had the opportunity to ask any questions related to this study and I have had all my questions answered to my satisfaction.		
I may request a report summary, which will come as a result of this study.		

Participant		Consent taken by (Researcher)	
Name		Name	M Boyce
Signature		Signature	
Date		Date	20/01/2020

Please answer the questions on the questionnaire, which should take approximately 10-15 minutes to complete. A summary of the research questions, methods and results, for reference, is attached. After completion of the questionnaire, please return to researcher.

Questionnaire information pack

A cost estimating model for new products at a Transnet Foundry for preliminary quote purposes.

Mhlangabezi Boyce
(Student number: 726695)

School of Mechanical, Industrial and Aeronautical Engineering

University of the Witwatersrand

Johannesburg, South Africa.

Supervisors: Professor R Siriram

A Research Project submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering.

02 March 2020

List of Tables

List of Figures

1. Background and purpose of the study

Transnet Engineering (TE) is the manufacturing division of Transnet SOC Ltd. It has depots in Koedoespoort (KDS), Uitenhage, Bloemfontein, Salt River and Durban. The division mainly manufactures and maintains rolling stock for Transnet Freight Rail (TFR) and other external customers in the African continent. TE is partitioned into three customer facing businesses, Wagons, Locomotives and Coaches Business. There are 6 internal facing businesses that are mainly responsible for supplying and servicing the customer facing businesses. Internal facing businesses are the foundry, wheels, rotating machines and rolling stock and equipment. As one of TE's internal businesses, the Foundry Business is not positioned to be profit making, but rather as a means to support the customer facing businesses and reduce the supply risk associated with rolling stock components.

This research work will be focussed on TE's KDS foundry business. The business is a sand casting foundry, using both chemically bonded sand and green sand. The foundry business operations are supported by product development (engineering), logistics, finance, sales, quality and lean departments. When a new product is developed, the product development (PD) department designs the gating and the risering systems, together with the heat treatment path the new casting ought to follow to meet technical specification. Upon completion of technical development, PD hands the bill of material (BOM) to the logistics and finance departments for calculation of the product cost. Costing follows the technical development because TE' KDS Foundry is mainly mandated to supply components to the company's customer facing businesses.

However, TE's organizational vision for the future means the foundry business has to move to being a profit center. the mandate has to change to both internal supply and establishing an external market. This is due to two reasons. One, tough economic conditions demand the full use of an organization's available resources, particularly ones that have high fixed cost implications. Two, Transnet SOC Ltd is looking to increase its foothold in Africa (Transnet SOC Ltd, 2019) , TE as the engineering arm will be one of the key drivers of such an expansion. Therefore, there lies an opportunity for the foundry business, to not only be an internal supporting business, but to have external customers. External customers could potentially demand a higher level of service, agility, responsiveness and competitive products.

The evolving mandate means the Foundry Business will need to adopt a more versatile pricing method to meet the more stringent needs of external customers. Additionally, the tough economic climate, particularly in the manufacturing sector in South Africa, leaves businesses with no choice but to review and continuously improve their process methodology. The Foundry Business has potential even beyond rolling stock, because cast products are extensively used in the agricultural, automotive and mining sectors. TE is cognisant of this fact and plans are in place to tap into those external markets.

2. Theoretical Motivation

According to Miles and Snow (1994) one of the reasons businesses lose their competitive edge and disappear is the lack of awareness and inability to recognize new opportunities. Therefore it is important for any organization to understand its own strategic intent and how the strategy will be managed. Thompson and Martin (2005) go on to show what a typical strategic management framework looks like. See Figure C1. Transnet SOC Ltd realized the opportunity for growth in the movement of goods by rail in the African market. Transnet Engineering as the engineering arm of Transnet SOC Ltd was given the objective of increasing its foothold in the African rolling stock market. TE's formulated a corporate strategy to meet these objectives, termed Vision 20-2-1. As one of the competitive strategies, the company grouped its businesses into customer-facing and support businesses. This research work is anchored on the assumption that one of the strategic decisions TE will take is to utilize its support businesses by extending their current scope to both internal and external customers.

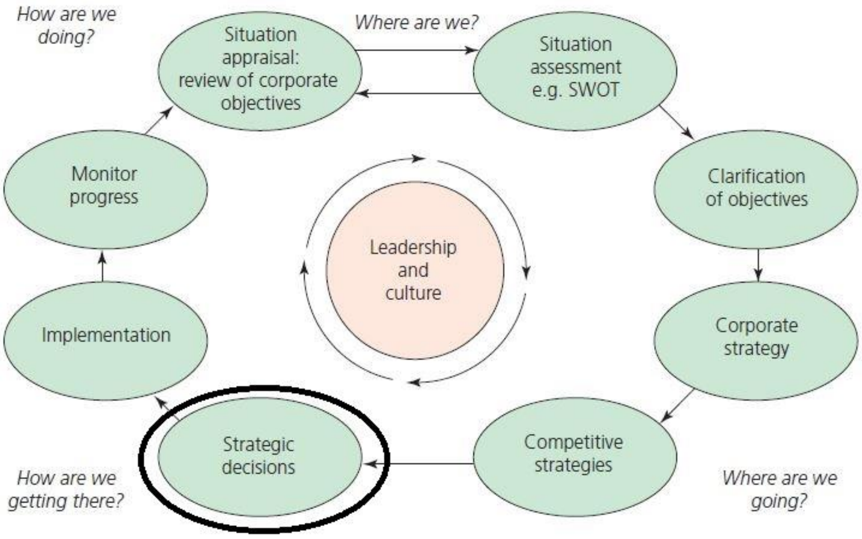


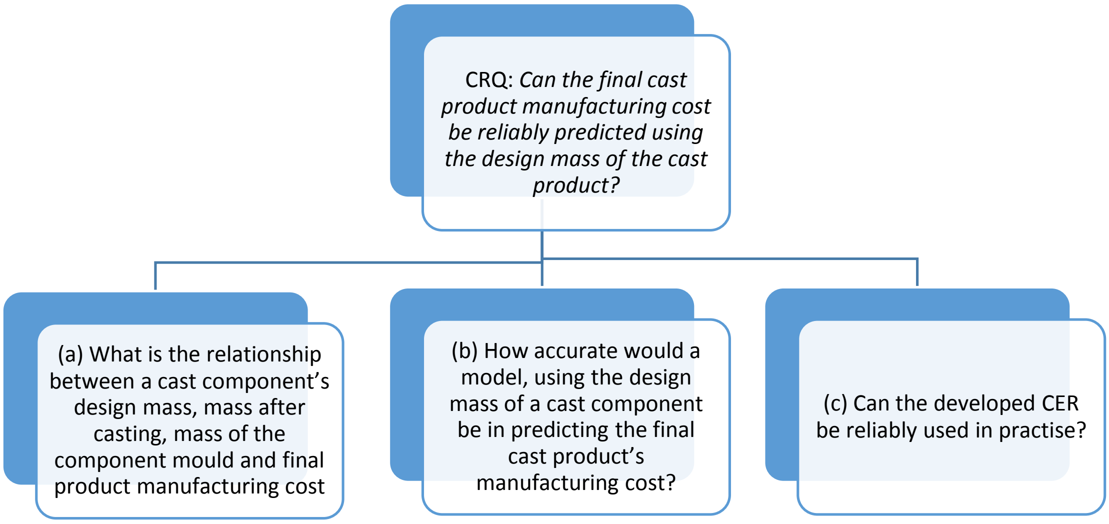
Figure C.1: Strategy management framework (Thompson & Martin (2005))

There exists parts of literature (Davies (2015; Krieg & Cunningham (2014)) that support the full utilization of foundry businesses to achieve strategic objectives. These sources reveal that foundries can be utilized to generate-revenue on various fronts such as the automotive industry, mining, agriculture, rolling stock and general engineering industries. Transnet Engineering generated R9.4 billion and R11.3 billion in revenue in 2017 and 2018 respectively (Transnet SOC Ltd, 2018). The Foundry Business is a key supplier of the components that are utilized in building and maintenance of wagons, locomotives and coaches that TE generates its revenue from. Currently, the KDS foundry business is budgeted to generate over R60 million revenue in internal sales for the 2019/2020 financial year. There exist therefore substantial financial opportunity given market potential and business volume.

In order to compete in all these markets and potentially increase revenue and profit however, the foundry needs to have a product-cost estimating mechanism in place. Maciol (2017) indicates that in the modern competitive market, customers expect quick answers (in the case of quotations). Furthermore, there needs to be a balance in accuracy and risk. This shows the importance of having a valid and reliable cost estimating model in a foundry if the goal is to tap into all these markets.

3. Critical Research Questions

The research was designed to address the following questions (Figure C2).



CRQ: *Can the final cast product manufacturing cost be reliably predicted using the design mass of the cast product?*

(a) What is the relationship between a cast component's design mass, mass after casting, mass of the component mould and final product manufacturing cost

(b) How accurate would a model, using the design mass of a cast component be in predicting the final cast product's manufacturing cost?

(c) Can the developed CER be reliably used in practise?

Figure C2: Breakdown of the critical research question

4. Research Design

The following (Figure C3) research design was used to address the research problem.

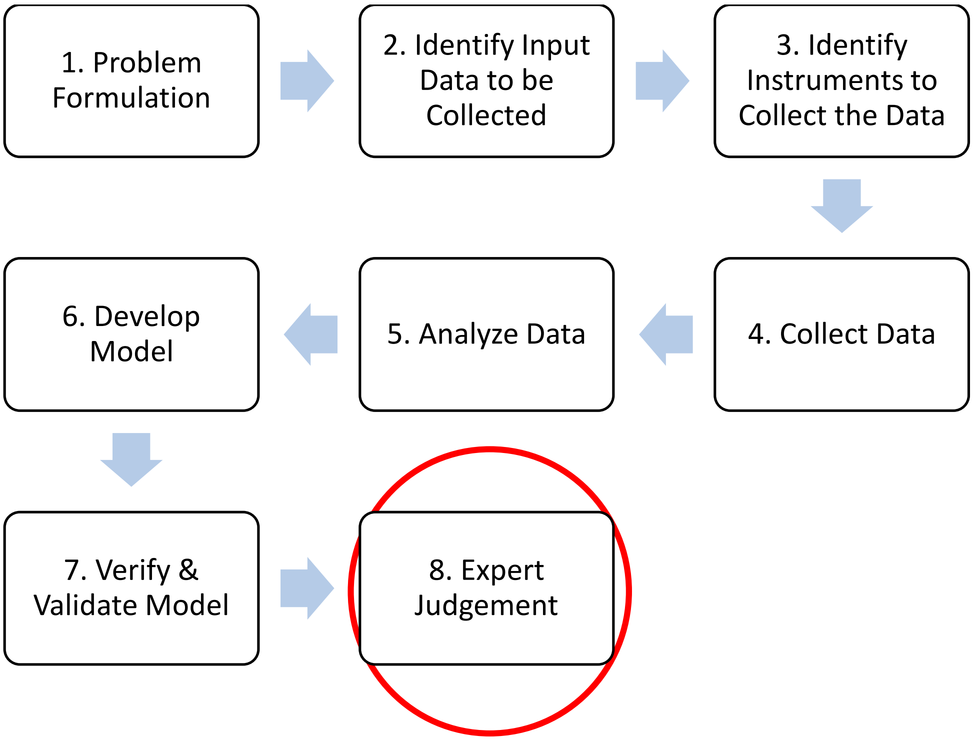


Figure C3: Research design

5. Results

The following chapter contains all the data and information collected, as per the research design, and the collation thereof. Figure C4 shows the chapter outline.

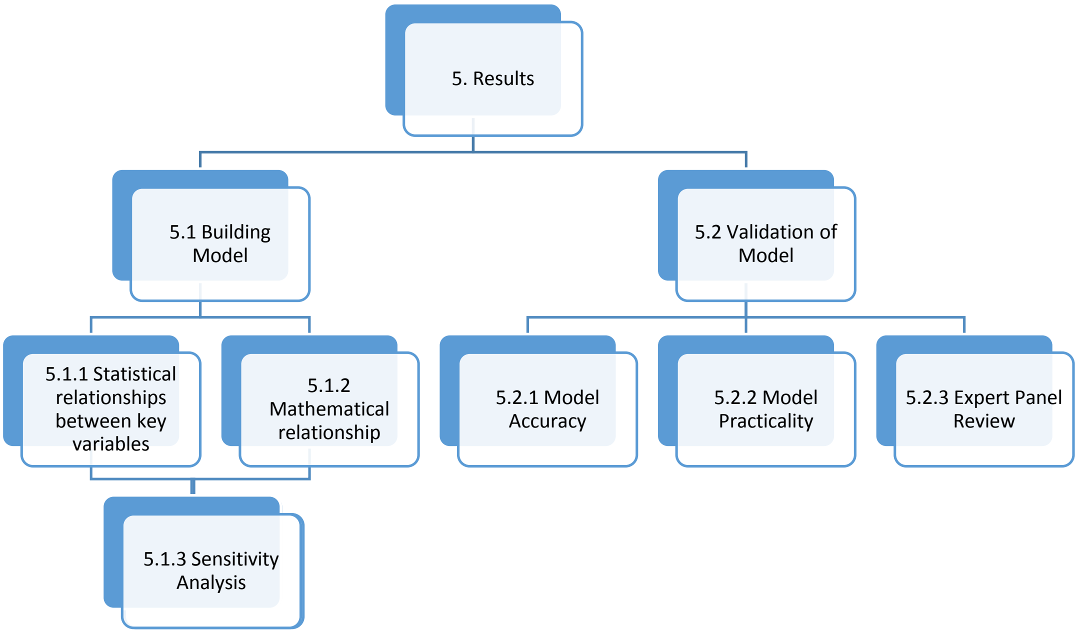


Figure C4: Results section outline

Section 5.1 details all the results pertinent to building of the cost estimating model. This is consistent with research objective (a) and (b), which stated that a relationship between the various variables and the final manufacturing cost will be established. Additionally, the parametric relationship between the chosen design parameter (mass of the component) and the final manufacturing cost was formulated. Upon establishing the parametric relation (5.1.2) and relationship between the input variables (5.1.1), a sensitivity analysis (5.1.3) was conducted. This was to ascertain the level of influence important foundry variables (material costs, labour costs, overheads) have on the final manufacturing cost, as predicted by the model.

Section 5.2 details the internal and external validation of the cost estimating model. The model accuracy was tested using three different products that are produced at the KDS Foundry, whose costs were already known. Additionally, a side by side comparison of the predictive model setup and the current model was done. For reliability, the developed cost estimating model was to be externally validated. An expert panel was used for validation purposes.

5.1 Building the Model

Figure C5 schematically represents the flow logic and where the various variables fit in, for section 5.1.

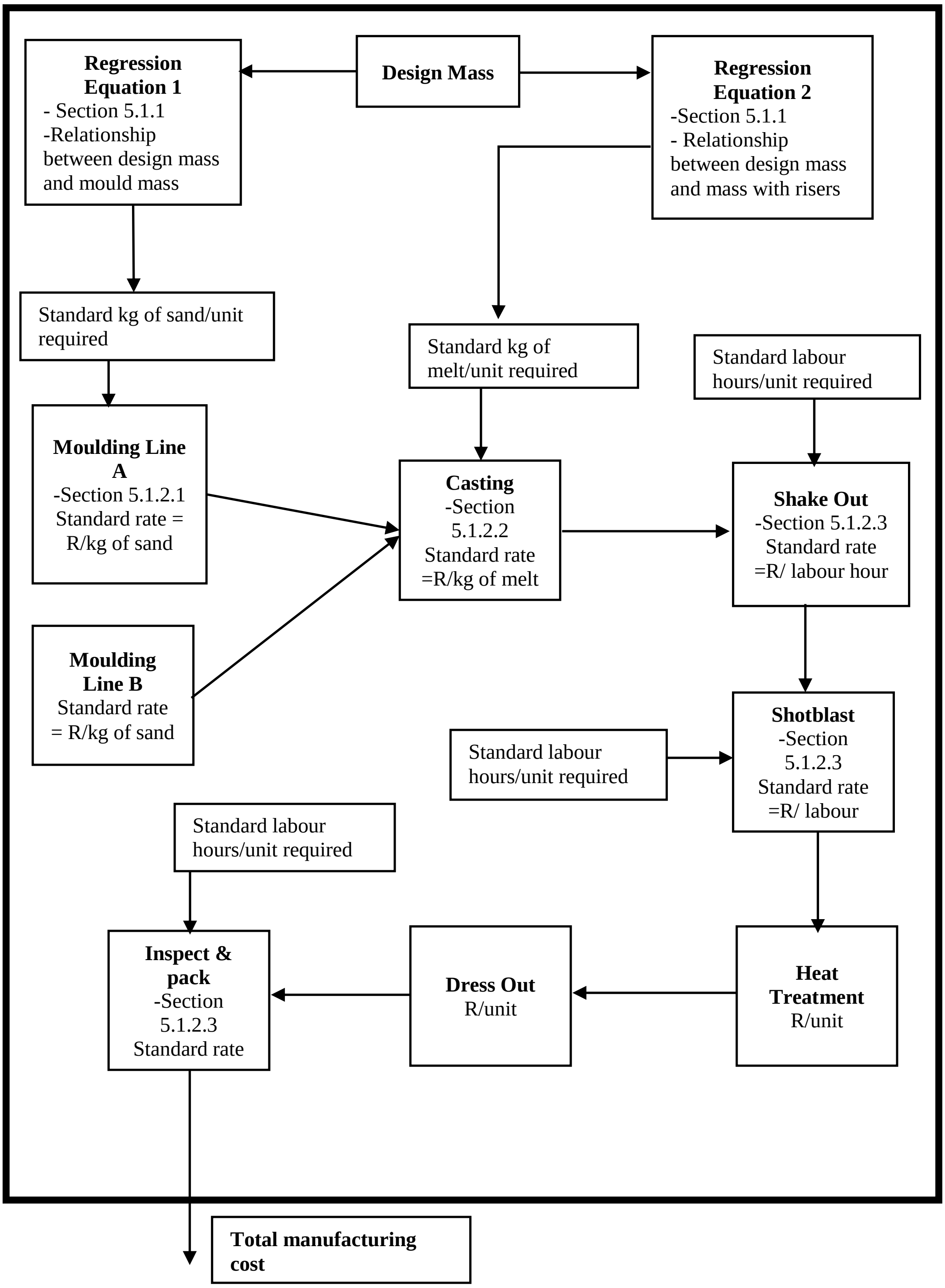


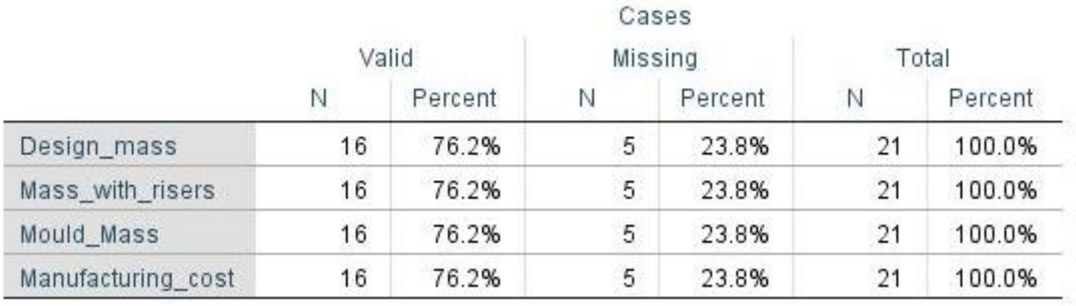
Figure C5: Outline of section 5.1 showing how the various variables link

5.1.1 Relationship between design parameters and final manufacturing cost

5.1.1.1 Normality

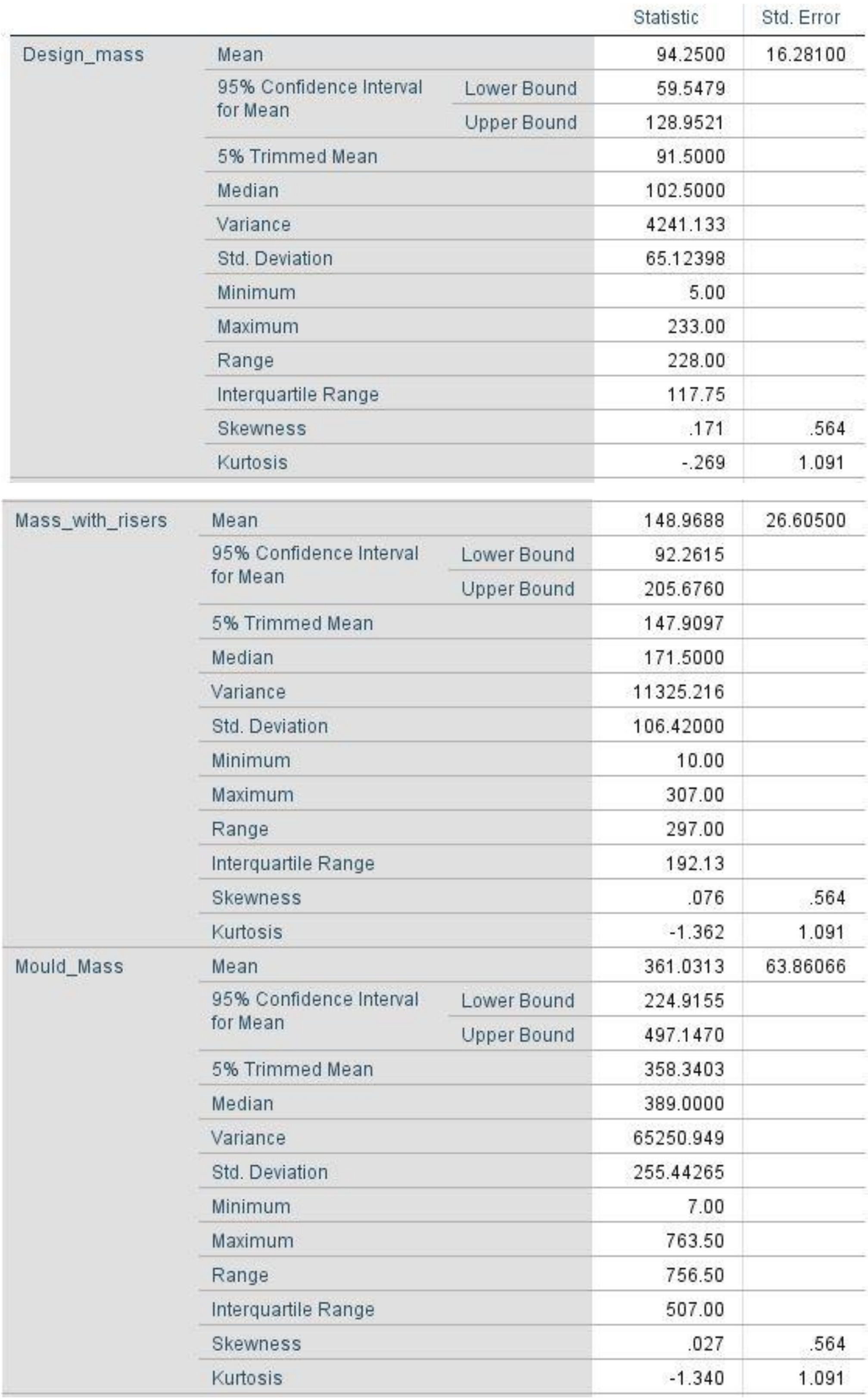
In an attempt to address research question (a), correlation between final manufacturing cost and input parameters was established. However, normality of the data involved had to be established first. 21 different components were used for the design mass, mass with risers, mould mass and manufacturing. Table C1 shows the number of valid data points (N) used to compute normality statistics. Table C2 shows the descriptive statistics for mass of the moulds, mass of the components with risers and the manufacturing cost. Lastly, the summary of the Shapiro-Wilk and Kolmogorov-Smirnov tests of normality statistics are shown in Table C3. The quantile-quantile (Q-Q) plots for design mass and manufacturing cost are shown in Figures C6-7.

Table C1: Summary of design mass, mass with risers, mould mass and manufacturing cost data

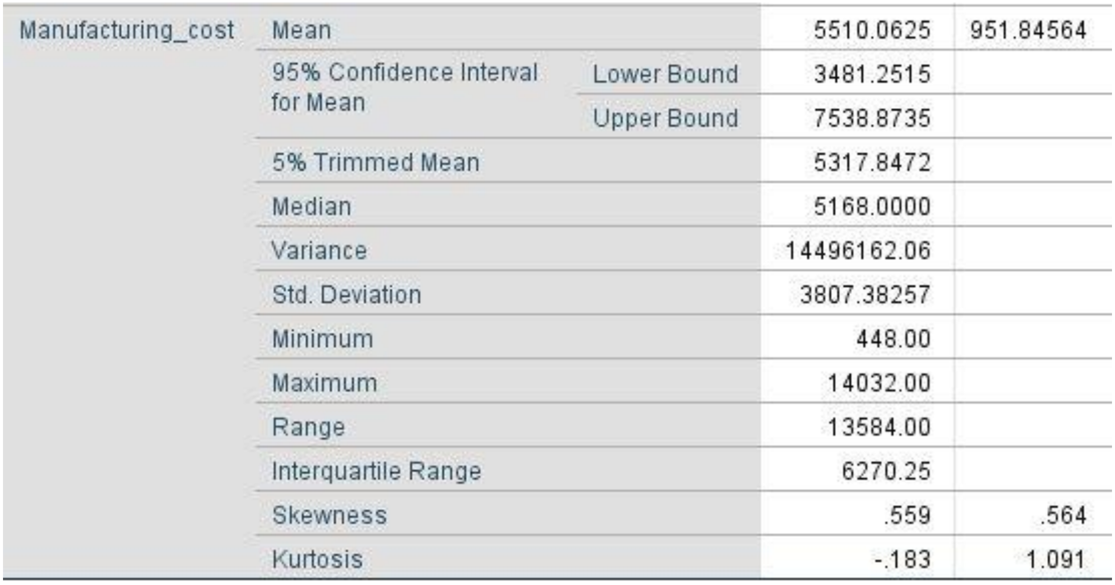


	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Design_mass	16	76.2%	5	23.8%	21	100.0%
Mass_with_risers	16	76.2%	5	23.8%	21	100.0%
Mould_Mass	16	76.2%	5	23.8%	21	100.0%
Manufacturing_cost	16	76.2%	5	23.8%	21	100.0%

Table C2: Descriptive statistics for design mass, mass of the moulds, mass of the components with risers and the manufacturing cost

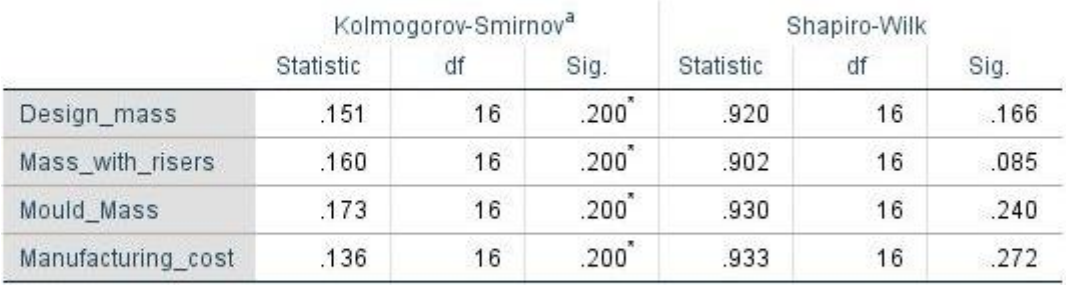


			Statistic	Std. Error
Design_mass	Mean		94.2500	16.28100
	95% Confidence Interval for Mean	Lower Bound	59.5479	
		Upper Bound	128.9521	
	5% Trimmed Mean		91.5000	
	Median		102.5000	
	Variance		4241.133	
	Std. Deviation		65.12398	
	Minimum		5.00	
	Maximum		233.00	
	Range		228.00	
	Interquartile Range		117.75	
	Skewness		.171	.564
	Kurtosis		-.269	1.091
Mass_with_risers	Mean		148.9688	26.60500
	95% Confidence Interval for Mean	Lower Bound	92.2615	
		Upper Bound	205.6760	
	5% Trimmed Mean		147.9097	
	Median		171.5000	
	Variance		11325.216	
	Std. Deviation		106.42000	
	Minimum		10.00	
	Maximum		307.00	
	Range		297.00	
	Interquartile Range		192.13	
	Skewness		.076	.564
	Kurtosis		-1.362	1.091
Mould_Mass	Mean		361.0313	63.86066
	95% Confidence Interval for Mean	Lower Bound	224.9155	
		Upper Bound	497.1470	
	5% Trimmed Mean		358.3403	
	Median		389.0000	
	Variance		65250.949	
	Std. Deviation		255.44265	
	Minimum		7.00	
	Maximum		763.50	
	Range		756.50	
	Interquartile Range		507.00	
	Skewness		.027	.564
	Kurtosis		-1.340	1.091



Manufacturing_cost	Mean		5510.0625	951.84564
	95% Confidence Interval for Mean	Lower Bound	3481.2515	
		Upper Bound	7538.8735	
	5% Trimmed Mean		5317.8472	
	Median		5168.0000	
	Variance		14496162.06	
	Std. Deviation		3807.38257	
	Minimum		448.00	
	Maximum		14032.00	
	Range		13584.00	
	Interquartile Range		6270.25	
	Skewness		.559	.564
	Kurtosis		-.183	1.091

Table C3: Summary of tests of normality



	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Design_mass	.151	16	.200*	.920	16	.166
Mass_with_risers	.160	16	.200*	.902	16	.085
Mould_Mass	.173	16	.200*	.930	16	.240
Manufacturing_cost	.136	16	.200*	.933	16	.272

Design_mass

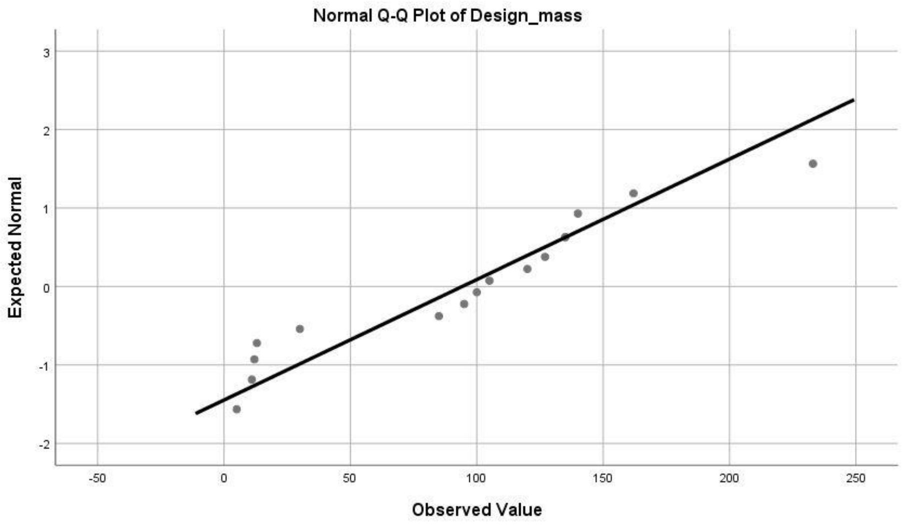


Figure C6: Q-Q plot of design mass

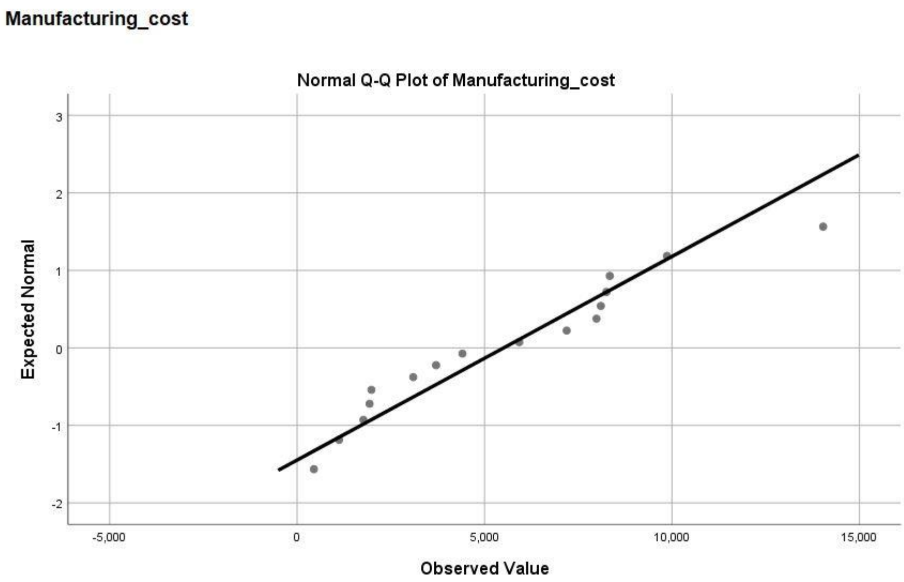


Figure C7: Q-Q plot of manufacturing cost

5.1.1.2 Correlation

Upon establishing normality of the data, the correlation between design and manufacturing cost was computed. A scatter plot of the data is shown in Figure C8. The Pearson correlation coefficient is shown in Table C4.

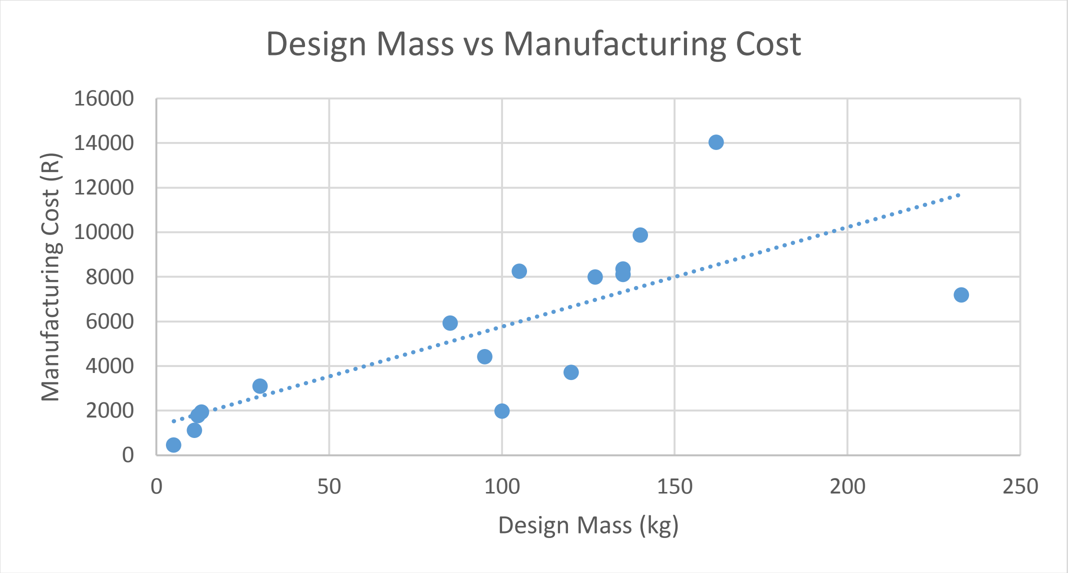
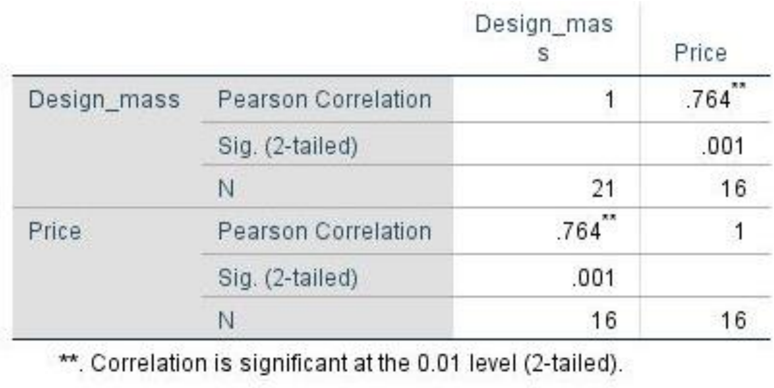


Figure C8: Manufacturing cost as a function of design mass

Table C4: Pearson correlation coeffiecient for design mass and manufacturing cost.



		Design_mass	Price
Design_mass	Pearson Correlation	1	.764**
	Sig. (2-tailed)		.001
	N	21	16
Price	Pearson Correlation	.764**	1
	Sig. (2-tailed)	.001	
	N	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

5.1.1.3 Parametric relationship between design mass and standard amount of sand required

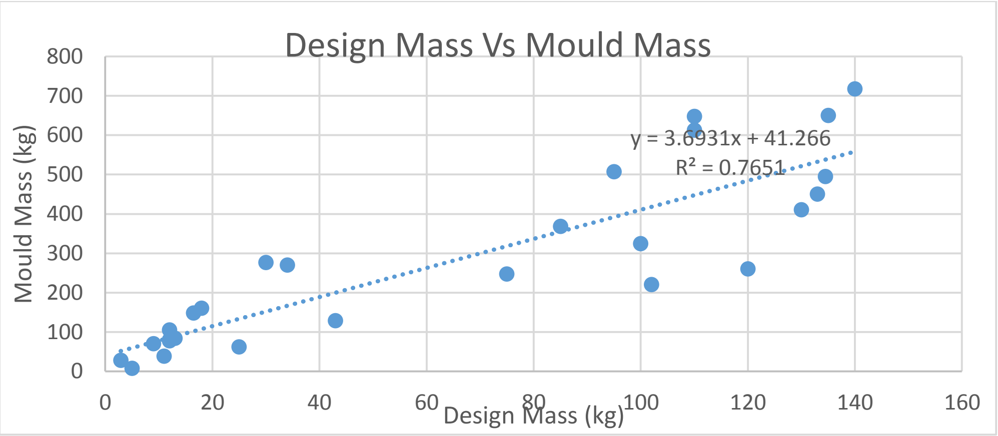


Figure C9: Mould mass as a function of design mass

D_m=3.6931x+41.266 ……………………………………………………………1

Where D_m = Standard mould mass of the component

x = design mass of the component

5.1.1.4 Parametric relationship between design mass and standard amount of melt required

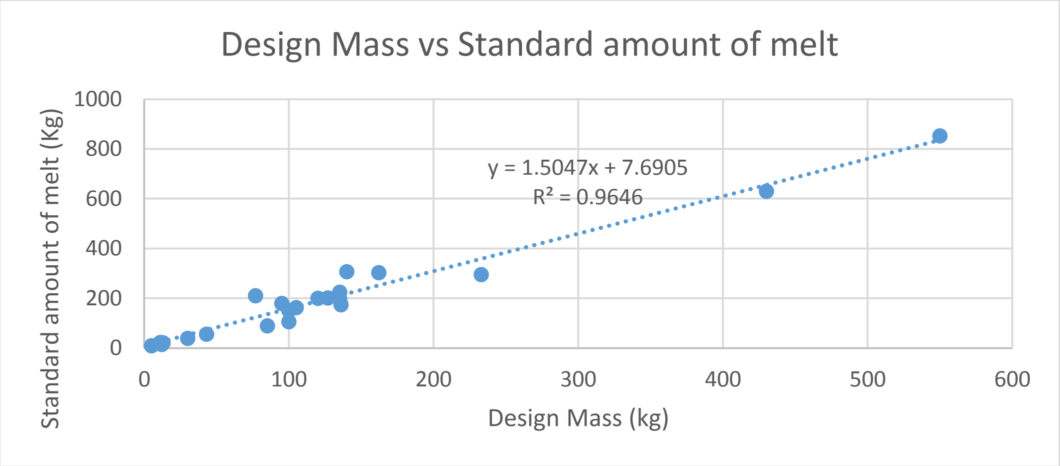


Figure C10: Mass with risers as a function of design mass

M_Z=1.5047X+7.6905 ……………………………………………………………2

Where M_z = Standard amount of melt required (kg)

X = design mass of the component (kg)

5.1.2 Conceptual Description

5.1.2.1 Moulding

Standard rate moulding line A (M_{RA}) $=\frac{Total\ Costs\ to\ run\ moulding\ line\ A\ (TCA)}{Planned\ annual\ activity\ on\ moulding\ line\ A(PAA)}$

TCA = Material Cost$_A$ + Labour Cost$_A$ + Overhead Costs$_A$

Material Cost$_A$ $=\sum Number\ of\ units\ of\ material\ i\ x\ unit\ price\ of\ material\ i$

where i = sand, resin, catalyst, zip strip paint, sleeves

Labour $\text{Cost}_A = \sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard Costs_A = f(energy, depreciation, support services, overtime and other operating expenses)

$PAA = \sum standard\ amount\ of\ sand\ used\ by\ product\ k1$,

where k1 = all the products for line A in the production plan for the period in review.

Standard rate moulding line B (M_{RB}) $= \frac{Total\ Costs\ to\ run\ moulding\ line\ B\ (TCB)}{Planned\ annual\ activity\ on\ moulding\ line\ B(PAB)}$

TCB = Material Cost_B + Labour Cost_B + Overhead Costs_B

Material $\text{Cost}_B = \sum Number\ of\ units\ of\ material\ l\ x\ unit\ price\ of\ material\ l$
where l = green sand, bentonite, water, starch, cores

Labour $\text{Cost}_B = \sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard Costs_B = f(energy, depreciation, support services, overtime and other operating expenses)

$PAB = \sum standard\ amount\ of\ sand\ used\ by\ product\ k2$, where k2 = all the products for line B in the production plan for the period in review.

5.1.2.2 Casting

Standard rate casting (C_{RA}) = $\frac{Total\ Costs\ to\ run\ casting\ section\ (TCC)}{Planned\ annual\ activity\ on\ casting\ section (PAC)}$

TCC = Material $Cost_C$ + Labour $Cost_C$ + Overhead $Costs_C$

Material $Cost_C$=$\sum Number\ of\ units\ of\ material\ z\ x\ unit\ price\ of\ material\ z$ where z = scrap metal, patching material, additives (ferromanganese, ferrosilicon)

Labour $Cost_C$ = $\sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard $Cost_C$ = f(energy, depreciation, support services, overtime and other operating expenses)

PAC = $\sum standard\ amount\ of\ melt\ used\ by\ product\ k1 + k2$,

5.1.2.3 Shake Out / Shotblast / Inspect & Pack (Finishing)

Standard rate casting (F_{RA}) = $\frac{Total\ Costs\ to\ run\ casting\ section\ (TCF)}{Planned\ annual\ activity\ at\ finishing\ section (PAF)}$

TCF = Material $Cost_F$ + Labour $Cost_F$ + Overhead $Costs_F$

Material $Cost_F$ =$\sum Number\ of\ units\ of\ material\ c\ x\ unit\ price\ of\ material\ c$ where c = scrap metal, patching material, additives (ferromanganese, ferrosilicon)

Labour $\text{Cost}_F = \sum Number\ of\ workers\ at\ j\ x\ j\ wage\ rate\ x\ j\ labour\ hours$,

where j = The remuneration band

Overheard Costs_F = f(energy, depreciation, support services, overtime and other operating expenses)

$PAF = \sum standard\ amount\ of\ labour\ hours\ used\ for\ products\ k1 + k2$,

5.1.2.4 Summary

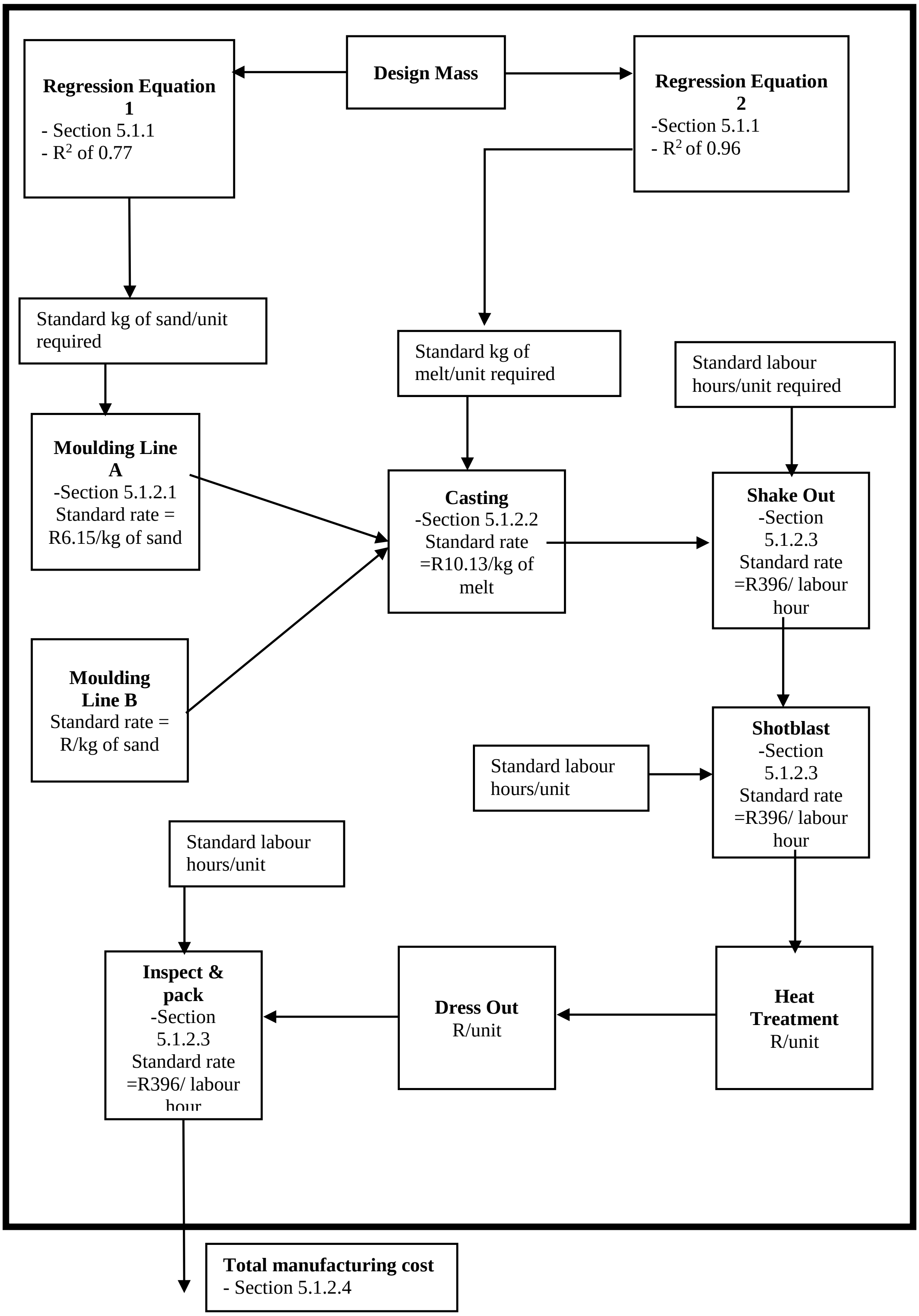


Figure C11: Summary of results

5.2 Model Accuracy

The developed model was tested using four products, of known design mass and manufacturing cost, that were not included in the model data. Table C5 shows the results, including the Mean Absolute Percentage Error (MAPE), a standardized measure of model accuracy. Table C6 shows a one-way analysis of variance (ANOVA) for manufacturing cost as predicted by the developed model and according to TE's KDS foundry model. Figure C12 graphically shows how the developed cost compares to the current TE KDS foundry model over a design mass range for products similar to products A-D.

Table C5: Accuracy of the developed model versus the current TE KDS foundry

Product	**Characteristics**	**Model Cost**	**Actual Cost**	**% Difference**	**MAPE (%)**
A	Design mass of 550kg	R24489	R28945	15.4%	9.23
B	Design mass of 53 kg	R5621	R5972	5.88%	
C	Design mass of 48 kg	R5431	R5596	2.95%	
D	Design Mass of 21 kg	R4406	R3989	-10.45%	

% Difference = $\frac{Actual\ Cost - Model\ Cost}{Actual\ cost}$x100

Mean Absolute Percentage Error = $\frac{\sum_{n=1}^{n}\left|\frac{Actual\ cost - Model\ cost}{Actual\ cost}\right|}{n}$x100 (Lewis, 1982)

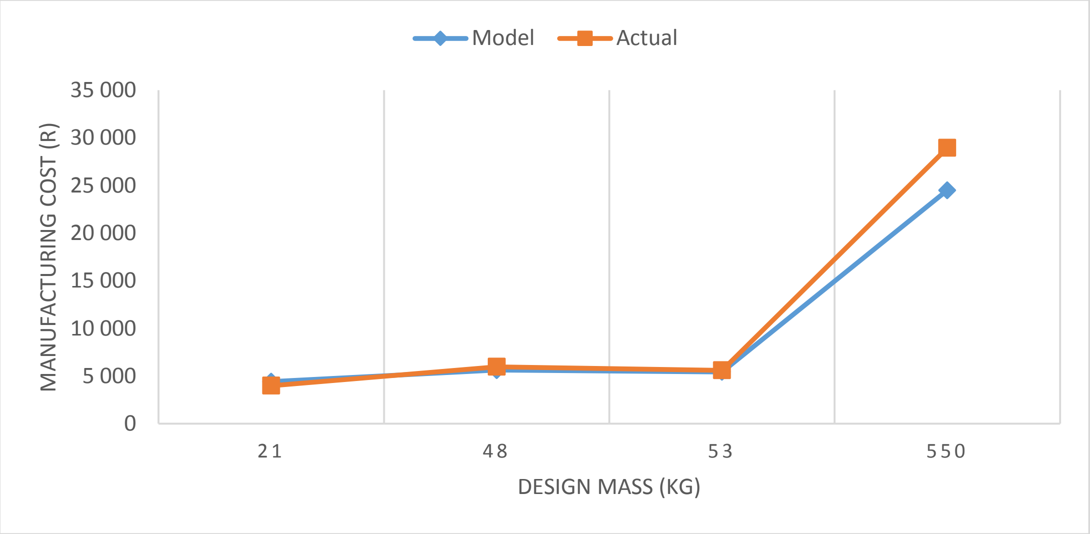


Figure C12: Developed model versus TE's KDS foundry model

Table C6: One-way ANOVA for manufacturing cost as predicted by the developed model and according to TE's KDS foundry model.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1905696.1	1	1905696.1	0.21068	0.6496	4.1829
Within Groups	262310007.3	29	9045172.667			

5.3 Model Practicality (Internal assessment)

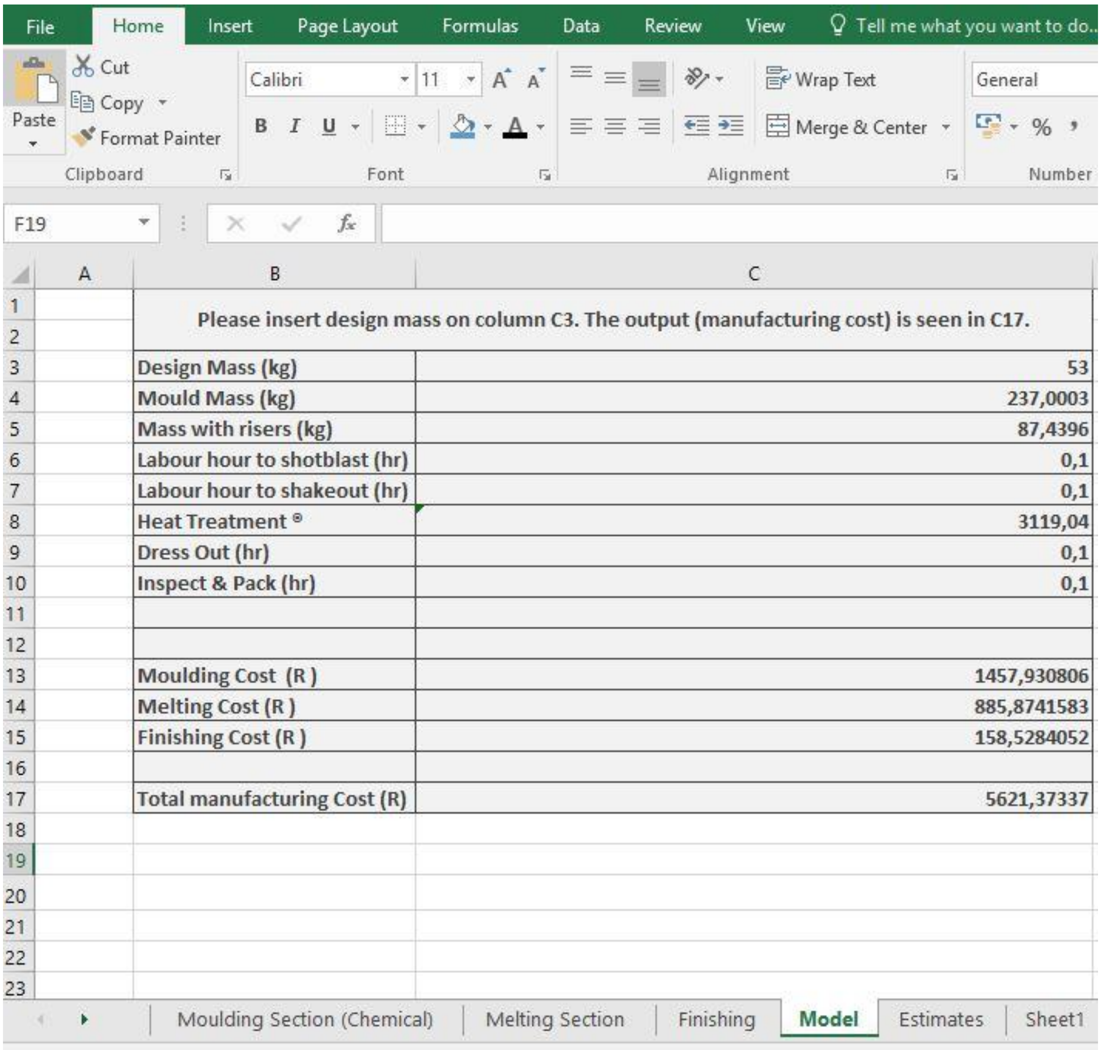
The results in this section are for the second aspect of the internal validation of the developed model. As already stated, three critical success factors of any model were used a criteria for the comparison of the developed model and the current model. This is consistent with the model development frameworks discussed in section 3.6 of the main report (Verification and Validation). Furthermore, the theme of research objective (c) is assessing the usability of the model in practise. Table C7 shows the comparison between the developed model and the current model.

Table C7: Model practicality versus current TE KDS foundry model

Characteristic	**Developed Model**	**Current Model**
Ease of use	(a) Model inputs and outputs all on Microsoft Excel (b) Any user competent in Microsoft packages can use and understand model (c) Requires little to no training (d) Can generate a preliminary quote immediately	- Cannot generate a quote -Model inputs and outputs are housed in different departments -Model inputs only accessible to users trained on the use of SAP systems
Scope	-Allows a customisable view of the entire foundry from a costing perspective in one place -Uses a design variable that has the biggest influence on foundry costs -Level of detail as a preliminary cost estimator is appropriate.	-Not intended to provide quotes
Flexibility	- Addition/removal of any aspect to the model can be easily made due to the simplified layout of the mathematical relationships. -Provides an immediate view of the effects of the various factors on manufacturing cost.	- Routing methodology employed is complex -May be victim of process latency -Prone to error because of multiple stakeholders involved.

5.4 Model Capabilities

The model interface on Microsoft Excel is shown in Figure C13.



Please insert design mass on column C3. The output (manufacturing cost) is seen in C17.

Design Mass (kg)	53
Mould Mass (kg)	237,0003
Mass with risers (kg)	87,4396
Labour hour to shotblast (hr)	0,1
Labour hour to shakeout (hr)	0,1
Heat Treatment ®	3119,04
Dress Out (hr)	0,1
Inspect & Pack (hr)	0,1
Moulding Cost (R)	1457,930806
Melting Cost (R)	885,8741583
Finishing Cost (R)	158,5284052
Total manufacturing Cost (R)	5621,37337

Figure C13: Model interface

5.4.1 Scenario 1

-Management wants to understand the relative effects of each cost element on the manufacturing cost. This is to aid strategic decision making i.e. which cost element to pay more attention to in order to control costs.

Table C8: Characteristics of product A used for the sensitivity analysis

Product V	
Design mass (kg)	250
Standard mould mass (kg)	965
Mass with risers (kg)	384

The percentage contribution of each element to the total manufacturing cost at TE’s KDS foundry is shown in Figure C14. Sensitivity of the manufacturing cost to total labour costs, total material costs and total overheads is shown in Figure C15.

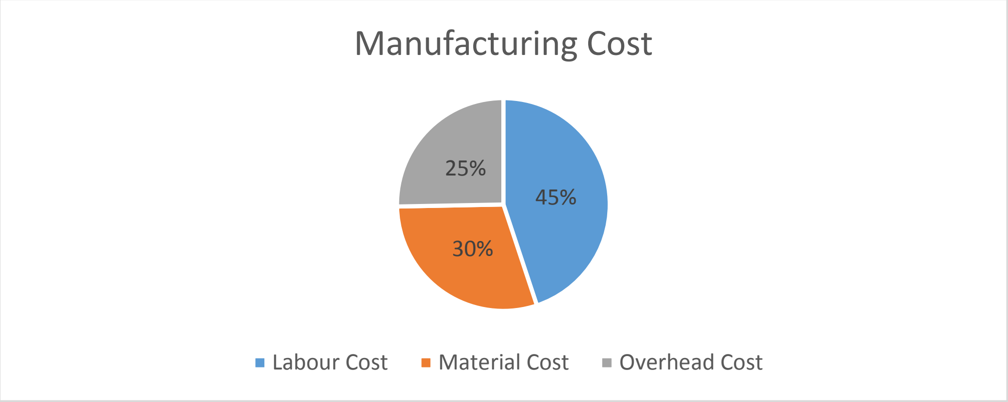


Figure C14: Percentage contribution of each element to the total manufacturing cost

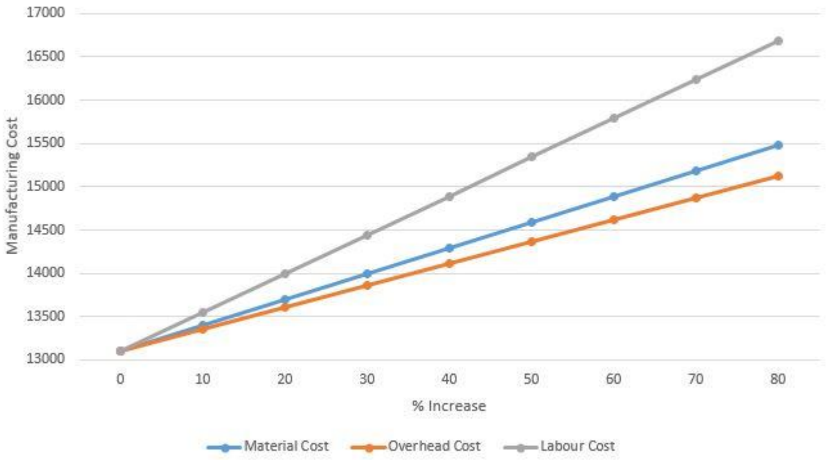


Figure C15: Sensitivity of the manufacturing cost to total labour costs, total material costs and total overheads

5.4.2 Scenario 2

-There is an inflationary increase across all costs. How are individual component manufacturing costs affected (Figure C16)?

Practically, how this information is useful:

(a) Internal budgeting.

(b) Allows the different customers (internal and external) to have a view of how and why the selling price might increase.

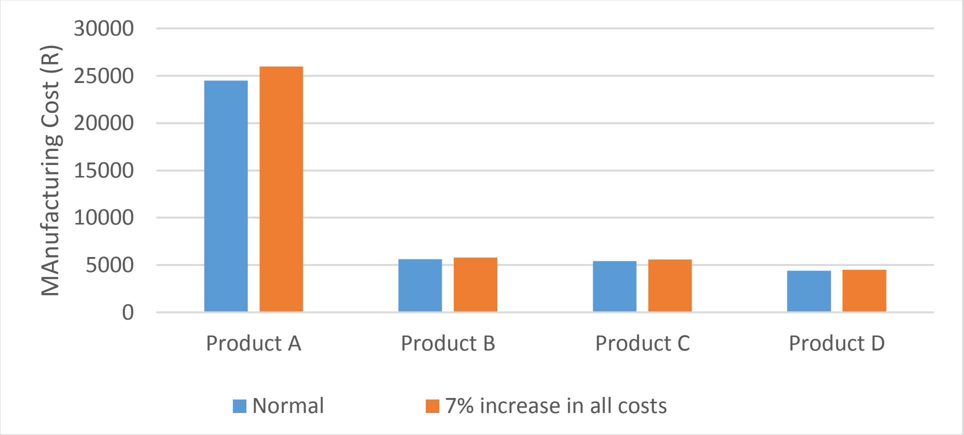


Figure C16: Effect of a 7% increase in material, labour and overhead costs on manufacturing cost

5.4.3 Scenario 3

- A product mix decision has to be made. A client wants to know the range of prices for certain order numbers. How does activity affect individual component prices (Figure C17)?

Practically, how this information is useful:

(a) Internal budgeting (for example, an important, strategic customer is only willing to buy the product at a certain price, TE's KDS foundry business can readily ascertain the level of activity needed to get to the target cost) .

(b) Production planning

(c) Allows the different customers (internal and external) the options to vary order numbers with an immediate view of the effect on the price they will pay.

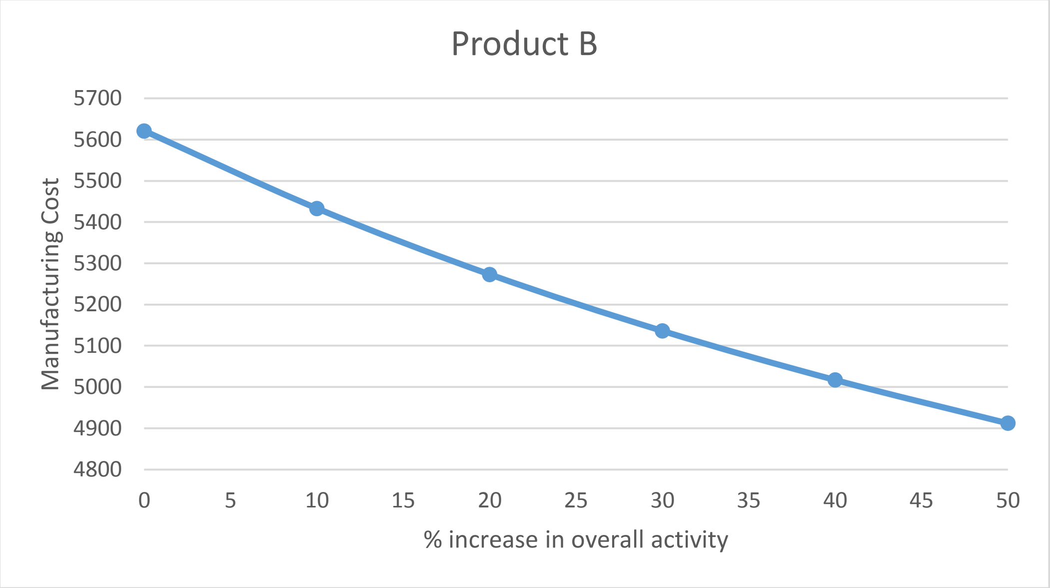


Figure C17: Effect of increasing activity on component prices

Questionnaire

Scope

1. Do you believe the model can generate a reliable preliminary quote?

Response:

2. What is your view on the level of detail of the model as a preliminary cost estimator?

Response:

3. What is your view on the use of design mass as the model input? Do you believe there is another variable that could have been used?

Response:

4. Do you believe there are any model shortcomings in terms of scope? Please elaborate.

Response:

Accuracy

5. What are your views on the model accuracy? Do you believe it is sufficient for competitive bidding?

Response:

6. Do you believe the model accuracy is sufficient for internal sales/production budgeting?

Response:

Consistency

7. Do you believe the model applied standard costing principles correctly in the foundry context?

Response:

8. In your view, are the model outputs consistent with the model inputs?

Response:

9. What can be done to increase/improve the consistency (input-output, mathematical logic, etc) of the model?

Response:

Flexibility

10. Do you believe the model can be easily tailored for use in any foundry environment?

Response:

11. In your view, does the model allow the user to make informed decisions around the effect of material usage on product cost?

Response:

12. Do you believe the model adequately shows the effect of labour-related decisions (e.g. the number of people to have at each section) on product cost?

Response:

13. In your opinion, can the model be easily modified if the need arose?

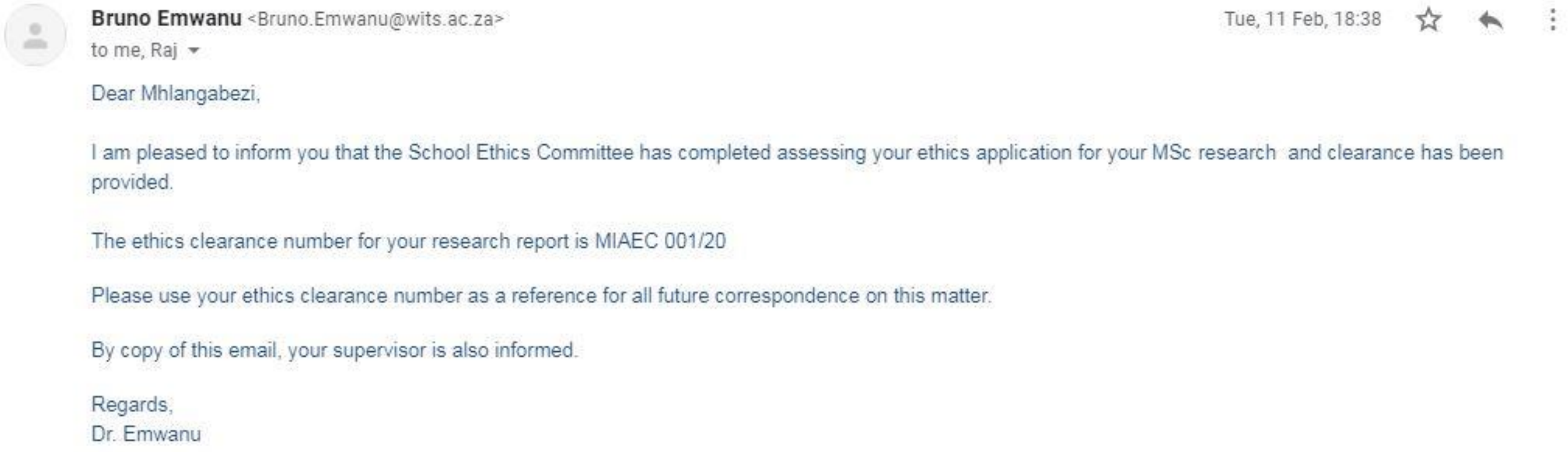
Response:

Ease of Use

14. What do you think of the use of Microsoft Excel as the package software for the model? Do you think it is appropriate for what the model is trying to do? **Response:**
15. Do you think the model output is easy enough to understand for someone without technical background? **Response:**

Appendix D

Figure D1 shows the ethics clearance provided by the University of the Witwatersrand for this research work.



Bruno Emwanu <Bruno.Emwanu@wits.ac.za>
to me, Raj

Tue, 11 Feb, 18:38

Dear Mhlangabezi,

I am pleased to inform you that the School Ethics Committee has completed assessing your ethics application for your MSc research and clearance has been provided.

The ethics clearance number for your research report is MIAEC 001/20

Please use your ethics clearance number as a reference for all future correspondence on this matter.

By copy of this email, your supervisor is also informed.

Regards,
Dr. Emwanu

Figure D1: Ethics clearance provided by the University of the Witwatersrand