CHAPTER 4

Comment [Editor1]: Please be consistent wit spellings especially in the graphs and charts and tables: governor, optimised, unfilling, broken gate variant, organisation, etc. I have changed them in text but these need to be made uniform in the diagrams too.

CASE IMPLEMENTATIONS

4.1 INTRODUCTION

The Six Sigma approach to quality and process improvement has been used predominantly by manufacturing organisations since its ~~birth~~inception. Presently, many service organisations are also utilising th~~e popularity of Six Sigma~~is methodology~~. The reason is its~~ primarily because of its customer~~-~~-driven~~-methodology~~ basis. Manufacturing organisations build their ~~six~~ Six ~~sigma~~ Sigma efforts on an established ~~base~~ foundation of measurable processes and ~~established~~ set quality management programmes. In service organisations, the S~~s~~ix S~~s~~igma programme is introduced to establish and map the key processes that are critical to customer satisfaction. There are numerous manufacturing companies applying the ~~six~~ Six ~~sigma~~ Sigma to their ~~various~~ diverse non-manufacturing processes, such as human resources, payroll, accounting, customer relations, supply chain management, safety and hazard engineering,~~;~~ ~~and~~ organi~~z~~sation change and innovation because many of the methods used in ~~six~~ Six ~~sigma~~ Sigma are applicable to both manufacturing and non-manufacturing industries or services.

All these methods are practiced to minimise not just process variation in manufacturing but also ~~and to minimise~~ the variation of expectations to perception in service organisations. ~~Differences~~ The differences between goods and services lead to service firms and goods-producing firms having different success factors for Six Sigma. The extent to which Six Sigma~~six sigma~~ fulfils the quality gaps, leads to the improvement of the product or service quality. This is ~~dependant~~ dependent ~~of~~ on the apparent challenges posed by the very nature and core premises of the industry. Hence, it is necessary that ~~required to verify~~ the performance of the TPE model in both manufacturing and service sectors be verified before ~~taking~~ a decision regarding its suitability is taken. Two case implementations were conducted to assess the performance of the TPE model, one in the manufacturing industry and ~~another~~ the other in the service industry.

In the manufacturing industry, this TPE model ~~is~~ was implemented to minimise the defect probability of the die casting operation with the core objective of improving the productivity. In the service industry, it was used to ~~minimising~~ minimise the gap ~~of~~ between customer expectations and perceptions within an automotive service operation ~~is undertaken through this TPE model~~. The details of the studies are presented in the subsequent sections of this chapter.

4.2 CASE IMPLEMENTATION - 1

4.2.1 About the company

A south India~~n~~-based automobile horn~~s~~ manufacturing ~~industry~~ company was considered suitable for the application of this ~~for applying this~~ TPE model. The company ~~is~~ undertook~~engaged with~~ casting of alumini~~in~~um components to cater to the needs of various industrial sectors. The apprehensions of the company vis a vis ~~industry due to~~ the rejections of cast products was tackled ~~using~~ through use of the TPE model. A ~~Variety~~ variety of casting techniques were used ~~being used~~ by the ~~industry~~ company including~~es~~ aluminium pressure casting of automotive components for their domestic as well as international clientele. The production process ~~follows~~ followed a ~~batch~~ batch-type production with different lot sizes ~~of~~ for the different components. The product range for instance ~~includes~~ included governor housing for fuel injection pumps, heat-sink and field moulds for alternators, oil pumps and pump body covers, fixing brackets for car starters, and pivot housing for wiper motors. The company's present production facility ~~is~~ was expanded to make castings for the textile and medical ~~filed~~ fields ~~like~~ and created ring holders for ring frames, iron sole plates for electric irons, and clam shells for surgical interconnect systems.

The major domestic clients of the company ~~are~~ were Lakshmi Machine Works (LMW), Lucus- India, MICO, Philips India, Pricol, TVS Motor Company Limited and Wipro Infotech; while the international clients consisted of TRICO, UK and Zinser, Germany ~~are~~ all of who accounted for ~~supplied by~~ 20% of the overall production.

Comment [Editor2]: Do you mean to say 20% of the sales were for these international clients?

The present production capacity of the company ~~is~~ was estimated at 920 tonnes per annum with state-of-art techniques in the present production set-up. ~~-~~The production schedule was prepared against the client order. The company ~~suffers~~ suffered ~~with~~ because of a high rate of defectives in each batch and was penalised ~~forced to penalize~~ by ~~their~~ clients for not meeting the order delivery commitments. The company ~~has~~ had its well equipped quality control department to assess the quality of the castings in terms of dimensional variability, various casting defects and handling damages. However, they were looking for a ~~systemized~~ systemised methodology for ~~optimizing~~ optimising the casting process to reduce~~minimize~~ the occurrence of loss of productivity and the ~~to reduce the~~ costs incurred in rejections and in payment of ~~penalty~~ penalties to the ~~delayed~~ concerned customers.

4.2.2 About the Process

The various production processes ~~of~~ surrounding components include die casting, sand casting, permanent mould casting~~,~~ and investment casting. The most widely ~~practicing~~ practiced casting method is die casting because of its inherent properties like a high volume of production at a low cost, high~~ly~~ ~~precise~~precision rates, and excellent surface finish which eliminate~~s~~ post machining requirements. However, a ~~Among the industries,~~ high cost of die and porosity in the cast ~~ed~~ product are the issues that plague this industry. ~~mostly discussed problems in the die casting operations.~~ The vital components of a typical aluminium pressure die casting process are shown in ~~figure~~ Figure 4.1.

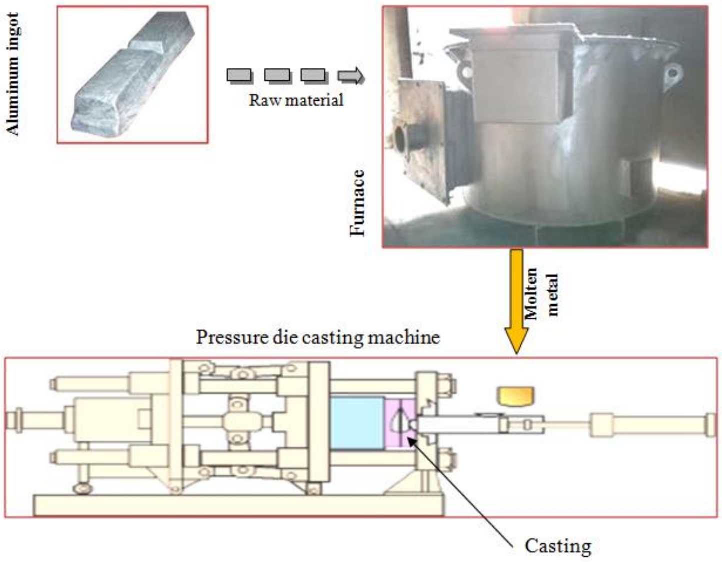

Figure 4.1 Aluminium die casting process

The die casting process involves the use of a furnace, raw material, die casting machine~~,~~ and die. The metal is melted in the furnace and then, injected into the dies in the die casting machine. After the molten metal is injected into the dies, it rapidly cools and solidifies to take its final form~~into the final part~~, called the casting. The entire die casting process is pasteurized in ~~figure~~ Figure 4.2.

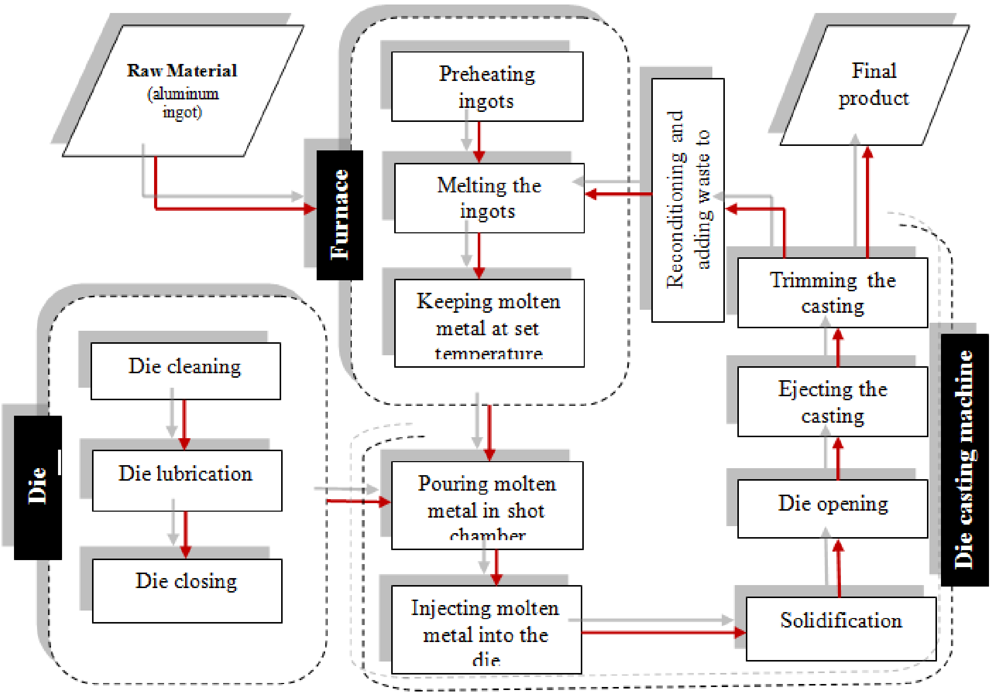

Figure 4.2 Die casting process flow chart

The process cycle for die casting consists of five main stages, which are explained below. The total cycle time is very short, typically between 2 seconds and 1 minute.

4.2.2.1 Stage 1 - Clamping

Preparation and clamping of the two halves of the die ~~is~~ constitutes the first process. Each die half is first cleaned from the previous injection and then, lubricated to facilitate the ejection of the next part. The lubrication time increases with the size of the ~~part size~~component, as well as the number of cavities and side-cores. Lubrication may ~~not~~ be required after ~~each cycle, but after~~ 2 or 3 cycles, depending upon the material. ~~After~~ Post lubrication, the two die halves, ~~which are~~ attached inside the die casting machine, are closed and securely clamped ~~together~~. Sufficient force must be applied to the die to keep it securely closed while the metal is injected. The time required to close and clamp the die is dependent upon the machine. ~~l~~Larger machines

Comment [Editor3]: Please check for clarity.

(those with greater clamping forces) ~~will~~ require more time~~.~~ and this can be estimated ~~This time can be estimated~~ from the dry cycle time of the machine.

4.2.2.2 Stage 2 – Injection

Comment [Editor4]: Please make heading sty consistent throughout the documents. If you are using the em dash as the separator for the fourth level headings, use them consistently.

The molten metal, which is maintained at a set temperature in the furnace, is ~~next~~ subsequently transferred into a chamber where it is injected at high pressures into the die. Typical injection pressures range~~s~~ from 1,000 to 20,000 psi. This pressure holds the molten metal in the dies during solidification. The amount of metal that is injected into the die is referred to as the shot. The injection time is the time required for the molten metal to fill all of the channels and cavities in the die. This time is ~~very short,~~ short, typically less than 0.1 seconds, in order to prevent early solidification of any one part of the metal. ~~The p~~Proper injection time can be determined by the thermodynamic properties of the material, as well as the wall thickness of the casting.

4.2.2.3 Stage 3 - Cooling

The molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity. The final shape of the casting is formed ~~When~~ when the entire cavity is filled and the molten metal solidifies~~, the final shape of the casting is formed~~. The die can~~-~~not be opened until the cooling time has elapsed and the casting is solidified. The cooling time can be estimated from several thermodynamic properties of the metal, the maximum wall thickness of the casting, and the complexity of the die. A greater wall thickness will require a longer cooling time. The geometric complexity of the die also requires a longer cooling time because the additional resistance to the flow of heat.

Comment [Editor5]: Repetitive intent

4.2.2.4 Stage 4 - Ejection

The die halves are opened and an ejection mechanism pushes the casting out of the die cavity after the predetermined cooling time has elapsed. The time to open the die can be estimated from the dry cycle time of the machine and the ejection time is determined by the size of the ~~casting's~~ casting's envelope and should include time for the casting to fall free of the die. The ejection mechanism must apply some force to eject the part ~~because~~ since the part may shrink and adhere to the die during cooling ~~the part shrinks and adheres to the die~~. Once the casting is ejected, the die can be clamped shut for the next injection.

4.2.2.5 Stage 5 – Trimming

Comment [Editor6]: Please make heading sty consistent

The material in the die channel solidifies during cooling along with the casting. This excess material, along with any flash that has occurred, must be trimmed from the casting either manually via cutting or sawing, or through the ~~using~~ use of a trimming press. The time required to trim the excess material can be estimated from the size of the ~~casting's~~ casting's envelope. The scrap material that results from this trimming is either discarded or can be reused in the die casting process. Recycled material may need to be reconditioned to the proper chemical composition before it can be combined with non~~-~~-recycled metal and reused in the die casting process.

4.2.3 Scope of the study

The company being studied ~~is~~ manufactur~~ing~~es 58 ~~variety~~ varieties of products of which invariably ~~the company faces the problem of~~ there is a higher defective percentage. Problems persisting consist of ~~Besides~~ the loss in productivity~~,~~ and customer orders ~~were also~~ not being met ~~in due~~on time. To keep the company on track, the production department ~~has~~ used a strategy of producing more components than the ordered levels to compensate for the rejections. This exercise ~~has created~~ increased~~increase~~ the ~~in~~ cycle times for each component and thereby, a loss in ROI. The nature of casting defects ~~frequently noted in the industry are~~ may be of two types~~;~~ : one, the defect ~~can be~~that is noticed immediately after casting the molten metal. Such defects ~~are~~ may be un-filling, gate broken; damage, weld, crack, un-wash, rib broken, and metal peel off. The second ~~categories~~ category of defects ~~are~~ is not noticeable until the post machining processes are completed. Those defects are porosity, blow holes etc. ~~Later~~ Eventually, these defects cause~~s~~ ~~more~~ greater losses than the former category in terms of money since ~~it~~ they involve~~s~~ post machining processes. Improving the organisational productivity is the foremost objective for the research model being proposed in this situation. A cross functional team ~~has~~ was therefore, ~~been~~ formed by the ~~head~~ Head of the ~~quality~~ Quality ~~assurance~~ Assurance department ~~from~~ in the company. The organisation's objective was taken as the driver for this study and iterated using the QFD concept to coincide with ~~nfine with~~ what needed ~~needs to be~~ modifi~~ed~~cation / ~~improved~~improvement / ~~reduced~~ reduction to achieve the goal. Then, the selected improvement project ~~is~~ was analysed and improved in the subsequent stages of the research model. -The flow chart deployed in ~~figure~~ Figure 4.3 depicts a summary of the ~~summarises the step~~ step-~~by~~ by-step activities ~~done in this study~~undertaken.

4.2.4 TPE Stage 1: QFD process

The QFD technique explained in chapter () / section () was ~~indented~~ intended to identify the possible ways to accomplish the objective through the analysis of the HoQ matrix. The development of the customer information table (horizontal matrix) was simplified ~~made easy~~ with a single objective as the requirement. In this study, the CCP analysis was not performed since the requirement considered in the matrix ~~is~~ was of a unique nature. That is, it would not fetch any useful information because each ~~organization~~ organisation could have ~~may have~~ different objectives to run their business. A cause and effect (C&E) analysis was carried out to sort ~~out~~ the strategies to find out which would influence the objective. In ~~figure~~ Figure 4.4, the strategies chosen from the C&E analysis were cross referred with the objective in the HoQ matrix. In the HoQ matrix, the strategies S_1 and S_4 were found equally important to fulfil~~l~~ the ~~needed~~ necessary objective. As a ~~thump~~ thumb rule, the strategy S_1 (~~minimizing~~ minimising the defective fraction) was chosen in order to continue ~~further~~.

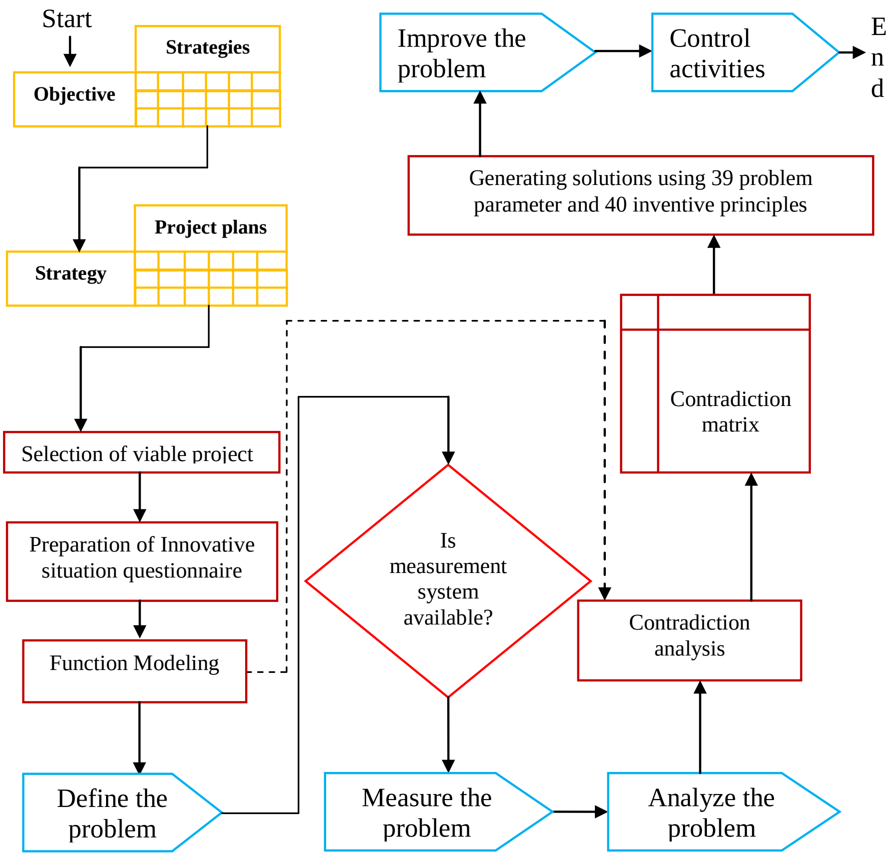

Figure 4.3 TPE model in case implementation 1

4.2.4.1 Developing project plans to ~~realize~~ realise the strategy S_1

The previous history of records showed that the rate of rejection ~~was~~ ranged from 0.72% to 14.53% of production due to various defects, but the company target was 1.5%. Nearly 25 casting defects were reported in their record as reasons ~~for~~ explaining the defective products.

		S_4	81	27	27	
		S_3	27	9		27
		S_2	27		9	27
		S_1		27	27	81
			S_1	S_2	S_3	S_4
	Importance	*Weight*	Minimizing defective fraction	Improving process quality	Improving employee productivity	Minimizing COPQ
Objective	d_i	W_i	*Strategies*			
Improving productivity	9	1	9	3	3	9
	Weight	W_j	0.375	0.125	0.125	0.375
		Priority	*I*	*II*	*II*	*I*

Figure 4.4 QFD matrix – Objective Vs Strategies

With the information in hand, ~~front of team members,~~ the following project plans ~~have~~ were formulated to mitigate the occurrence of defects in casting~~.~~:

1. Process parameter ~~optimization~~optimisation
2. Die design analysis
3. Component design evaluation
4. Equipment capability analysis

Each project was explained in details ~~elaborated~~ to the top management as shown ~~given~~ below~~;~~:

4.2.4.2 Process parameter ~~optimization~~optimisation

The die casting process handles hot metal~~,~~. ~~the~~ The metal temperature is the first and foremost important process parameter which has greater influence on defect formation like un-filling, and flash like the others. Other operational parameters are injection pressure (first and second stages), die coat~~,~~ and metal mixing ratio. ~~In~~ For the case company, the aluminium alloy is the ~~principle~~ principal material used for most

Comment [Editor7]: Please check for hyphenation and make this consistent of the components at different proportions. ~~Variation~~ A variation in temperature of the hot molten metal has greater affinity to cause defects in the final product. Low temperatures result~~s~~ in improper solidifications, where~~-~~as high temperatures cause~~s~~ excess casting hardness, ~~leads~~ leading to defects like cracks. Next, an equally important parameter is the injection pressure, which refers the pressure applied on molten metal while pushing it into die cavity from shot chamber. Low pressure may result in a partial solidification of casting due to delay in cavity filling. Excess injection pressure may however, damage the gate or increase the gate velocity, which contributes to the casting defect like porosity. ~~Next~~ The next parameter of interest is the die coat, which is the medium used to lubricate the hot die for the purpose of easy ejection after the solidification process. With respect to the die coat, the attention is needs in frequency of die coating and die coat material used. Last but not the least, the metal mixing ratio is one ~~an~~other important process parameter, which might contribute to gas inclusions in the casting due to contamination~~s in~~ of the recycled materials. The ratio in which the scrap or trimmed materials are mixed with the new raw material in furnace is ~~the~~ however, of real interest.

Comment [Editor8]: Do you mean to say 'attention is paid to the frequency of die coating rather than the material used'?

The scope of this project proposal is to estimate the optimum setting of the chosen parameters to obtain high quality casting with reduced or eliminated defects.

4.2.4.3 Die design analysis

Dies are the custom ~~tooling~~ tools used in this process ~~in which~~where the molten metal is injected to form a casting. The fundamental arrangement of a die is illustrated in ~~figure~~ Figure 4.5. It is composed of two halves~~ -~~: the cover die, which is mounted onto a stationary platen, and the ejector die, which is mounted onto a movable platen. This design allows the die to open and close along its parting line. Once closed, the two die halves form an internal part cavity. The cover die allows the molten metal to flow from the injection system, through an opening, and into the part cavity. The flow of molten metal into the part cavity requires several channels like venting holes, sprue, runners, overflow-well and gates. Apart from ~~this~~ these hot metal channels, there are also cooling channels ~~are also~~ designed in the dies to allow coolant medium water or oil to flow through the die~~,~~. These are located adjacent to the cavity~~,~~ and remove heat from the die. Apart from these structural design parameters, there are other design issues like the draft angle, and undercuts to ~~assure~~ ensure easy flow of molten metal and accommodation of complex casting features.

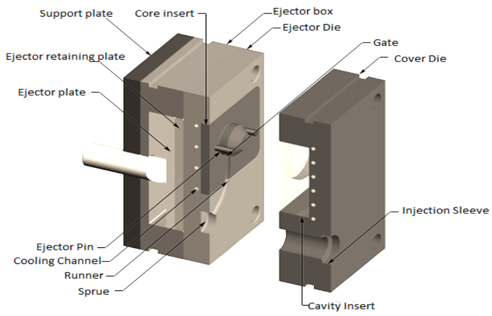

Figure 4.5 Die Structure and design features

~~Selection~~ Selecting the material is another aspect of designing the dies~~,~~. ~~it~~ Dies can be fabricated out of many different types of metals. High grade tool steel is the most common and is typically used for 100-150,000 cycles. However, steels with low carbon content are more resistant to cracking and can be used for 1,000,000 cycles. Other common materials for dies include chromium, molybdenum, nickel alloys, tungsten~~,~~ and vanadium.

In a nutshell, the essential design features of dies are:

- Hot metal channel; sprue, runners, gates and overflow well
- Air ~~channel~~channel, ~~;~~ venting holes
- Cooling channels~~;~~, coolant paths
- Structural parameters~~;~~, draft angle and undercut and
- Die material.

Comment [Editor9]: Please check for hyphenation and make this consistent

A project may be formulated to evaluate the influence of stated die design features on defect occurrences through the Six Sigma~~six sigma~~ and the TRIZ processes.

4.2.4.4 Component design evaluation

The production of defect free components in the pressure die casting process solely depends on product design and development factors like die design, operational parameters and materials used. But the probability of defect occurrence is high ~~depends~~ depending on the design complexity of the product. For instance to cast components with high wall thickness, the injection pressure should be more than enough to fill the deep cavity. But it has the adverse effect on ~~the~~ casting quality like gas bubble inclusion and porosity. Likewise, external ~~rib~~ rib-like shapes create extra designs on the die to accommodate external slides, which not only increase the cost of die but also the operational complexity. Some of design flaws resulting casting defects are illustrated in ~~figure~~ Figure 4.6.

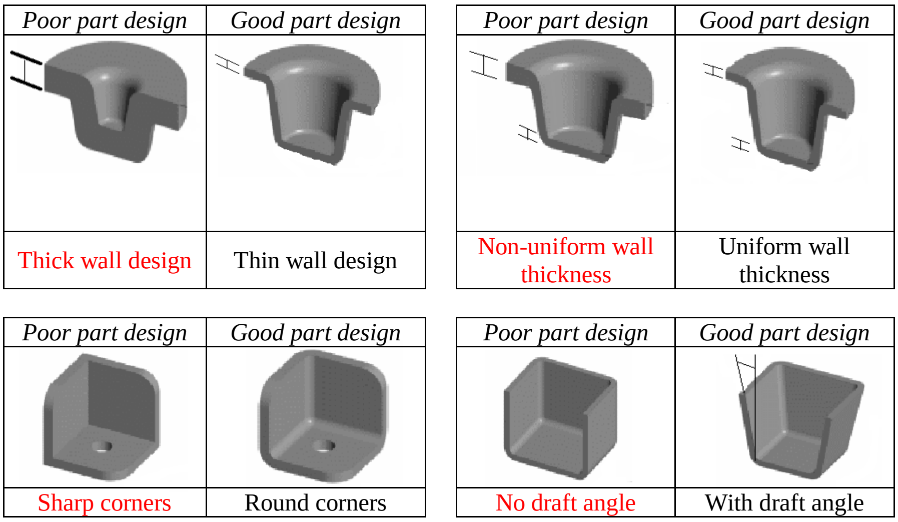

Figure 4.6 Design flaws causing casting defect

The project may be used to evaluate the design of die for assessing the proneness of the cavity design ~~for the~~to casting defects.

4.2.4.5 Equipment capability analysis

This involves an evaluation of the machine's capability towards producing defect free castings. In ~~Subject~~ the subject ~~Company~~company, the die casting process uses cold chamber high pressure die casting machines shown in ~~figure~~ Figure 4.7 for producing aluminium castings. The existing production setup includes 9 such type of machines with varying capacity from 25ton to 500 ton of clamping force. The main parts of the machine are: control box panel, fixed plate, moving plate, back plate, accumulator, injection cylinder, injection rod, ejector system, oil tank, die regulating valve, pressure regulating valve. The injection pressure can be varied ~~through~~ using the pressure regulating valve. Control~~is~~s are provided on the machines ~~for~~ to regulate the die opening time, closing time and the ejector time for the ejection of the cast product.

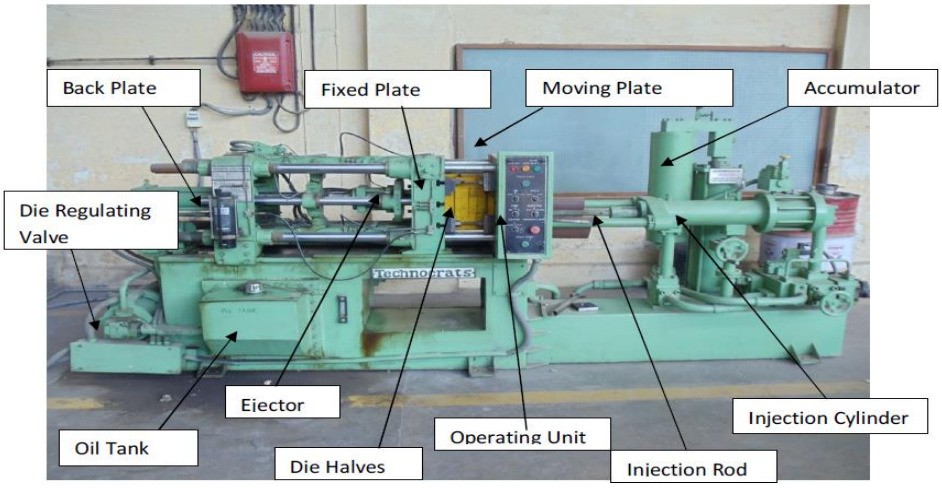

Figure 4.7 Cold chamber high pressure dir casting machine

The machine can be operated in manual as well as in the automatic modes. Sample specifications of 80 ton cold chamber die casting machines ~~is~~ are given in ~~table~~ Table 4.1. In the cold chamber type of high pressure die casting machine, the molten metal is transferred into the cold chamber cylinder through a port or pouring slot. A hydraulically operated plunger ~~pressurizes~~ pressurises the molten metal in the shot chamber and injects it into the die cavity.

Table 4.1 Specifications of an 80 ton hydraulic pressure die casting machine

Locking force	80 ton	Dist. of centre and bottom injection	85 mm
Injection force	11.5 ton		
Ejection force	4 ton	Motor capacity	5.5 kw
Die mounting plates	520x520 mm	Working pressure	100-135 kg/cm^2

Tie bar space	330x330 mm
Die height – max	400 mm
Die height – min	200 mm
Tie bar diameter	60 mm
Die opening stroke	200 mm
Injection stroke	250 mm

Vane pump	70 ltr/min
Oil tank capacity	300 ltr
Machine weight	3.5 ton
Shot capacity	950 grm
Ejection stroke	50 mm

A second stage injection is applied to ~~assure~~ ensure complete packing of the molten metal into the profiles of die cavity. After the predefined solidification time, the moving die retracts and the casting is drawn from the machine. Now the hot die halves are cooled by the application of the die coat and both dies are clamped together. The second cycle is started and ~~continues~~ continued as described in ~~figure~~ Figure 4.8.

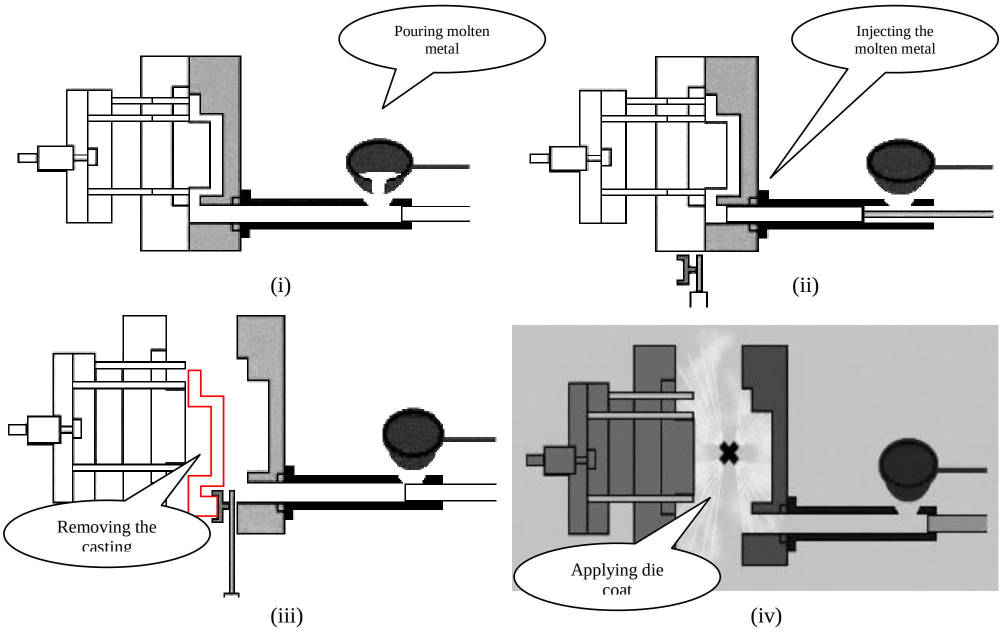

Figure 4.8 Operations of high pressure die casting machine

The objective of this project ~~would be~~ is the validation of machine specifications and operating ranges against the casting characteristics, such as casting weight and solidification time etc.

These proposals are ~~prioritized~~ prioritised based on their importance ~~for~~ to accomplish~~ing~~ the strategy after briefing the projects to the apex management. Figure

4.9 illustrates the HoQ in which the projects were weighted and prioriti~~z~~sed. The project proposal “P1 – ~~Optimizing~~ Optimising the process parameters” was chosen to ~~execute in~~be executed in the subsequent stages of this study since it ~~has~~ had the more weight ~~that~~ than the rest of the projects and ~~also~~ b~~ears~~ore a strong cooperative interrelationship.

Comment [Editor10]: Please check for hyphenation and make this consistent with the oth documents.

		P₄	9	3	3	
		P₃	27	9		
		P₂	27			
		P₁				
			P_1	*P_2*	*P_3*	*P_4*
	Importance	*Weight*	Optimizing process parameters	Analysing die design	Evaluating component design	Machine capability analysis
Strategy – S_1	*d_i*	*W_i*	*Project plans*			
Minimizing defective fraction	9	1	9	3	3	1
	Weight	*W_i*	0.563	0.186	0.186	0.063
		Priority	*I*	*II*	*II*	*III*

Figure 4.9 QFD iteration – Strategy Vs Project plans

4.2.5 TPE Stage 2: Six Sigma and Triz processes

Comment [Editor11]: Should this be TRIZ o Triz? Please check and make consistent in all the documents.

The following activities have been executed in this process to develop a feasible solution to the project selected~~. The following activities were carried out~~:

- Developing the problem statement using Triz - ISQ.
- Measuring the magnitude of present defective rate and its ~~sigma~~ Sigma level.
- ~~Analyzing~~ Analysing defect causes and remedies.
- Resolving contradictions.

Comment [Editor12]: Please be consistent w punctuation marks for all bulleted points

4.2.5.1 Defining the problem statement

A literal problem statement was developed to ~~progress~~ push the study in the right direction. Since the present operations ~~done~~ performed by the ~~organization~~ organisation were individually unique~~ and~~, there was no relationship between the components except for the casting process. But the process parameters ~~are~~ were common and ~~for producing each type of components,~~ the parameter values were only changed as specified by the production department for producing each type of component. In this situation, an innovative approach ~~is~~ was needed to guide the team to execute the study. ISQ, problem modelling / formulation and IFR~~,~~ along with the Triz analytical tools were used to define the problem by mapping the process. First, the ISQ was designed to ~~analyze~~ analyse the present situation, and then, we undertook problem formulation ~~with~~ using problem modelling~~ was done~~. Finally, the IFR was developed to define the problem.

4.2.5.2 ISQ for Situation Analysis

An ISQ was developed with a~~of~~ set of questions deployed in T~~t~~able 4.2 to ascertain~~ the~~ better understanding of the nature of the present process setup and the defects~~ nature~~. The answers of the ISQ were used to stimulate problem formulation.

Table 4.2 ISQ

Innovative Situation Questionnaire
1. What is the purpose of the process parameter optimization?
It is required to optimize the process parameters to minimize the defect probability of the die casting process for improving the productivity.
2. What are the existing defects?
23 different defects are noticed in the present process
3. What can be done to avoid defects in castings?
Several attempts were made in the area of product design evaluation and die design evaluation but process optimization is not attempted so for. Hence to resolve the crisis, process optimization may be practiced.
4. What are the advantages and disadvantages of the known solutions?
The expected benefits of process parameter optimization include reduced defective fraction, reduced cycle time, improved resource utilisation and improved quality. The

possible disadvantages are high time and cost involvement for process setup modification, all the defect possibilities may not be eradicated, individual product requires separate process optimization hence it might be a cumbersome approach.
5. What is the ideal solution to the original problem?
Zero rejections of castings due to defects
6. What are the local constraints and limitations?
Since each component requires its own customized parameter settings, it is high costly approach to determine optimum factor settings to each one. This approach may be beneficial only to frequently repeated batch of same component.

4.2.5.3 Problem modelling and formulation

Problem modelling was ~~done~~ undertaken after obtaining information from the ISQ situation analysis. It involved the building of a function diagram by using the function analysis as shown in ~~figure~~ Figure 4.10.

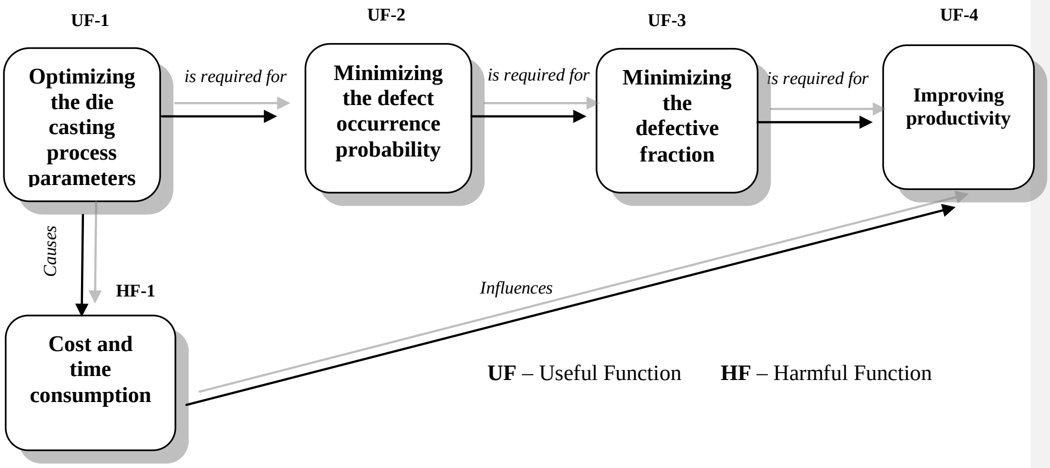

Figure 4.10 Function modelling using the TRIZ function analysis

The cause-and-effect relationships among the functions were ~~publicized~~ publicised in this functional diagram. The useful function UF-1 was found to be the~~as~~ prerequisite to deliver the UF-2. ~~and t~~The~~n~~ UF-2 ~~is~~ was mandatory for achieving UF-3 and thereon, the UF4. However, UF-1 ~~will~~ would produce harmful Function HF-1, which ~~can~~ could have a reverse effect on the effectiveness of UF-1. Problem formulation was examined based on a functional diagram, subsequently aiding the identification of the following problem statements ~~were identified~~;

1. *Identifying an alternative way to ~~optimize~~ optimise the process parameters without adding cost and time to it.*
2. *Formulating a methodology to resolve the contradiction of UF-1 delivers UF-2, but causes HF-1.*
3. *Developing an alternative process setup to carry out UF-1*

~~M~~

The most viable problem among the problem statements was identified based on the following ~~criterion~~criteria:

- *Selection of a problem with the best cost / benefit ratio. The more radical the problem, the greater the potential benefit.*
- *Elimination of the harmful causes than ~~to~~ alleviat~~e~~ion of results.*
- *Considering the level of difficulty involved in implementing a solution. Too radical a solution may prove unacceptable, depending on an ~~organization's~~ organisation's culture and psychological inertia.*

Finally, ~~the~~ problem definition was defined by considering~~taking into consideration of~~ the ~~organization's~~ organisation's culture and the expectations of the management ~~expectation~~:

"Determining the optimum parameter settings of the die casting process by resolving the contradiction of process parameter optimization for minimizing the defect probability but it causes time and cost consumption incurred for modifying present operational setup"

4.2.5.4 Six Sigma measure stage

The information review and data collection was ~~done in~~undertaken at this stage to measure the present performance of the ~~organization~~organisation. The current process was also quantified ~~Quantifying the current process was sought at this moment~~then. The following metrics were established t~~T~~o make this stage more systematic~~, the following metrics were established~~:

- ***Output*** – quantity produced
- ***Defective (r)*** – casting being rejected due to the presence of defect(s)
- ***Defect*** – any non-conformity
- ***Yield (y)*** – output after rejections
- ***Opportunity (m)*** – chances of being defective (number of defects)
- ***Defects probability ($p_{(x)}$)***– chances of containing one or more defect in single casting
- ***Defective fraction*** – ratio of defective to output
- ***Defects per unit (DPU)*** – ratio of defective to output
- ***Defects per opportunities (DPO)*** – ratio of DPU to prevailing defect opportunities
- ***Defects per million opportunities (DPMO)*** – DPO multiplied by 1,000,000

Past history on production and rejection was collected from the ~~organization~~ organisation's database for ~~the~~ a period of three months for further analysis~~to analyze further~~. ~~Data~~ The data review was consolidated as:

- The company has produced 58 different castings as batches
- The net production was 10, 49,424 units (output)
- The total rejections was 38,523 units (defective)
- There were 27 casting defects reported (opportunities)
- Out of 58 varieties of castings, only 6 casting variety had defective fraction less then target of 1.5%
- Overall defective fraction found ranged between 1.06% to 31.25%

Figure 4.11illustrates the magnitude level of defective fraction from the data arranged in ~~table~~ Table 4.3.

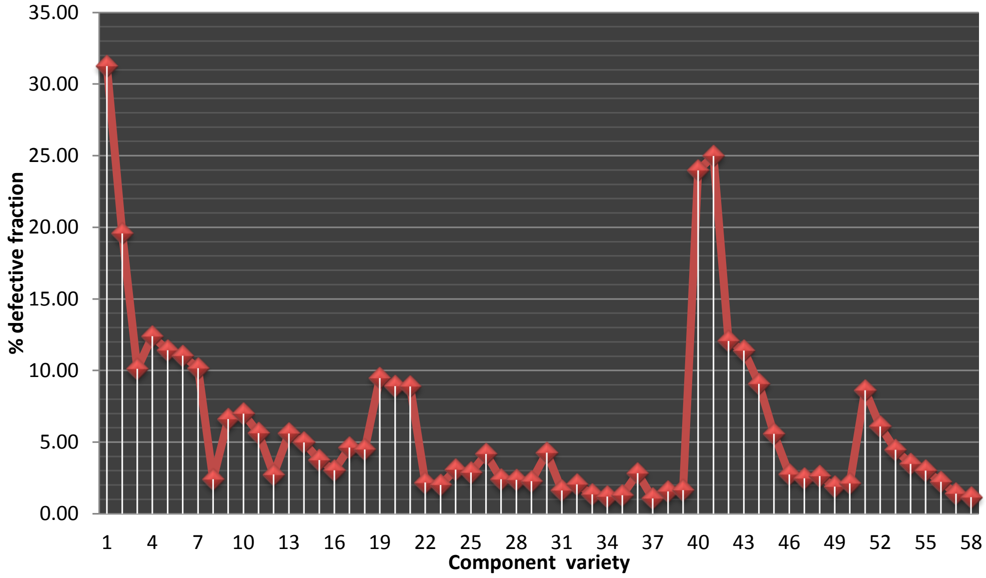

Figure 4.11 Defective fractions run chart

SL. NO	Item name	part number	PRODUCTION QTY			PRODN TOTAL	REJECTION QTY			REJ. TOTAL	REJ %
			NOV 07	DEC 07	JAN 08		NOV 07	DEC 07	JAN 08		
1	Cover	1622 3661 00	1966	2159		4125	706	583		1289	31.25
2	Governer cover	F002 a31 032	2325	2021	104	4450	642	218	11	871	19.57
3	Governer housing	F002 a21 342	15251	7769	17522	40542	2452	796	850	4098	10.11
4	Sre bracket	26216315	1294	869	992	3155	169	153	69	391	12.39
5	Rfi shield housing	21420-21310	8140			8140	929			929	11.41
6	De bracket	2625 9934	2230			2230	246			246	11.03
7	Sre bracket	4606 (r7)	8401	21493	5654	35548	798	2163	653	3614	10.17
8	Stop housing	1425 209 028	688	12392		13080	64	250		314	2.40
9	Rocker arm	-	33044	14272		47316	2908	221		3129	6.61
10	Sre bracket	4606 (r6)	12581	1999		14580	940		79	1019	6.99
11	Filter housing	1615 7767 02	3486	1414		4900	245	31		276	5.63
12	Foot rest rh	982023	2965			2965	81			81	2.73
13	Foot rest lh	982022	2965			2965	166			166	5.60
14	Tensioning bracket	4-234-50-0220	9152			9152	455			455	4.97
15	Intermediate housing	Z 007557	3890	3966	4126	11982	188	89	172	449	3.75
16	Big housing	1615 7668 02	1211	1827		3038	57	35		92	3.03
17	Valve seat	Fdopa125-01c	12832			12832	593			593	4.62
18	Head cylinder casting	K010039	5244			5244	235			235	4.48
19	Caliper support	597759	1257	1740	2037	5034	56	125	296	477	9.48
20	Pump housing	F002 g11 525	20678	6494		27172	885	1534		2419	8.90
21	Governer housing	F002 a33 002	4356	1008		5364	186	291		477	8.89
22	Port body voss	Z011883	4202	4772	13338	22312	141	151	193	485	2.17
23	Closing cover	1415 626 114	13636	27594		41230	452	375		827	2.01
24	Cover oil pump	Fdopa 125-02c	4919	884		5803	154	25		179	3.08
25	Corner	1613 9963 00	17244			17244	497			497	2.88
26	Connection pipe	1503 2854 00	1474	1880	2591	5945	39	141	68	248	4.17
27	De bracket	26216314	1243			1243	30			30	2.41
28	Gear housing drw	Sw6s 5 1800	2965			2965	70			70	2.36
29	Closing cover	1421 060 013	24452	20784		45236	558	472		1030	2.28

30	F8b housing	2641 2432	12190	6351	5120	23661	230	570	210	1010	4.27
31	Super sonic grill	903063-10	675	6636	3730	11041	11	110	59	180	1.63
32	Megasonic grill	905032-10	29025	27490	10818	67333	411	837	128	1376	2.04
33	Knuckle	03-7831-0300	1256			1256	17			17	1.35
34	Ce bracket	2625 9888	7100			7100	85			85	1.20
35	Fixing bracket	2625 2922	6519	2305		8824	74	40		114	1.29
36	Delivery pipe	1503 2853 00	2725		640	3365	30		65	95	2.82
37	Regulating holder	1	49112			49112	521			521	1.06
38	Front wheel hub	Ii 560284	5158	11627	7198	23983	53	230	93	376	1.57
39	Tension roller	5/0654 708/0	123558	185025	65827	374410	1266	1945	2951	6162	1.65
40	Valve seat	1503 2867 00		583	589	1172		198	83	281	23.98
41	Oil pump body	1503 2865 00		4910		4910		1227		1227	24.99
42	Scherenlanger	4 393 21 0001		688		688		83		83	12.06
43	De bracket	2625 9906		1028		1028		117		117	11.38
44	Flange assly	1615 7768 80		1656		1656		150		150	9.06
45	C111 cover f.unloader	1622 3163 00		3885		3885		217		217	5.59
46	Deckel	4 393 17 0008		1714		1714		47		47	2.74
47	Housing clutch	N8070219		10128		10128		251		251	2.48
48	Cover outlet	1616 6507 00		7138	3313	10451		163	112	275	2.63
49	Cover l cylinder head	N8010280		6684		6684		126		126	1.89
50	Rear bracket	2621 6569		3167	645	3812		34	47	81	2.12
51	Ce bracket	2625 9925			174	174			15	15	8.62
52	C77 housing unloader	1622 1713 05			4180	4180			255	255	6.10
53	Stop cover	1425 520 033			202	202			9	9	4.46
54	Gear case casting	K080049			1120	1120			39	39	3.48
55	De bracket	26214564			8310	8310			250	250	3.01
56	Rear bracket	2621 4309			1656	1656			37	37	2.23
57	Cover	C40 1616 7265 00			2370	2370			33	33	1.39
58	Rear bracket	2621 4406			9407	9407			108	108	1.15
					Total Production	1049424			**Total Rejection**	38523	

4.2.5.5 Calculating defect probability using the Poisson distribution

Since the subject case contained discrete data ~~as~~ for the number of defectives, we used the Poisson distribution ~~was used~~ to calculate the defects probability as tabulated in ~~table~~ Table 4.4. The probability of observing exactly (x) defects in a single casting ~~is~~ was given by the Poisson probability density function:

$$P(X=x)=p(x)=\frac{e^{-\lambda}\lambda^{x}}{x!},\quad x=0,1,2,\ldots m \qquad -----Equ\ 1$$

where

e = a constant equal to 2.71828

λ = defects per unit (DPU)

For our analysis the equation was rewritten as:

$$P(X=x)=p(x)=\frac{e^{-DPU}DPU^{x}}{x!},\quad x=0,1,2,\ldots m \qquad --Equ\ 2$$

In this case, our interest was focused ~~to~~ on minimising~~minimize~~ the defect probability~~,~~. This~~it~~ was calculated as:

$$Defect\ probability\ \ p(x)=1-Probability\ of\ having\ zero\ defects$$

$$=1-\frac{e^{-DPU}DPU^{0}}{0!}$$

$$=1-\ e^{-DPU} \qquad --------Equ\ 3$$

It is obvious from ~~figure~~ Figure 4.12~~;~~ that the concentration of defect probability of components was noticed as being below 12%. Hence, it was benchmarked ~~to~~ for team members to work-out the future actions towards ~~minimizing~~ minimising it further, below 12% as much as possible.

4.2.5.6 Process yield and Sigma quality level calculation

Since the collected data ~~belongs~~ belonged to the discrete type, it was converted into to yield and the corresponding ~~sigma~~ Sigma level was calculated using the standard normal distribution equation 4.

$$\phi(Z) = \int_{-\infty}^{Z} \frac{1}{\sqrt{2\pi}}\, e^{\frac{-w^2}{2}}\, dw \; - - - - - - - - - - \; Equ\ 4 = y$$

The ~~sigma~~ Sigma level Z corresponding to yield 'y' was obtained from the standard normal distribution table given in ~~appendix~~the Appendix. Since the value of Z ~~represents~~ represented the long term ~~sigma~~ Sigma level, then, the short term ~~sigma~~ Sigma level was obtained by:

$$Z_s = Z_l + 1.5$$

~~-~~The~~e~~is calculation ~~was~~ has been summarized in ~~table~~ Table 4.5. From this ~~table~~Table, it was inferred that the majority of the component casting processes found operating with a yield equal~~s~~ to a ~~sigma~~ Sigma level ~~of~~ between 3.76 ~~to~~ and 3.84 has been indicated in radar chart 4.13.

4.2.5.7 Defects stratification using the Pareto principle

It becomes imperative to stratify the defects for distinguishing the "vital few from the trivial many. To spot ~~out~~ the ~~dominating~~ dominant defects in the present process setup, ~~the~~ we applied the Pareto principle ~~was applied~~. The contribution of each defect was ~~summarized~~ summarised in ~~table~~ Table 4.6. It was noticed from the Pareto chart in ~~figure~~ Figure 4.14 that the defects 1 to 5 (Un-filling; Blow holes; Gate broken; Damage; and Flash) were found contributing to nearly 78.63% of the overall rejections. Improving the process by ~~optimizing~~ optimising the parameters to reduce

Comment [Editor13]: Please check for a missing closed quotation mark.

these defects was felt necessary ~~to~~ and imperative to improve productivity significantly.

Table 4.4 Defect probability calculations using the Poisson distribution

S.no	Product name	Output	Defective	DPU	P(x=0)	Defect probability	% defect probability
1	Cover	4125	1289	0.31248	0.73163	0.26837	26.84
2	Governer cover	4450	871	0.19573	0.82223	0.17777	17.78
3	Governer housing	40542	4098	0.10108	0.90386	0.09614	9.61
4	Sre bracket	3155	391	0.12393	0.88344	0.11656	11.66
5	Rfi shield housing	8140	929	0.11413	0.89214	0.10786	10.79
6	De bracket	2230	246	0.11031	0.89555	0.10445	10.44
7	Sre bracket	35548	3614	0.10167	0.90333	0.09667	9.67
8	Stop housing	13080	314	0.02401	0.97628	0.02372	2.37
9	Rocker arm	47316	3129	0.06613	0.93601	0.06399	6.40
10	Sre bracket	14580	1019	0.06989	0.93250	0.06750	6.75
11	Filter housing	4900	276	0.05633	0.94523	0.05477	5.48
12	Foot rest rh	2965	81	0.02732	0.97305	0.02695	2.69
13	Foot rest lh	2965	166	0.05599	0.94555	0.05445	5.44
14	Tensioning bracket	9152	455	0.04972	0.95150	0.04850	4.85
15	Intermediate housing	11982	449	0.03747	0.96322	0.03678	3.68
16	Big housing	3038	92	0.03028	0.97017	0.02983	2.98
17	Valve seat	12832	593	0.04621	0.95484	0.04516	4.52
18	Head cylinder casting	5244	235	0.04481	0.95618	0.04382	4.38
19	Caliper support	5034	477	0.09476	0.90960	0.09040	9.04
20	Pump housing	27172	2419	0.08903	0.91482	0.08518	8.52
21	Governer housing	5364	477	0.08893	0.91491	0.08509	8.51
22	Port body voss	22312	485	0.02174	0.97850	0.02150	2.15
23	Closing cover	41230	827	0.02006	0.98014	0.01986	1.99
24	Cover oil pump	5803	179	0.03085	0.96962	0.03038	3.04
25	Corner	17244	497	0.02882	0.97159	0.02841	2.84
26	Connection pipe	5945	248	0.04172	0.95914	0.04086	4.09
27	De bracket	1243	30	0.02414	0.97615	0.02385	2.38
28	Gear housing drw	2965	70	0.02361	0.97667	0.02333	2.33
29	Closing cover	45236	1030	0.02277	0.97749	0.02251	2.25
30	F8b housing	23661	1010	0.04269	0.95821	0.04179	4.18
31	Super sonic grill	11041	180	0.0163	0.98383	0.01617	1.62
32	Megasonic grill	67333	1376	0.02044	0.97977	0.02023	2.02
33	Knuckle	1256	17	0.01354	0.98656	0.01344	1.34
34	Ce bracket	7100	85	0.01197	0.98810	0.01190	1.19
35	Fixing bracket	8824	114	0.01292	0.98716	0.01284	1.28
36	Delivery pipe	3365	95	0.02823	0.97216	0.02784	2.78
37	holder	49112	521	0.01061	0.98945	0.01055	1.06
38	Front wheel hub	23983	376	0.01568	0.98444	0.01556	1.56

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39	Tension roller	374410	6162	0.01646	0.98368	0.01632	1.63
40	Valve seat	1172	281	0.23976	0.78682	0.21318	21.32
41	Oil pump body	4910	1227	0.2499	0.77888	0.22112	22.11
42	Scherenlanger	688	83	0.12064	0.88635	0.11365	11.36
43	De bracket	1028	117	0.11381	0.89242	0.10758	10.76
44	Flange assly	1656	150	0.09058	0.91340	0.08660	8.66
45	f.unloader	3885	217	0.05586	0.94568	0.05432	5.43
46	Deckel	1714	47	0.02742	0.97295	0.02705	2.70
47	Housing clutch	10128	251	0.02478	0.97552	0.02448	2.45

Table 4 Contd…..

S.no	Product name	Output	Defective	DPU	P(x=0)	Defect probability	% defect probability
48	Cover outlet	10451	275	0.02631	0.97403	0.02597	2.60
49	Cover l cylinder head	6684	126	0.01885	0.98133	0.01867	1.87
50	Rear bracket	3812	81	0.02125	0.97898	0.02102	2.10
51	Ce bracket	174	15	0.08621	0.91740	0.08260	8.26
52	f.unloader	4180	255	0.061	0.94082	0.05918	5.92
53	Stop cover	202	9	0.04455	0.95642	0.04358	4.36
54	Gear case casting	1120	39	0.03482	0.96578	0.03422	3.42
55	De bracket	8310	250	0.03008	0.97036	0.02964	2.96
56	Rear bracket	1656	37	0.02234	0.97790	0.02210	2.21
57	Cover	2370	33	0.01392	0.98617	0.01383	1.38
58	Rear bracket	9407	108	0.01148	0.98858	0.01142	1.14

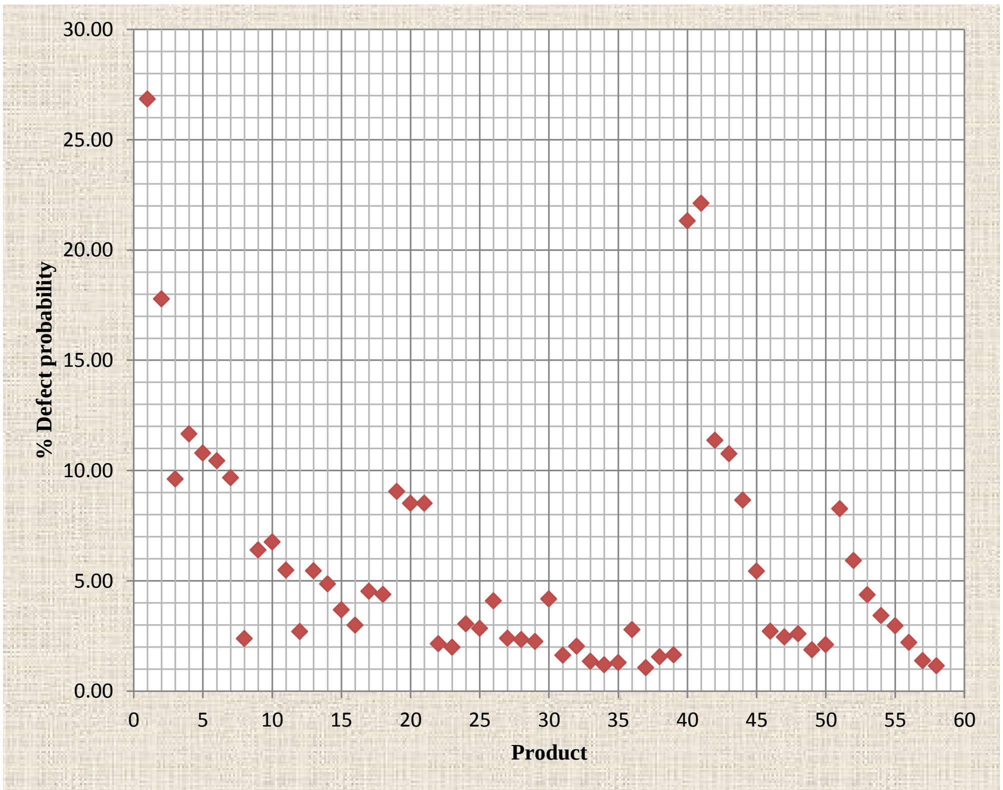

Figure 4.12 Concentration of defect probability

Table 4.5 Yield and Sigma level calculation using standard normal distribution

S.no	Product name	Output (n)	Defective (r)	Defective fraction p = r / n	Yield y = 1 - p	Standard normal variant (Z)	Sigma level $Z_s = Z_l + 1.5$
1	Cover	4125	1289	0.31248	0.68752	2.46	3.96
2	Governer cover	4450	871	0.19573	0.80427	2.405	3.905
3	Governer housing	40542	4098	0.10108	0.89892	2.36	3.86
4	Sre bracket	3155	391	0.12393	0.87607	2.37	3.87
5	Rfi shield housing	8140	929	0.11413	0.88587	2.37	3.87
6	De bracket	2230	246	0.11031	0.88969	2.37	3.87
7	Sre bracket	35548	3614	0.10167	0.89833	2.36	3.86
8	Stop housing	13080	314	0.02401	0.97599	2.33	3.83
9	Rocker arm	47316	3129	0.06613	0.93387	2.35	3.85
10	Sre bracket	14580	1019	0.06989	0.93011	2.35	3.85
11	Filter housing	4900	276	0.05633	0.94367	2.35	3.85
12	Foot rest rh	2965	81	0.02732	0.97268	2.34	3.84
13	Foot rest lh	2965	166	0.05599	0.94401	2.35	3.85
14	Tensioning bracket	9152	455	0.04972	0.95028	2.34	3.84

15	Intermediate housing	11982	449	0.03747	0.96253	2.34	3.84
16	Big housing	3038	92	0.03028	0.96972	2.335	3.835
17	Valve seat	12832	593	0.04621	0.95379	2.335	3.835
18	Head cylinder casting	5244	235	0.04481	0.95519	2.335	3.835
19	Caliper support	5034	477	0.09476	0.90524	2.365	3.865
20	Pump housing	27172	2419	0.08903	0.91097	2.36	3.86
21	Governer housing	5364	477	0.08893	0.91107	2.36	3.86
22	Port body voss	22312	485	0.02174	0.97826	2.335	3.835
23	Closing cover	41230	827	0.02006	0.97994	2.335	3.835
24	Cover oil pump	5803	179	0.03085	0.96915	2.335	3.835
25	Corner	17244	497	0.02882	0.97118	2.335	3.835
26	Connection pipe	5945	248	0.04172	0.95828	2.33	3.83
27	De bracket	1243	30	0.02414	0.97586	2.33	3.83
28	Gear housing drw	2965	70	0.02361	0.97639	2.33	3.83
29	Closing cover	45236	1030	0.02277	0.97723	2.33	3.83
30	F8b housing	23661	1010	0.04269	0.95731	2.34	3.84
31	Super sonic grill	11041	180	0.01630	0.98370	2.335	3.835
32	Megasonic grill	67333	1376	0.02044	0.97956	2.335	3.835
33	Knuckle	1256	17	0.01354	0.98646	2.33	3.83
34	Ce bracket	7100	85	0.01197	0.98803	2.33	3.83
35	Fixing bracket	8824	114	0.01292	0.98708	2.33	3.83
36	Delivery pipe	3365	95	0.02823	0.97177	2.335	3.835
37	Regulating sleeve holder	49112	521	0.01061	0.98939	2.33	3.83
38	Front wheel hub	23983	376	0.01568	0.98432	2.335	3.835
39	Tension roller	374410	6162	0.01646	0.98354	2.335	3.835
40	Valve seat	1172	281	0.23976	0.76024	2.43	3.93
41	Oil pump body	4910	1227	0.24990	0.75010	2.43	3.93
42	Scherenlanger	688	83	0.12064	0.87936	2.375	3.875
43	De bracket	1028	117	0.11381	0.88619	2.37	3.87
44	Flange assly	1656	150	0.09058	0.90942	2.36	3.86
45	C111 cover f.unloader	3885	217	0.05586	0.94414	2.35	3.85
46	Deckel	1714	47	0.02742	0.97258	2.335	3.835

Table 5.5 Contd ……

S.no	Product name	Output (n)	Defective ®	Defective fraction p = r/n	Yield y = 1 - p	Standard normal varient (z)	Sigma level zs = zl +1.5
47	Housing clutch	10128	251	0.02478	0.97522	2.335	3.835
48	Cover outlet	10451	275	0.02631	0.97369	2.335	3.835
49	Cover l cylinder head	6684	126	0.01885	0.98115	2.335	3.835
50	Rear bracket	3812	81	0.02125	0.97875	2.335	3.835
51	Ce bracket	174	15	0.08621	0.91379	2.36	3.86
52	C77 housing f.unloader	4180	255	0.06100	0.93900	2.35	3.85
53	Stop cover	202	9	0.04455	0.95545	2.34	3.84
54	Gear case casting	1120	39	0.03482	0.96518	2.34	3.84
55	De bracket	8310	250	0.03008	0.96992	2.34	3.84
56	Rear bracket	1656	37	0.02234	0.97766	2.335	3.835
57	Cover	2370	33	0.01392	0.98608	2.33	3.83
58	Rear bracket	9407	108	0.01148	0.98852	2.33	3.83

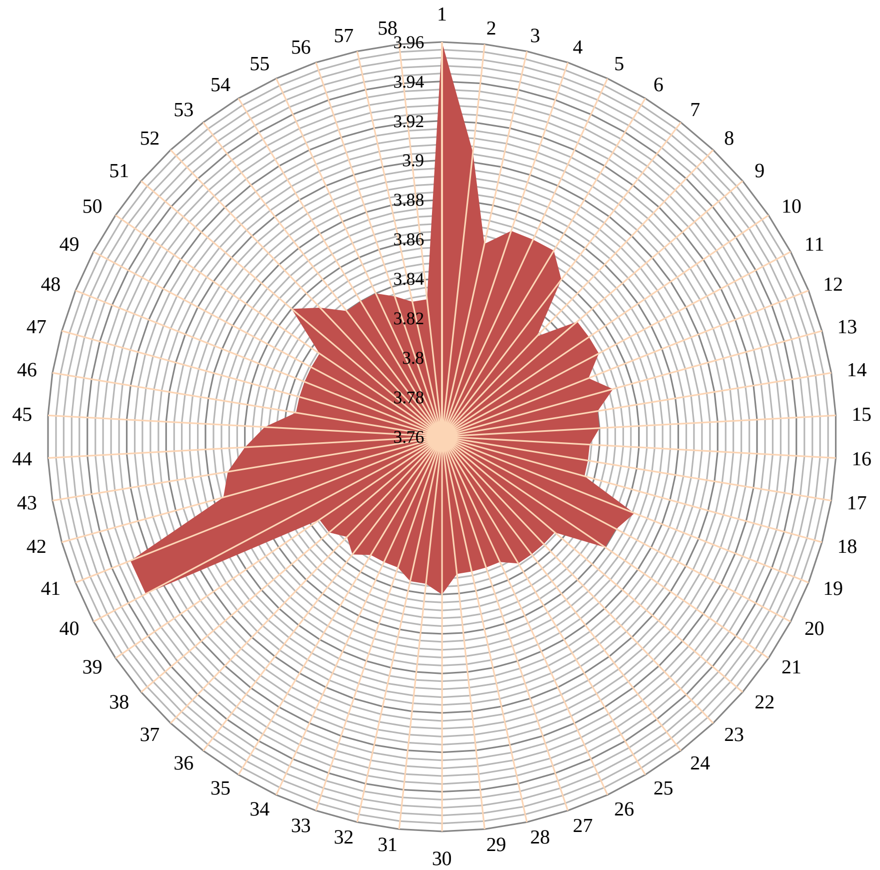

Figure 4.13 Sigma quality level radar chart

Table 4.6 Summary of defects data under Pareto principle

S.No	Defects	Quantity rejected			Total rejected	%	Cumulative frequency	Cumulative %
		Month 1	Month 2	Month 3				
1	Unfilling	4793	3965	2918	11676	29.21	11676	29.21
2	Blow holes	5896	3618	1333	10847	27.14	22523	56.35
3	Gate broken	1596	1887	801	4284	10.72	26807	67.07
4	Damage	1005	1140	662	2807	7.02	29614	74.09
5	Flash	1104	514	197	1815	4.54	31429	78.63
6	weld	699	771	345	1815	4.54	33244	83.17
7	Bend	974	621	102	1697	4.25	34941	87.42
8	Crack	231	495	237	963	2.41	35904	89.83
9	Unwash	77	396	251	724	1.81	36628	91.64

Comment [Editor15]: Elsewhere this is hyphenated. Please check and make consistent

10	Shrinkage	238	384	13	635	1.59	37263	93.23
11	White rust	258	242	1	501	1.25	37764	94.48
12	Handling damages	55	208	27	290	0.73	38054	95.21
13	Insert blow holes	124	75	16	215	0.54	38269	95.75
14	Dimension problem	50	95	63	208	0.52	38477	96.27
15	Pin broken	115	84	1	200	0.50	38677	96.77
16	Insert damage	59	84	48	191	0.48	38868	97.25
17	Gate hole	96	46	31	173	0.43	39041	97.68
18	Bubbles	20	99	54	173	0.43	39214	98.11
19	Metal peel off	52	83	35	170	0.43	39384	98.54
20	Dent mark	78	81	0	159	0.40	39543	98.93
21	Ovality	81	25	0	106	0.27	39649	99.20
22	Ej. pin projection	11	15	55	81	0.20	39730	99.40
23	Rib broken	39	32	8	79	0.20	39809	99.60
24	Bush exposer	9	68	2	79	0.20	39888	99.80
25	Insert offset	21	9	12	42	0.11	39930	99.90
26	Insert flash	15	6	4	25	0.06	39955	99.96
27	Without insert	2	9	3	14	0.04	39969	100.00
		17698	**15052**	**7219**	**39969**			

4.2.5.8 Six Sigma analys~~z~~e stage

Recalling the function modelling depicted in ~~figure~~ Figure 4.10 at the define stage; ~~optimizing~~ optimising the process parameters is ~~much~~ mandatory to produce another useful function of defect occurrence probability ~~minimization~~ minimisation, while the ~~whereas the~~ UF1 ~~has~~ create~~d~~s the harmful function HF1~~;~~ and entails cost and time consumption.

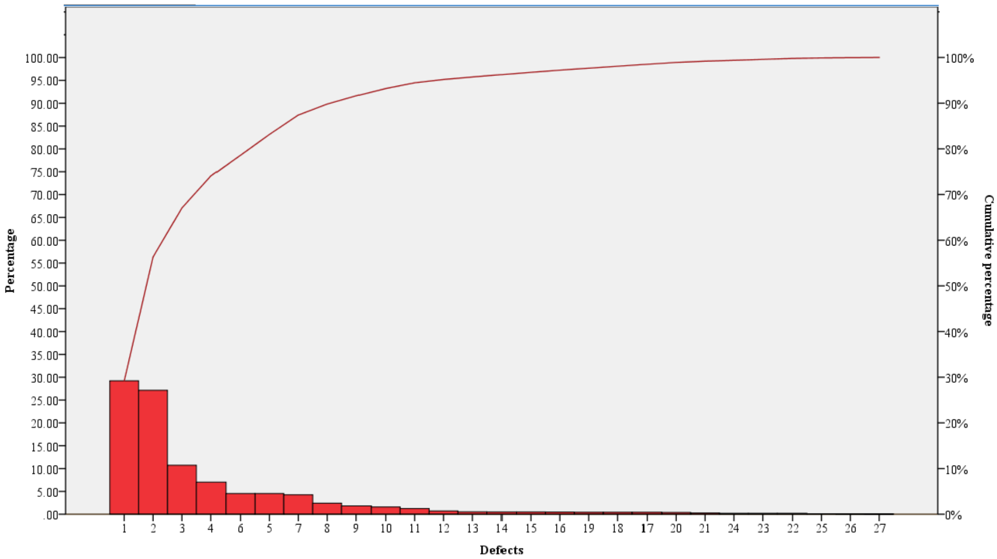

Figure 4.14 Pareto chart of defects

Before attempting to ~~optimize~~ optimise the process parameters, it was imperative to ~~needed to~~ resolve the contradiction for which the TRIZ contradiction algorithm ~~was~~ had been executed and exposed in ~~figure~~ Figure 4.15.

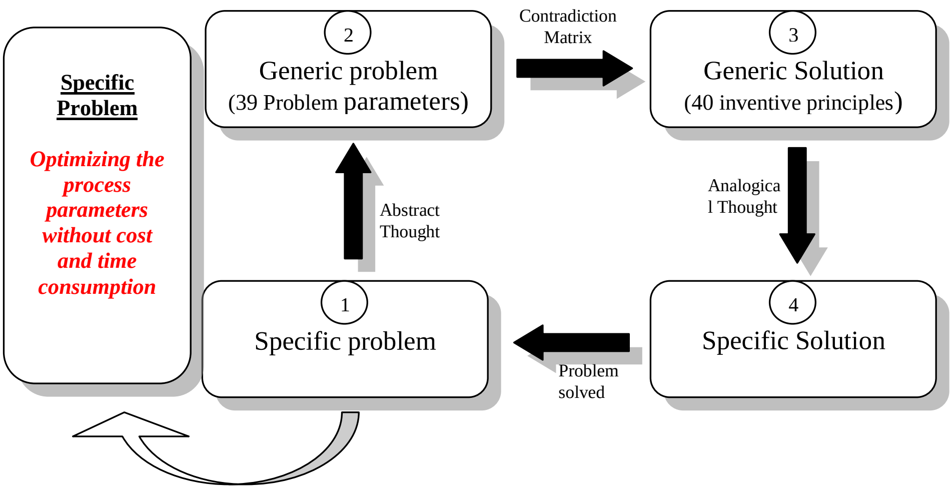

Figure 4.15 Technical Contradiction Algorithms

In the contradiction algorithm, the present contradiction was recorded to a specific problem to abstract it to a generic problem. Figure 4.16 illustrated the process of abstracting using the TRIZ 39 problem parameters.

Comment [Editor16]: Do you mean to say 'applied'?

	~~specific~~ Specific problem	Generic problem parameter
UF	Process parameter optimization	Quantity of substance **(26)**
HF		Ease of

	Cost and time consumption	operation **(33)**

Figure 4.16 Triz abstracting process

The following generic problem parameters were chosen:

No: 26 – Quantity of substance

The number or amount of a system's materials, substances, parts or subsystems that might be changed fully or partially, permanently or temporarily

No: 33 – Ease of operation

The process is NOT easy if it requires a large number of people, large number of steps in the operation, needs special tools, etc.

By cross referring the Quantity of substance **(26)** with Ease of operation **(33)** in Triz contradiction matrix, the inventive principles marked in ~~figure~~ Figure 5.17 were chosen to develop a general solution.

HF / UF	Ease of operation (33)
Quantity of substance (26)	**(35) (29) (25) (10)**

Figure 4.17 TRIZ contradiction matrix

The identified solution principles were:

Number 35: Parameter change was the principle that focused the team to change the parameter in one or other way like:

- *Changing the object's physical state e.g.~~,~~ to a gas, liquid or solid*
- *Changing the concentration or consistency*
- *Changing the degree of flexibility*
- *Changing the temperature*

Number 29: Pneumatics and hydraulics insisted on the use of gas or liquid parts of an object instead of the solid parts.

Number 25: Self service ~~makes~~ made an object serve itself by performing auxiliary helpful functions.

Number 10: Preliminary action ~~states~~ entailed the~~to~~ performance, before it ~~is~~ was needed, the required change of an object either fully or partially.

The inventive principle No 10: Preliminary action ~~is~~ was chosen to develop a generic solution because of its relevance to the present problem solving scenario. As per this principle, it was decided to preset the operation parameters to the trail level at the start of production~~, —~~. Therefore,~~thus~~ a separate time ~~— needed~~ to conduct ~~optimization~~ optimisation was eliminated and thereon the cost associated. To determine the parameters, we analysed the defects data summarized in ~~table~~ Table 6 ~~were analyzed~~. Defects No. 3 and 4 (Gate broken and Damage) were found occurring only after the casting process. These defects ~~are~~ occurred due to mishandling of the castings while trimming and transporting. The rest of the defects (1-Un-filling, 2-Blow holes and 5-Flash) were noticed to have occurred ~~be occurred~~ during the casting operation. A cause and effect analysis, illustrated in ~~figure~~ Figure 4.18 was performed to identify the parameters that influenced the occurrence of these process defects.

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Slow injection

(Injection pressure)

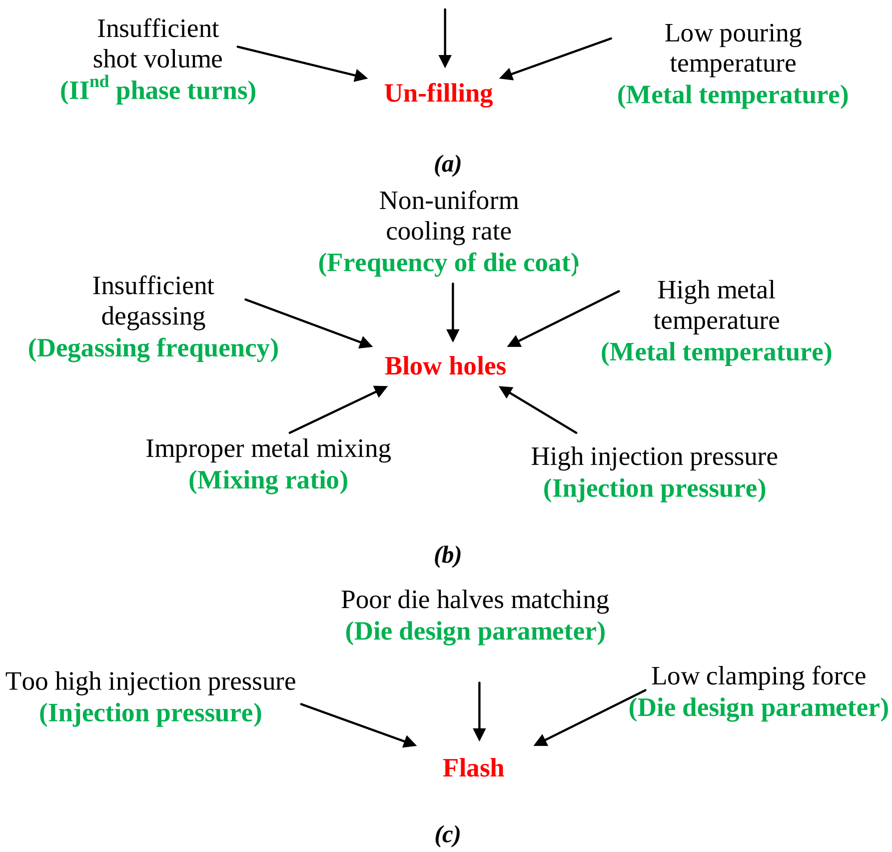

Figure 4.18 (a)(b)(c) Defect causes analysis

The following process parameters were selected from the cause and effect analysis for further study since these parameters were frequently modified in each process setup to cast a different variety of components:

- ***Metal temperature (T_m):*** ~~In t~~The present process setup~~,~~ saw the~~the~~ fresh metal ~~was~~ being melted in the furnace– at the set temperature before it was poured ~~pouring~~ into the die cavity. The temperature ~~ranges~~ ranged from ~~625'~~ 625^0 C to ~~900'C~~ 900^{0}C ~~depending~~ dependent upon the component design.

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- ***Injection pressure (P_i):*** It refers to the pressure at which the molten metal is pushed into the die cavity from the shot chamber. The normal working range of injection pressure was 190 kg/cm^2 to 270 kg/cm^2

- ***IInd phase turns (N_s):*** After injecting the molten metal inside the die, a second injection called "Cushioning" was applied to ensure complete packing of the metal inside the cavity. This cushioning effect ~~can~~ could be adjusted by means of a lead screw provided in the shot chamber of the machine.

- ***Degassing frequency (f_g):*** To evaporate the gas content~~s~~ in the molten metal, at a predefined interval, a degassing agent was mixed with the molten metal in the furnace. The present practice ~~involves~~ entailed~~the~~ degassing at every 200 to 350 shots for different components.

- ***Metal mixing ratio (R_m):*** After the trimming operation, the scrap metal was reused with fresh raw metal in the furnace. The necessary reconditioning was ~~done~~ performed before mixing the scrap metal with fresh metal. The company followed a ratio of 80:20 (80 of new metal was mixed with 20% of scrap metal) for casting several component varieties.

The die coating frequency was fixed as ~~it's~~ it was only applied at the beginning of each shot and hence, not considered ~~it was not considered~~ for ~~optimization~~optimisation. Injection time and shot volume were not considered because those parameters were associated with the equipment in which they ~~are~~ were designed at a predefined value.

4.2.6 TPE stage 3: Implementing and control processes

Taguchi's ~~orthogonal~~ Orthogonal ~~array~~ Array (OA~~)~~)-based ~~design~~ Design of ~~experiment~~ Experiment (DoE) was employed to ~~optimize~~ optimise the parameters in the foregoing analysis. The reason driving the selection of ~~behind the selection of~~ Taguchi's DoE approach was to complete the investigation with minim~~um number of~~al trail experiments over the traditional full factorial experimental approach. It was planned that one~~o select one~~ component would be selected in such a way that it would represent the ~~for the~~ entire range of components given the ~~since the~~ company ~~has~~ had been facing defects invariably in all components. Figure 4.12 infers that the average defect probability was around 12%~~ around;~~. ~~the~~ The components possessing higher defect probability were targeted to ~~optimize~~ optimise ~~its~~ the process parameters. Such components and ~~its~~ their defect~~s~~ contributions ~~were~~ have been listed in ~~table~~ Table 4.7 ~~below~~. The component "Oil pump body" (No.41) having DPU at the rate of 25% with occurrence probability near ~~to~~ 22% was selected for process ~~optimization~~ optimisation since it possessed ~~the occurrence of~~ all the process defects.

Table 4.7 List of components having high defect probability and ~~its~~ their defect contribution

S.No (as on Table 4)	Component name	DPU (as on Table 4)	% defect probability (as on Table 4)	Process defects			Other defects
				Un-filling	Blow holes	Flash	
1	Cover	0.31248	26.84	32	755	-	502
2	Governor cover	0.19573	17.78	326	420	-	125
40	Valve seat	0.23976	21.32	-	236	-	45
41	Oil pump body	0.2499	22.11	40	1073	2	112

4.2.6.1 DoE Step 1: determination of factor levels

All the parameters were considered ~~at~~across ~~3~~three levels to accommodate the non-linear relationship between factors as shown in Table 4.8.

Table 4.8 Process parameters with levels

Factor Notation	Controllable factors	*Metric*	Level 1	Level 2	Level 3
T_m	Metal temperature.	Centigrade	665	690	715
P_i	Injection pressure.	Kg/cm^2	220	240	260
f_g	Degassing frequency.	Shots per degassing	320	240	160
N_s	II phase turns.	Nos.	3	3.25	3.5
R_m	Metal mixing ratio.	Ratio	80:20	70:30	60:40

4.2.6.2 DoE Step 2: Selection of orthogonal array

It is interesteing~~d~~ to study the ~~following~~ interaction effects on the component with respect to defect occurrence:

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- Metal temperature and injection pressure [T_m x P_i]
- Injection pressure and degassing frequency [P_i x f_g].
- Metal temperature and degassing frequency [T_m x f_g].

L_{27}, a three level orthogonal array was chosen since it ~~has~~ had a greater degree of freedom (DOF=27) than that of the factors and interactions (DOF=22) as computed in T~~t~~able 4.9.

Table 4.9 Degrees of freedom

Factors / Interactions	DOF (No of level -1)
T_m	2
P_i	2
f_g	2
N_s	2
R_m	2
T_m x P_i	2 x 2
P_i x f_g	2 x 2
T_m x f_g	2 x 2
Total DOF	**22**

4.2.6.3 DoE Step 3: Arranging factors and interactions in L_{27} OA columns

The main factors T_m, P_i, f_g, N_s, and R_m were assigned to columns 1, 2, 5, 9 and 10 respectively, and the interactions T_m x P_i, P_i x f_g and T_m x f_g in columns 3 ~~&~~ and 4, 8 ~~&~~ and 11, and 6 ~~&~~ and 7 respectively using the linear graphs and triangular tables (see the ~~appendix~~Appendix) and only then was the resultant trail matrix ~~was~~ prepared (Table 5.10).

4.2.6.4 DoE Step 4: Execution of experiments

As planned upon the contradiction analysis to conduct the experimental trails along with usual production run, the operator was given the parameter levels for each trail run and instructed to carry out the casting process of oil pump body accordingly. The operator used to preset the parameters at the start of the operations and ~~continues~~ continued that particular production run until they stopped. The~~n~~ next trail run was carried out ~~on~~ the next day. Likewise, all the 27 trial runs were completed in a span of ~~3~~ three and a half months and at the end of each trail, 500 components were randomly chosen in two replications. Since the number of good components (y_i) was recorded as a response in each test, the “Higher is ~~best~~Best” S/N ratio characteristic was selected and calculated using the ~~below~~ equation provided and the results were recorded as shown in Table 4.11.

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Table 4.10 Factor assigned to L_{27} Orthogonal Array

Test No.	Columns													Objective function		S/N ratio
	T_m	P_i	T_m P_i	T_m P_i	f_g	T_m f_g	T_m f_g	P_i f_g	N_s	R_m	P_i f_g	*	*	Run 1	Run 2	

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**			
1	1	1	1	1	1	1	1	1	1	1	1	1	1	$y_{1,1}$	$y_{2,1}$	S/N_1
2	1	1	1	1	2	2	2	2	2	2	2	2	2	$y_{1,2}$	$y_{2,2}$	S/N_2
3	1	1	1	1	3	3	3	3	3	3	3	3	3	$y_{1,3}$	$y_{2,3}$	S/N_3
4	1	2	2	2	1	1	1	2	2	2	3	3	3	$y_{1,4}$	$y_{2,4}$	S/N_4
5	1	2	2	2	2	2	2	3	3	3	1	1	1	$y_{1,5}$	$y_{2,5}$	S/N_5
6	1	2	2	2	3	3	3	1	1	1	2	2	2	$y_{1,6}$	$y_{2,6}$	S/N_6
7	1	3	3	3	1	1	1	3	3	3	2	2	2	$y_{1,7}$	$y_{2,7}$	S/N_7
8	1	3	3	3	2	2	2	1	1	1	3	3	3	$y_{1,8}$	$y_{2,8}$	S/N_8
9	1	3	3	3	3	3	3	2	2	2	1	1	1	$y_{1,9}$	$y_{2,9}$	S/N_9
10	2	1	2	3	1	2	3	1	2	3	1	2	3	$y_{1,10}$	$y_{2,10}$	S/N_{10}
11	2	1	2	3	2	3	1	2	3	1	2	3	1	$y_{1,11}$	$y_{2,11}$	S/N_{11}
12	2	1	2	3	3	1	2	3	1	2	3	1	2	$y_{1,12}$	$y_{2,12}$	S/N_{12}
13	2	2	3	1	1	2	3	2	3	1	3	1	2	$y_{1,13}$	$y_{2,13}$	S/N_{13}
14	2	2	3	1	2	3	1	3	1	2	1	2	3	$y_{1,14}$	$y_{2,14}$	S/N_{14}
15	2	2	3	1	3	1	2	1	2	3	2	3	1	$y_{1,15}$	$y_{2,15}$	S/N_{15}
16	2	3	1	2	1	2	3	3	1	2	2	3	1	$y_{1,16}$	$y_{2,16}$	S/N_{16}
17	2	3	1	2	2	3	1	1	2	3	3	1	2	$y_{1,17}$	$y_{2,17}$	S/N_{17}
18	2	3	1	2	3	1	2	2	3	1	1	2	3	$y_{1,18}$	$y_{2,18}$	S/N_{18}
19	3	1	3	2	1	3	2	1	3	2	1	3	2	$y_{1,19}$	$y_{2,19}$	S/N_{19}
20	3	1	3	2	2	1	3	2	1	3	2	1	3	$y_{1,20}$	$y_{2,20}$	S/N_{20}
21	3	1	3	2	3	2	1	3	2	1	3	2	1	$y_{1,21}$	$y_{2,21}$	S/N_{21}
22	3	2	1	3	1	3	2	2	1	3	3	2	1	$y_{1,22}$	$y_{2,22}$	S/N_{22}
23	3	2	1	3	2	1	3	3	2	1	1	3	2	$y_{1,23}$	$y_{2,23}$	S/N_{23}
24	3	2	1	3	3	2	1	1	3	2	2	1	3	$y_{1,24}$	$y_{2,24}$	S/N_{24}
25	3	3	2	1	1	3	2	3	2	1	2	1	3	$y_{1,25}$	$y_{2,25}$	S/N_{25}
26	3	3	2	1	2	1	3	1	3	2	3	2	1	$y_{1,26}$	$y_{2,26}$	S/N_{26}
27	3	3	2	1	3	2	1	2	1	3	1	3	2	$y_{1,27}$	$y_{2,27}$	S/N_{27}

$$S/N_{HB} = -10\ log\left(\frac{1}{r}\sum_{i=1}^{r}\frac{1}{y_i^2}\right)$$

Where r = no of trials

y_i = response chosen

Table 4.11 Experiment response with S/N ratio

Test No.	**No of Good items out of 500**		**S/N ratio (HB)**	**Test No.**	**No of Good items out of 500**		**S/N ratio (HB)**
	Run 1	**Run 2**			**Run 1**	**Run 2**	

1	401	452	52.55	**15**	458	478	53.39
2	462	450	53.17	**16**	490	486	53.76
3	421	436	52.63	**17**	369	389	51.56
4	390	401	51.94	**18**	385	368	51.5
5	369	354	51.15	**19**	436	455	52.97
6	469	476	53.48	**20**	395	421	52.19
7	485	468	53.55	**21**	459	462	53.26
8	359	346	50.93	**22**	463	475	53.42
9	310	264	49.07	**23**	401	426	52.31
10	418	431	52.55	**24**	485	476	53.63
11	479	469	53.51	**25**	495	486	53.81
12	352	378	51.22	**26**	425	435	52.66
13	301	320	49.82	**27**	465	452	53.22
14	329	365	50.77				

4.2.6.5 DoE Step 5: Data analysis

The data collected in ~~2~~ two replicates of 27 trials were ~~analyzed~~ analysed and the mean values of the response and S/N ratios were for the main factors and interactions. These are ~~were~~ ~~given~~ shown in Table 4.12. ~~Mean~~ The mean response for factor T_m at level 1 was calculated by averaging the responses of tests in which the factor T_m ~~is~~ was kept at level 1.

Thus, the mean response of factor T_m at L1 =

$$= \frac{(401+462+421+390+369+469+485+359+310)+(452+450+436+401+354+476+468+346+264)}{2\ X\ 9}$$

$$= 406.3$$

Similarly, the mean response and the mean S/N ratio values for all the factors and interactions at each level were also calculated.

Table 4.12 Mean Response and Mean S/N ratio

Factors \ levels	L1	L2	L3
T_m	406.3	403.6	450.7
P_i	432.1	413.1	415.4
f_g	436.3	402.4	421.9
N_s	420.8	419.4	420.4
R_m	419.7	410.5	430.4
T_m x P_i	442.4	425.5	405.4
P_i x f_g	412.2	436.1	412.3
T_m x f_g	425.4	420.9	414.2

Factors \ levels	L1	L2	L3
T_m	52.06	52.02	53.06
P_i	52.7	52.22	52.23
f_g	52.7	52.03	52.38
N_s	52.40	52.34	52.39
R_m	52.36	52.14	52.63
T_m x P_i	52.60	52.50	52.00
P_i x f_g	52.20	52.70	52.20
T_m x f_g	52.60	52.40	52.20

4.2.6.6 DoE Step 6: Response curve analysis

~~Response~~ The response curves pertaining to the mean response and the mean S/N ratio values were plotted in ~~figure~~ Figure 4.19 against each level of the factors to represent the change in the performance characteristics for the variation in factor levels.

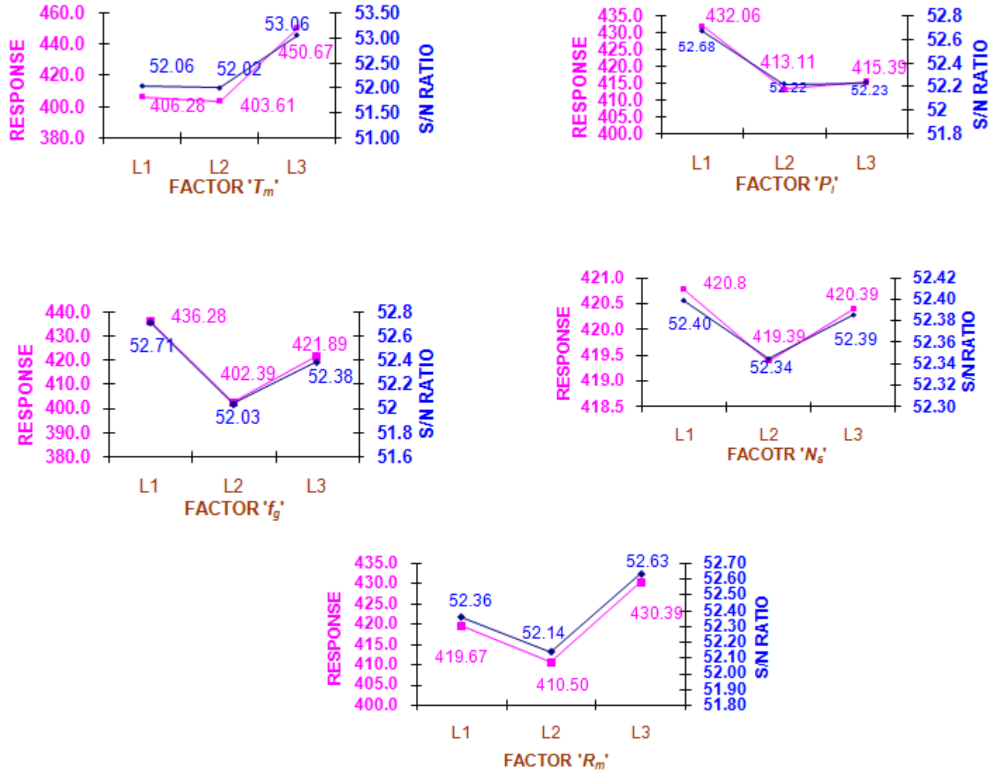

Figure 4.19 Response curves for process parameters

From Figure 4.19, we identified the optimum factor levels ~~were identified~~ based on the “Higher is Best” S/N ratio characteristic and listed these in Table 4.13.

Table 4.13 Optimum factor settings

Notation	**Factor**	**Optimum level**	**Value**
$\boldsymbol{T_m}$	Metal Temperature	L3	715^0 C
$\boldsymbol{P_i}$	Intensifier pressure	L1	220 Kg/cm^2
$\boldsymbol{f_g}$	Degassing frequency	L1	320 shots/degas
$\boldsymbol{N_s}$	II phase turns	L1	3 no
$\boldsymbol{R_m}$	Metal mixing ratio	L3	60:40

4.2.6.7 DoE Step 7: Mean response predicting

~~Confident~~ The confident interval and the mean response were estimated ~~as below~~ to validate the optimum factor level setting:

$$\mu_{Good} = \boldsymbol{T_{m3}} + \boldsymbol{P_{i1}} + \boldsymbol{f_{g1}} + \boldsymbol{N_{s1}} + \boldsymbol{R_{m3}} - 4M_{good}$$

Where

$\boldsymbol{T_{m3}}$ - mean response at level 3 of factor $\boldsymbol{T_m}$

$\boldsymbol{P_{i1}}$ - mean response at level 1 of factor $\boldsymbol{P_i}$

$\boldsymbol{f_{g1}}$ - mean response at level 1 of factor $\boldsymbol{f_g}$

$\boldsymbol{N_{s1}}$ - mean response at level 1 of factor $\boldsymbol{N_s}$

$\boldsymbol{R_{m3}}$ - mean response at level 3 of factor $\boldsymbol{R_m}$

M_{good} - overall mean response value

By using the mean response values from ~~table~~ Table 10, we calculated the estimated means ~~was calculated as~~:

$$\mu_{Good} = 450.7 + 432.1 + 436.3 + 420.8 + 430.4 - 4(420.18)$$

$$\boldsymbol{\mu_{Good} = 489.58}$$

~~Confidence~~ The confidence interval for the population was calculated using the following formula (Ross, 1988):

$$CI = \sqrt{(F_{\alpha;1;V_e} V_e \left[\frac{1}{n_e}\right])}$$

Where

$F_{\alpha;1;v_e}$ = F ratio required for α (risk)

v_e = error degree of freedom

V_e = error variance

n_e = experiment trails = 54

In this study,

α risk is taken as 0.10

Confidence = 1 - risk

v_e – degrees of freedom for error variance is 41 from table 4

V_e = 1929.65 from ANOVA table

F_α (1, 41) = 2.84 (taken from f – ratio table)

Hence,

$$CI = \sqrt{(2.84)(1929.65)[1/54]}$$

$$CI = 10.1$$

The estimated mean response ~~is~~ was 489.58 and at 90% CI, the predicted optimum output w~~ould be~~as estimated at:

$$[\mu_{Good} - CI] < \mu_{Good} < [\mu_{Good} + CI]$$

$$[489.58 - 10.1] < \mu_{Good} < [489.58 + 10.1]$$

$$\mathbf{479.5 < \mu_{Good} < 499.7}$$

4.2.6.8 Six Sigma control stage

The real challenge for the research approach in this study ~~was~~ lies not in making improvements to the process but in providing ~~a~~ sustained improvement in organisational productivity through process ~~optimization~~optimisation. This required ~~standardization~~ standardisation and constant monitoring and control of the optimized process. Process control limits were obtained using the optimum parameter levels for maintaining the process out of defects. Implementation of the aforementioned optimum factor levels resulted in an improvement of process yield and reduction in defect probability. ~~-~~Moreover, an iterative fashion in implementing the TPE model was found to be more indispensable. An extensive training programme for the personnel connected by the process changes was conducted within the company to ~~make easy~~ease the implementation of the ~~the~~ TPE model ~~implementation~~. It is well known that real improvement ~~only~~ comes only from the shop floor. Process sheets and control charts were made so that the operators ~~can~~ could be prepared to take preventive action before the critical process parameters and critical performance characteristics strayed outside of the control limits. A complete database was prepared to maintain the improvements to the results. Proper monitoring of the process helped to detect and correct out-of-control signals before they resulted in a loss of productivity.

Comment [Editor20]: Please check for incomplete sentence.

Comment [Editor21]: Do you mean to say keeping the process free of defects'?

4.3 RESULTS OF THE IMPLEMENTATION

In this case implementation, the application of the ~~has~~ TPE model brought down the process defects from 22.11% to 6.68% (15.43% decrease) and accelerated the component productivity from 77.9% to 93.3% (15.4% increase).

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