INVESTIGATIONS ON DRIVING INNOVATION IN SMALL SIZE FOUNDRIES THROUGH THE IMPLEMENTATION OF LEAN SIX SIGMA PRINCIPLES

A Thesis submitted to Gujarat Technological University

for the Award of

Doctor of Philosophy

in

Mechanical Engineering

by

Dave Darshana Kishorbhai

129990919003

Under Supervision

Of

Dr. Hitesh Panchal

GUJARAT TECHNOLOGICAL UNIVERSITY

AHMEDABAD

FEBRUARY – 2019

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DECLARATION

I declare that the thesis entitled **Investigations On Driving Innovation In Small Size Foundries Through The Implementation Of Lean Six Sigma Principles** submitted by me for the degree of Doctor of Philosophy is the record of research work carried out by me during the period from December 2012 to June 2018 under the supervision of Dr.R.Murugesh and Dr. Hitesh Panchal and this has not formed the basis for the award of any degree, diploma, associate ship, fellowship, titles in this or any other University or other institution of higher learning.

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ABSTRACT

In Indian SME's very few papers reported on lean six sigma from science direct, Inderscience, Taylor Francis and emerald publication .out of 17 papers only 8 papers reporting the LSS implementation in Indian SME's. In Indian SME'S papers reported work done in various sectors like cylinder frames manufacturing unit (Gnanaraj et al. 2011), Automobile accessories manufacturing unit (Kumar et al.(2007)), Rotary switches manufacturing organisation (Vinodh et al.2012), Automotive valves manufacturing organisation (Vinodh et al.2011), textile mill (Karthi et al.2013), frame work for An automotive component manufacturing organization(Swarnakar et al.2016),Aircraft Maintenance(karunakaran2016), and improvement of claim processing time(Mukhopadhyay and Ghosh 2013).Gujarat state satisfied the major need of cast automobile component and engine all over India and World. so author find the application of Lean Six Sigma in Foundry sector of Gujarat by developing a model and implement the model in several foundries and investigate the results of LSS in foundry .In foundry maximization of waste on floor so better result can be achieved with a proper directional training and monitoring waste on a floor and sources of major defect in casting can be identified by continuous monitoring the system as well workers as 80 percentage of problem occurs due to 20 percentage of causes. Author published a literature review paper (available in list of papers) of lean six sigma to identify this research gap in foundry. Authors identify LSS application in various sectors except foundry in literature review, so author identify foundry sector for LSS implementation and prepare a framework with a name LESSIFOUND (stands for LE-lean, SS-six-sigma, FOUND-foundry).In the context of drawing this inference, the doctoral work being presented in this thesis was carried out to implementing lean six sigma in several foundries of Gujarat. With the application of LSS in any industrial plant we can reduce the cycle time, meet the customer need, and reduce the 7 types of waste and financial benefit and global optimization. LESSIFOUND model enables the foundries to acquire core competencies in LSS. Framework of LSS is required to be formulated so as to enable the effective and successful implementation. Hence a framework of LSS for effectively implementing in foundries is presented in this thesis.Further a questioner is prepared and pilot survey is conducted by the author in various foundries of Gujarat by personnel conversation with managing director, senior personnel of the full time employee to find a best outcome of the survey. Questioner is authentified by lean six sigma black belt practitioner and verified by academic researchers as well. Literature survey and pilot survey conclude with a need of improvement and change in work culture of an Indian foundries. A 13 step LESSIFOUND model is design to reduce the casting defects, waste and total cycle time and hence productivity can be improved. Investigations on LESSIFOUND model in selected three foundries of Gujarat approves this model for LSS implementation in foundries as well there is no deficiencies found in model. Comparison of developed LESSIFOUND model with other researchers developed model also prepared in this thesis.

Dedicated

To

My Family & God

Acknowledgement

Interminable much gratitude goes to Lord Almighty for every one of the favors he has showered onto me, which has empowered me to compose this last note in my examination work. Amid the time of my exploration, as in whatever is left of my life, I have been honored by Almighty with some unprecedented individuals who have spun a trap of help around me. Words can never be sufficient in communicating that I am so appreciative to those unbelievable individuals throughout my life who made this postulation conceivable.

As they say, any journey cannot be accomplished without the able support of people who directly or indirectly lend their time or resources, in order to reach your goal. First and foremost, I would like to convey my heartfelt gratitude to my parents, my husband, my daughter and my entire family for their continuous motivation and adjustments during this crucial tenure.

I would like to thank from the bottom of my heart to my supervisor Dr. Hitesh Panchal, for believing in me, even when I gave up from time to time. His blessings, motivation and constant support in worst and best times, has finally paid off in terms of our research. It would not have been possible for me to constantly strive for better performance without his extraordinary vision. As a teacher and a guide, he never leaves the hands of his students. He is with you like a shadow during good and bad. He has always believed in me more than anyone else. I would also like to sincerely thank Dr. R.Murugesh, Dr. A.V.Gohil and Dr. Yogesh Chauhan, for their frank reviews and suggestions which made our journey a lot easier.

I might want to deliver uncommon because of the obscure analysts of my theory, for tolerating to peruse and audit this proposition. I wish to thank the proprietors of foundry who gave authorization and enable their sources to use in this examination work. I might want to welcome every one of the analysts whose works I have utilized, at first in understanding my field of research and later for updates. I might want to thank the numerous individuals who have encouraged me beginning with my teachers, my undergrad educators, and my post graduate instructors.

Table of Content

List of Abbreviation

TQM	Total Quality Management
TPS	Toyota Production system
LSS	Lean Six Sigma
LM	Lean Manufacturing
GTC	German Techno cast
MF	Mahalaxmi Foundry
SF	Sanjay Foundry
CGM	consultant of LESSIFOUND

List of Symbols

σ- SIGMA

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CHAPTER-1

Introduction

1.1. Introduction

Casting component requirement all around the world is about 91.67%.China is the leading country with 39.6% satisfying global demand and India is the 2nd largest supplier of casting product with 9.05 %. Figure 1.1 shows the share of significant casting producing Countries in the world. In India, approximately 4500 foundries located at various clusters like Ludhiana, Batala, Jalandhar, Delhi, Agra, Howrah, Bhopal/Indore, Chennai, Coimbatore, Belgaum, Kolhapur, Mumbai, Rajkot to produce a metal casting . This foundry produces 9 Million MT PA by using 5,00,000 Directly and 1,50,0000 indirect employment. Every cluster specialized for their manufacturing monopoly in the market like in south region Coimbatore cluster has the monopoly in pump-sets castings, In Gujarat, Rajkot cluster has the monopoly for manufacturing of diesel engine castings and automotive casting and Howrah cluster for sanitary castings etc. Figure 1.2 shows the primary sector wise consumption in India. In all the Application of casting products, highest production is auto components about 32%, and mainly Gujarat cluster satisfies this requirement by sub zonal of Rajkot, Bhavnagar, Ahmedabad and Baroda.

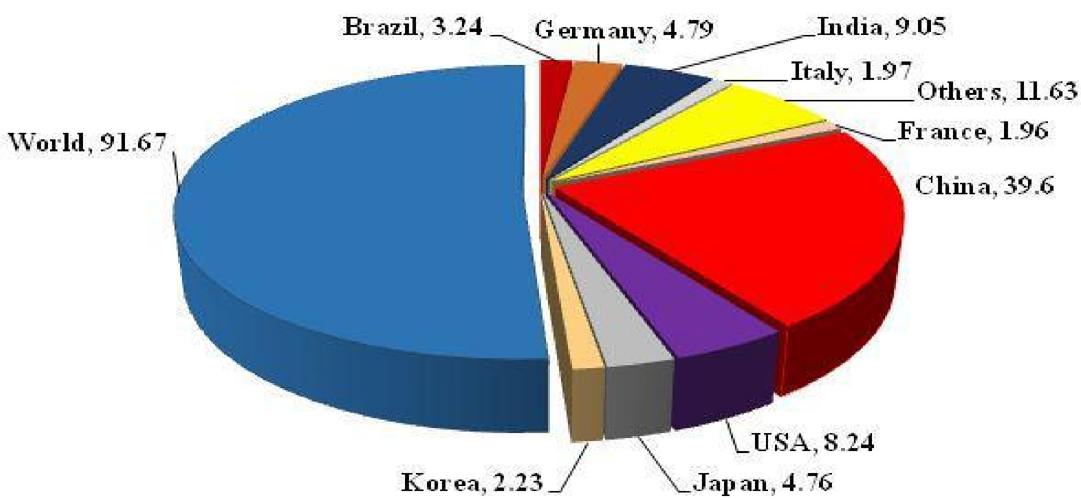


Figure: 1. 1 World consumption and significant supplier countries of casting Product

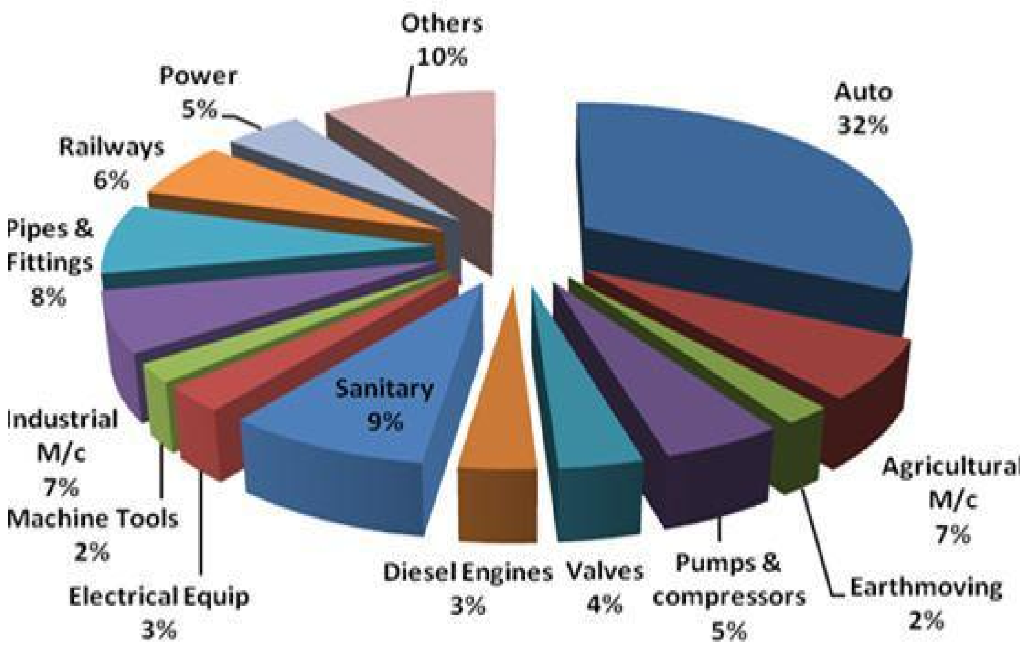


Figure:1.2 Sector wise significant consumers of castings. (Source: **The Institute Of Indian Foundry men)**

Figure.1.3 shows the product mix of cast metal component produce in India namely 68% of grey iron, 12% of steel, 10% of SG Iron,9% of nonferrous and 1 % malleable. Figure 1.4 shows the vision of Indian foundry industries. According to Institute of Indian foundry man in the year 2020 production of casting will be 25 million MT/PA while current production of casting is about 9.8 million MT/PA. To achieve this vision we have to focus on newer technique which improves the productivity and reduces the waste.

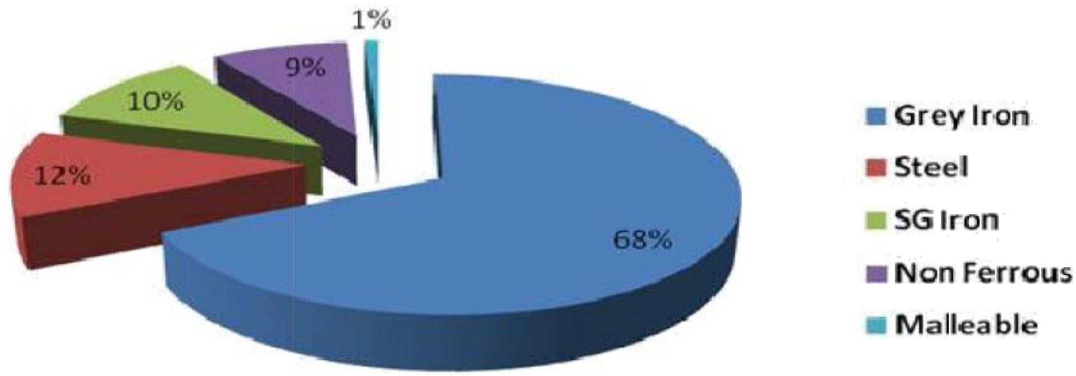


Figure:1.3 Product mix of cast metal- India (Source: The Institute Of Indian Foundry men)

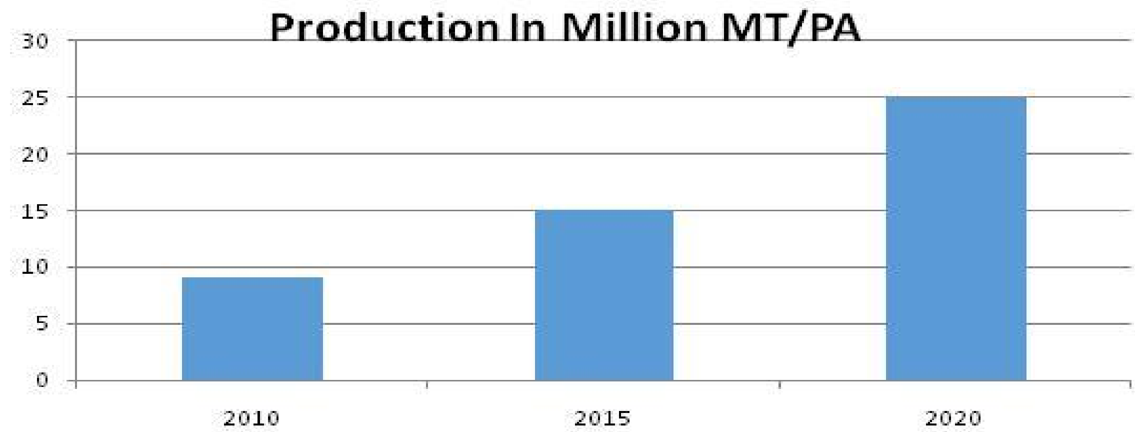


Figure: 1.4 Vision For Indian Foundry Industry (Source: The Institute of Indian Foundry men)

However, according to Figure 1.5, the statistics show, in the year 2016-2017 total production of casting product in India 11.35 in a million M.T./annum with 7.89% grey C.I., 1.18% SG iron,0.050 % Malleable,1.01 % of steel, and 1.22% of nonferrous casting. According to the vision, we cross the 15 Million M.T./annum, but with the nonproductive and traditional method, it is possible with the quality concept like lean and six sigma. We change the conventional casting methods with the hybrid technology called Lean Six Sigma with the utilization of the same resources and no need of high capital investment to introduce the same.

Lack of implementation of modern tools and techniques in foundries to acquire core competencies.

	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Grey C.I.	5.332	4.532	5.05	6.18	6.798	6.254	6.7	6.83	7.41	7.89
SG Iron	0.802	0.785	0.8	0.984	1.09	0.951	1.000	1.07	1.18	1.18
Malleable	0.0651	0.0605	0.0602	0.0692	0.066	0.0604	0.060	0.06	0.05	0.05
Steel	0.964	0.916	0.88	1.07	1.14	1.158	1.100	0.968	0.88	1.01
non ferrous	0.608	0.547	0.653	0.75	0.9	0.891	0.95	1.093	1.25	1.22
TOTAL	7.7711	6.8405	7.4432	9.0532	9.994	9.3444	9.810	10.021	10.77	11.35

Figure: 1.5 Productions of casting in a million M.T./Annum in India (Source: The Institute of Indian Foundry men)

During the beginning phase of pursuing the doctoral work reported in this thesis, the theoretical aspects of LSS were studied by, carrying out a literature review. While completing this writing audit, it was discovered that the specialists from a few viewpoints have analyzed the hypothetical and handy parts of LSS. This is an intriguing perception as the quantity of papers revealing inquires about on LSS has been less, however then issues tended to in them are many. This perception prompts a feeling that LSS has discovered expansive applications in numerous mechanical areas. Nonetheless, an audit toward this path in the writing field uncovered that LSS is yet to see usage in modern segments like foundry, pump and electronic devices fabricating divisions. This is a concerning situation as these industrial sectors play crucial roles in wealth and employment generation in numerous societies. In the context of this observation, on completing the first phase of the doctoral work reported in this thesis, it was decided to examine the implications of practically implementing the LSS in any one of these industrial sectors. Considering the expertise of the author of this thesis in the field of foundry technology, it was decided to investigate the implications of practically implementing LSS in the foundry sector. Subsequently, these investigations were conducted by implementing LSS in three different foundries. The experiences and knowledge gained by examining these theoretical and practical aspects of implementing LSS in general and particularly in the foundry sector are presented in this thesis.

1.2. Problem Definition

As mentioned in the previous section, Six –Sigma has been enabling the organisations, to facilitate to achieve ‘Zero defect manufacturing'. On the other hand, LM has been enabling the organisations, to improve quality and enhanced productivity while producing products by eliminating the wastes. Since these two approaches have been complimentary with each other, researchers brought out LSS concept by knitting both these approaches. Unlike LM and Six-Sigma, LSS has not found broad application in organisations. In a few organisations, in which the LSS has been applied, competitive strength has increased significantly. This observation indicates the need to study the implementation of LSS in sectors in which the implementation of the same has not yet been carried out. Foundry is one such sector in which the implementation of LSS in literature arena is, however, to be reported. During the beginning phase of conducting the research reported in this thesis, the absence of examining the implications of theoretically and practically implementing LSS was found to the primary problem of the doctoral work reported in this thesis.

On examining the theoretical aspects of LSS through the conduct of a literature review, it was discernable that the practical implementation of LSS in every sector is to be carried out by following unique models. As no research on implementing LSS in the foundry is yet to be reported in the literature arena, a model facilitating the implementation of LSS in foundry industrial sector is, however, to be contributed by the researchers. Apparently, due to this reason, the researchers have not examined the implications of practically implementing LSS in foundries. In this background, a model facilitating the implementation of LSS in foundries was considered as the secondary problem of the doctoral work reported in this thesis. To overcome these problems the doctorate work reported in this thesis was carried out.

1.3. Objectives

The following objectives were set beginning the doctoral work presented in this thesis to solve the quality problems in foundries.

1. To review the research activities conducted to examine the theoretical and practical aspects of LSS.

2. To study the research activities conducted in different industrial sectors to implement LSS practically.

3. To investigate the nuances of implementing LSS in the foundry sector.

4. To design a model for facilitating to achieve LSS in foundries.

5. To conduct investigations for gaining knowledge on the implications of practically implementing the designed model in foundries.

6. To study the results of conducting the investigations and examining the need to refine the designed model.

The above objectives were attained by pursuing the doctoral work reported in this thesis by following the systematic methodology which is described in the next section.

1.4. Methodology

The methodology followed to carry out the doctoral work reported in this thesis is shown in figure 1.6. As shown, this doctoral work was carried out in five phases. The first phase of the doctoral work was begun by gathering papers reporting researches on LSS. These papers were gathered from world's leading database namely science direct and the databases of United Kingdom-based publishers by names Emerald insight and Taylor and Francis. While carrying out this exercise care was taken to consider only the peer-reviewed papers for carrying out the review process subsequently. By reviewing these papers, the theoretical aspects of LSS were studied. The final observation of conducting this literature review was that though LSS is a powerful approach for acquiring competitive strength, it is yet to find applications in certain industrial sectors. Foundry is one among those sectors.

While carrying out the second phase of this doctoral work, a model named as LESSIFOUND (stands for Lean Six Sigma in Foundries) was designed by referring to the observations and knowledge gained by conducting the literature review in the first phase. While designing this model care was taken to amalgamate the nuances of foundry practices and steps of LSS is an appropriate form. To examine the theoretical propositions of LESSIFOUND model were drawn while carrying out the third phase of the doctoral work being reported here. To carry out this exercise, a hypothetical case study on implementing LESSIFOUND model in an imaginary foundry was formulated. While making these formulations care was taken to ensure that the conditions of imaginary foundry were same as that of actual foundries.

By referring to the LESSIFOUND model and steps of the hypothetical case study, the investigations on implementing LESSIFOUND model were carried out during the fourth phase of the doctoral work being reported here. These three investigations were conducted separately in three different foundries located in the Gujarat state of India. During the fifth and last phase of carrying out the doctoral work being reported here, the results of examining the theoretical and practical aspects of LESSIFOUND model were analysed. This analysis was carried out by comparing the steps of the hypothetical case study with that of the actual case studies conducted to investigate the implications of practically implementing the LESSIFOUND model. Though there were deviations between practical and hypothetical case studies, the implementation of LSS through LESSIFOUND model was near success. In this background, this doctoral work was conducted by claiming that LESSIFOUND model is a valid model for successfully implementing LSS in foundries.

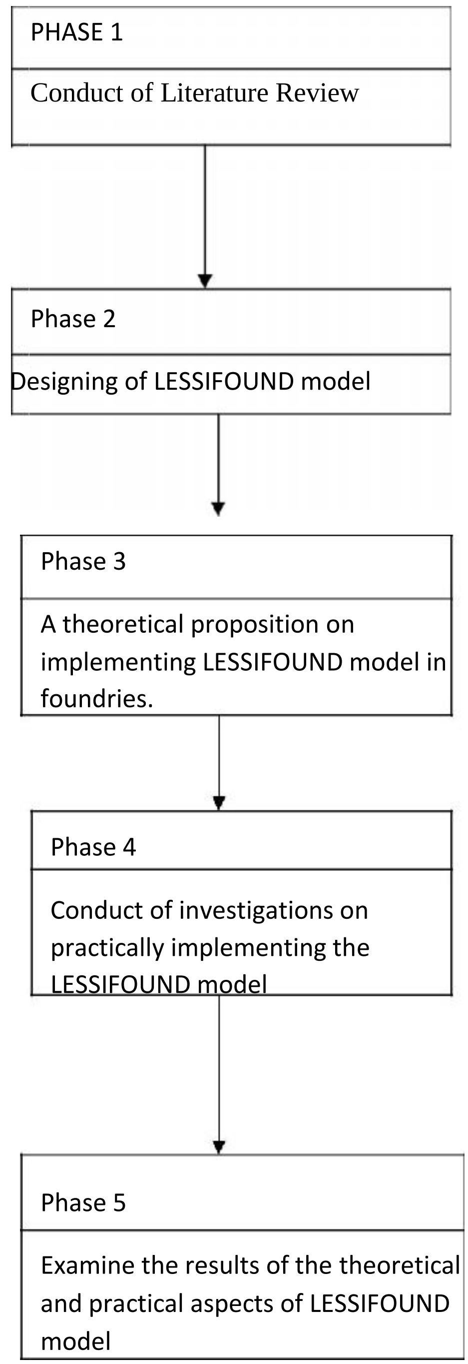


Figure 1.6 Methodology

1.5 Chapter Organisation

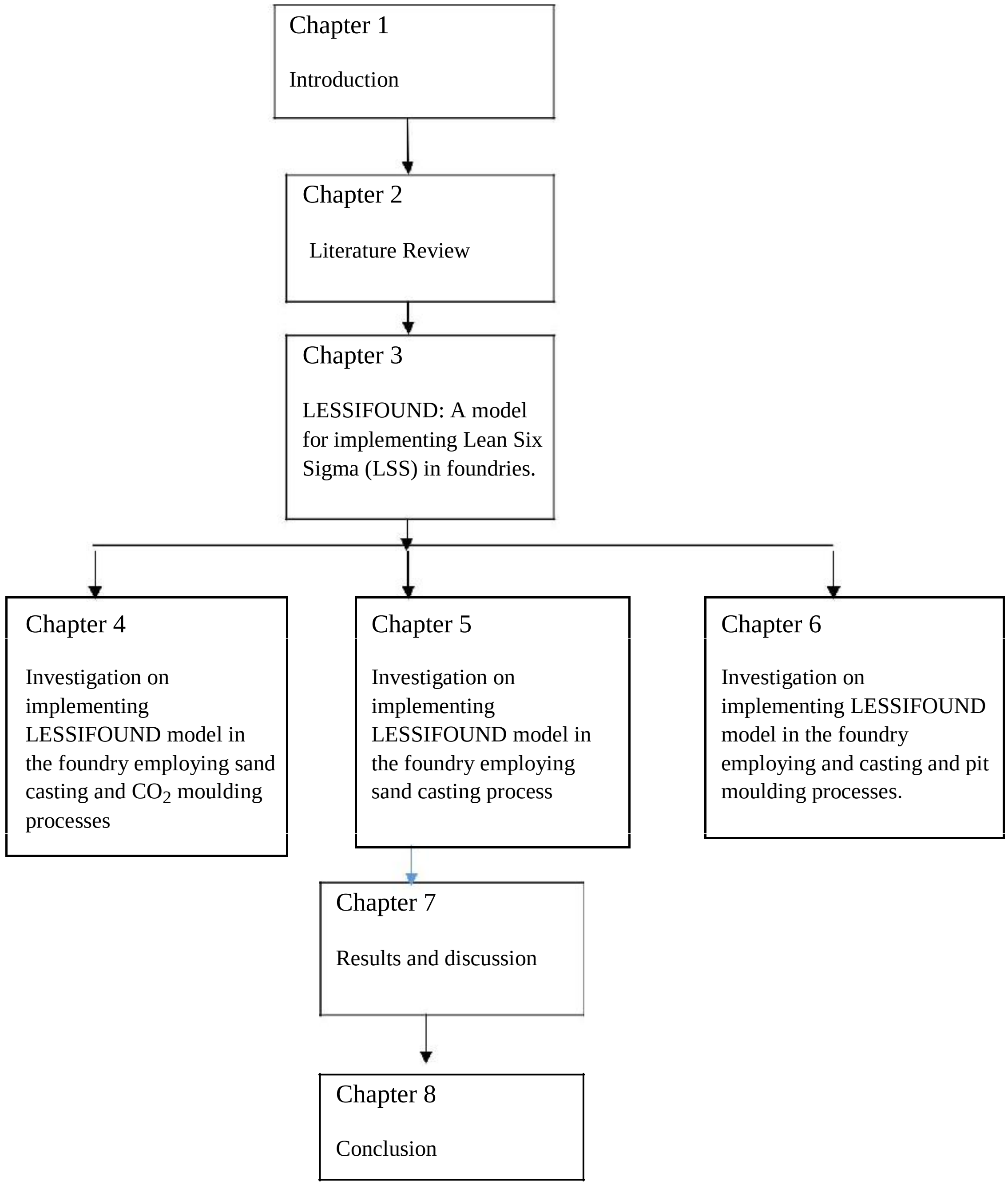


Figure 1.7 Chapter Organisations

The organisation of the chapters in this thesis is shown in figure 1.7. As shown the doctoral work been reported here is presented in this thesis in eight chapters. As shown in the current first chapter, the doctoral work and thesis are introduced. Notably, the power of LSS and the need of examining its practical implementation are appraised in this chapter. In the second Chapter, the researches on LSS which are reported in the literature arena are described. In this chapter, the research gap which has been filled by carrying out the doctoral work being presented here is pinpointed. In chapter 3, the theoretical aspects of implementing LSS in foundries are presented. In this chapter, the background of the LESSIFOUND model and the hypothetical case study are described. In chapter 4, 5 and 6, the three investigations conducted to examine the implications of practically implementing LESSIFOUND model are presented. These investigations were conducted in conventional foundries in which sand casting process is adapted to manufacture castings. However, these foundries differ from the types of moulds used while carrying out the sand casting process. In one foundry CO_2 moulding process is being adopted. In another foundry, conventional moulds are used. In yet another foundry, pit moulding process is being selected. In chapter 7, the results of conducting the investigations are discussed. Particularly in this chapter, the deviations observed while conducting investigations from the hypothetical case study are narrated. The thesis is undertaken in the eighth chapter. After describing the contributions and limitation of this doctoral work, the scope for pursuing further research in the direction of the doctoral work reported in this thesis is presented. This chapter is finally ended by making concluding remarks. Besides these chapters, the lists of papers referred and published are attached in this thesis. Efforts have been made throughout the thesis to use precise language, figures, photographs and tables to understand the activities carried out while pursuing the doctoral work being reported in this thesis.

1.6. Conclusion

During the past two decades, all industrial sectors have been facing the onslaught of the intensification of the competition. To meet this challenge, numerous strategies approaches, paradigms, techniques and tools are being implemented in industrial sectors. As a result, researchers have been examining the practicality of implementing these competitive strategies. While making these endeavours, during the recent years, engineers and researchers have been adopting strategies which combine different approaches and paradigms. One such strategy is the adoption of LSS. Since the synergy of implementing LM and Six-Sigma is achieved, LSS is a powerful technique for enabling industrial sectors to acquire capabilities to face the onslaught of intensified competition. Hence the theoretical and practical aspects of implementing LSS in the industrial sector are required to be examined. In the context of this realization, the examination of theoretical and practical aspects of implementing LSS in the foundry sector fell within the scope of the doctoral work presented in the following chapters of this thesis.

CHAPTER 2

Literature Survey

2.1. Introduction

After second world war competition is very high in a global market [35][42][62][63][68]. In today's customer has many options to purchase his product from the market as well from E-commerce like Amazon, Flip kart, Snap deal etc. with various attractive offers and discounts may vary from one site to another site so competition to survive in a market is quite high. Researchers have a pressure to identify a proper model or technique to implement in the industry to reduce the defect by identifying waste and eliminate the waste from the final product so total cost can be reduced and productivity and profitability can be increased. Before the 1980s industry relies on quality only, then TQM philosophy came and improved the quality of the product with the utilization of the same resources, but team involvement and job satisfaction were higher. TQM improves the quality of the product, but profitability was still an issue since it was not changed. So Motorola developed a Six –Sigma methodology to improve quality, productivity and profitability of an industry. So in worldwide many industries quickly implement Six-Sigma. Still, the industry wants to increase the profit by the reduction in product manufacturing cost by identifying a waste component on a shop floor, and Lean Manufacturing concept developed. We can also say that Lean manufacturing roots in TPS [2]. Basically in a market two types of system 1. Pull system and 2. Push system. Normally pull system is more preferable as manufacturer prepare the product as per customer's requirement so it can be absorbed in a market and zero inventory concept used and inventory cost can be reduced so manufacturer selling cost can be reduced and increases the profit. In the push system manufacture gives attractive offers to sell their product as the inventory of the product is high and if it sold out, then their profit may come. So the world starts to implement TPS concept. In 1990, lean manufacturing introduced by James P.Womack, Daniel T.Jones and Daniel Roos in their book entitled "The machine that changed the world" [5], [12]. The main objective of lean manufacturing is to the elimination of ‘wastes’ for continuous

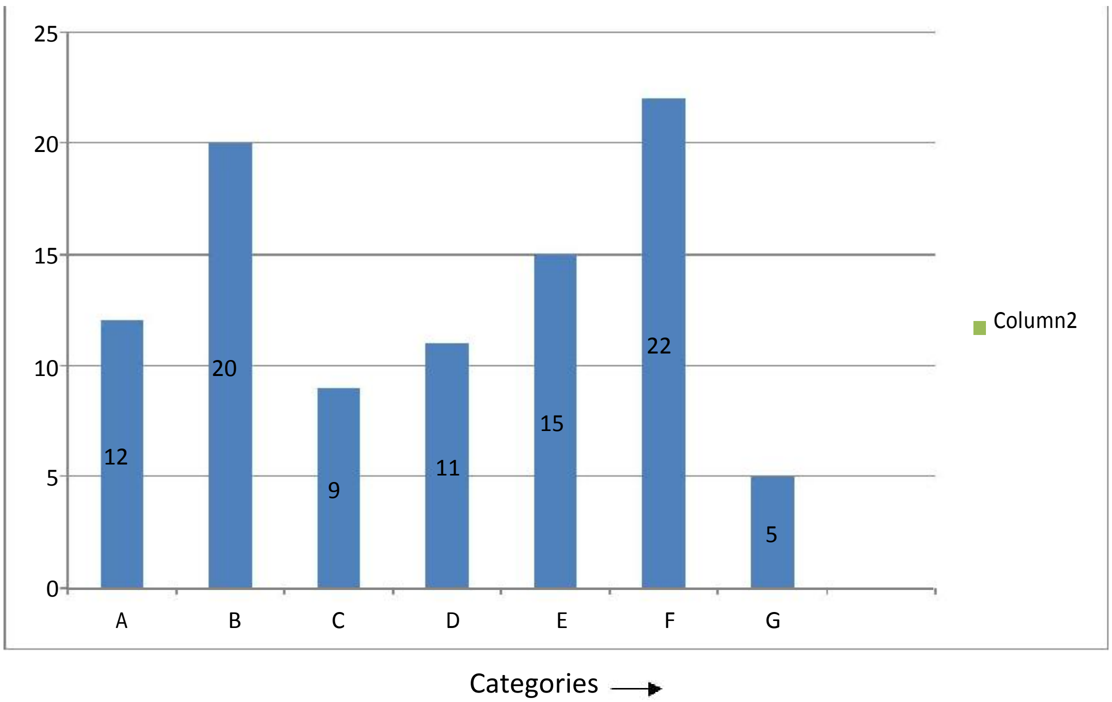
Improvement [14], [37] such as over-production, inventory and delay.

Few researchers are combining the Lean and Six-sigma to take the benefits of both technologies as LSS or Lean Six Sigma [2][12]. Such a way hybrid technology Lean six sigma developed in a worldwide [8] [9] [12][28][50][66]. The primary objective of LSS achieving Zero defect, waste elimination with continuous improvement [1].The much industrial organization started to implement LSS [3][10][22][23][63] and research papers on LSS also appeared in the literature review[43]. From this need-based analysis United Kingdom publication house 'Emerald Group Publishing Limited' launched a journal entitled 'International Journal of Lean six-sigma' for LSS researchers and academicians [63]. This upward trend revealed the need to examine the theoretical and practical aspects of LSS. Before beginning the doctoral work being reported here, the researchers said in the literature arena were surveyed. This literature survey was conducted with the primary objective of tracing the origin, examining the principles and identifying the applications of LSS in worldwide. The details of conducting this literature review are presented in this thesis chapter.

Here the literature survey was carried out in three phases. In the first phase, the collection of research papers from reputed higher impact factor journals with searching keyword as LSS.LSS is a new field, so research papers on LSS were quite less in numbers than lean, Six-sigma, TPM, TQM etc. From these research papers, review the content of this papers as the second phase of the literature review. During this second phase of the investigation, the author identifies seven section or categories of LSS like, the origin of LSS, tools and techniques of LSS, models of LSS, Success factors of LSS, Challenges in LSS implementation etc. reported in the subsection of this chapter. In the third phase, collected research papers are categorized into these seven issues or section for the more in-depth review.

2.2. Statistics

When searching with a Keyword LSS, 45 papers identified from world's most reputed data based journal of science direct, Springer link and emerald insight. During the review process, the author identified the contents of these papers and identified seven issues related to LSS. Most of these papers addressed more than one of these issues. The graph is plotted based on this research paper statistics are shown below in Figure 2.1.



Categories: A, B, C, D, E, F and G

Category A: Origin of LSS

Category B: Models of LSS

Category C: LSS Implementing Benefits

Category D: Success ingredients of Lean six-sigma

Category E: Tools and techniques used for LSS implementation

Category F: Areas / sectors of LSS applications

Category G: Barriers/Challenges of LSS implementation

Figure 2.2. Statistics of papers reviewed

From the Figure 2.1 classification F has most extreme 22 number of research papers demonstrating the territory and utilization of LSS while class G has least 5 number of research papers investigating difficulties in executing LSS. The data and information picked up by looking into these examination papers are displayed in the accompanying seven areas.

2.3. Origin of LSS

In this section, the author identified 12 papers reporting Origin, and meaning of LSS. Multinational companies like General Electronic, Motorola, Allied Signal used Six Sigma from the early 20th Century[8].Six Sigma works variability reduction and lean works on the elimination of wastes /Muda. LSS is the integration of Lean and Six-sigma focuses on both variability reduction and elimination of wastes. Literature shows standardized training modules for LSS implementation according to sector-wise /manufacturing unit wise, not available.LSS with DMAIC methodology implemented in any organization to achieve the benefits of LSS.

Some researchers reported in their research paper that LSS first time applied by GE by individually utilized lean and six sigma technology in their plant [55]. LSS offers various benefits like product cycle time reduction, waste identification and elimination by introducing value-adding components only. So LSS become popular worldwide in manufacturing sectors. Lokkerbal et al. (2012) have pointed out that LSS emerged from this manufacturing revolution. Meanwhile, LSS applied in service sectors also. Lean and six sigma concept emerged in the year 2000 [15].The synergy of Lean and Six- Sigma can be treated as LSS by proving a list of 14 checkpoints before implementing LSS through lean and Six-sigma[53][59]. Sarkar et al. (2013) have claimed that LSS roots in Juran's philosophy and LSS implemented through execution of DMAIC techniques. Some researchers focused on belt based LSS training modules for LSS implementation for the better quality of the product and higher customer satisfaction [40][41].A group of researchers reported in their research LSS encompasses the principles of both Lean and Six-sigma[33][34][45]. Lean manufacturing focuses on continuous improvement by waste elimination while Six-sigma focuses on zero defect by 3.4 DPMO (defects per million opportunities). To increase the financial profit of an organisation LSS works on process improvement through six aspects of bottom line achievement[63].LSS involves human issues as well as process issues makes it popular among all available methodology and this integration results in financial profit through bottom line achievement.

2.4. Models of LSS

For LSS implementation lean manufacturing and six-sigma integration is a prime requirement. Researchers and LSS practitioners understand this truth but many companies already applied LSS in Worldwide [3]. There is no standardized LSS model developed by Researchers and LSS practitioners. Meanwhile, some researchers pointed out that DMAIC technique used as the model of LSS implementation in industry.[23][42][60]. In the literature review, 20 papers reporting on models of LSS and among them ten papers deal with DMAIC. So researchers and LSS practitioners understand the implementation of LSS model by the merger of DMAIC with Lean manufacturing Various Lean manufacturing techniques like VSM, 5S, Kaizen TPM, SIPOC and 5-Whys techniques mainly used with DMAIC[10][11][16][17][26][39][41][59][63][64]. Some researchers used a term VSM [41] and some researchers used a term VFM in their LSS model[10][17][26][29][59][64]. A group of researchers identify various LSS models like DMADV, IDOV, DIDES and DMARIC [52][57]. So ultimately DMAIC is in the foundation of the LSS model. Integration of DMAIC with lean tools may vary according to organisation nature and scope of LSS implementation.

A group of researchers combining DMAIC with ISO standards and belt based training modules [33][34] [54] while some researchers used the 5S tool only for LSS implementation[61]. Meanwhile, one other group of researcher gave preference to a method employed for LSS implementation in an organization [59] [22][36]. Yamamoto and Bellgran (2013) demonstrates four types of innovative model term as manufacturing process innovation model (MPI) as structural and locally innovative model (MPI type-I) by installing new equipment's in the plant ,infrastructural and locally innovative model (MPI type II) by initialize new methodology like lean and six sigma ,structural and radically innovative model (MPI type III)by developing new equipment/machinery for an industry and infrastructural and radically innovative model (MPI type IV)by developing a new work methods and apply them in to factory. Lanza et al. (2013) demonstrate the use of OEE (overall equipment effectiveness) to improve the effectiveness of production globally using TEEP (total effective equipment productivity) and overall equipment effectiveness. OEE is a fundamental tool for TPM, but nowadays, it is successfully used in lean and six sigma projects also. Breyfogle III (2010) demonstrated the power of TOC for LSS implementation while Gibbons and Burgess (2010) showed research using OEE framework. Among all, Psychogios et al. (2012) presented a training infrastructure framework for LSS implementation. These researchers have emphasized that corporate strategy should be integrated with LSS project execution.

From the above survey, the author identifies there is no generalized model for LSS practitioner and researchers, so there is a need of a generalized core model according to various industrial sectors like Pharmatutical industry, Textile industry, Shipbuilding industry, Conventional unit, Rolling mill unit, Sheet metal unit, Foundry unit etc. However, DMAIC used as the core framework with the variety of lean tools like VSM, 5S; Kaizen may be used to developed LSS model according to core industry and take the benefit of LSS implementation.

2.5. LSS Implementing Benefits

Under this category nine papers identified to extract authentic LSS implementing benefits to the various industrial sectors. Most essential benefits are providing the product or services according to customer need[6][39][40][41], cycle time reduces[59][63][39][40][41][55],identify and eliminating non value added activities[24][41][63] by increasing value adding activities [6][24][40][41][55] , reducing the COPQ [39][40][41][59], Operation activities development and improvement [45][59], competitive advantage and process improvement by quality improvement and zero defect concept so waste reduces and financial benefit[41] [55][63] can be achieved by global optimization.

As per above discussion number of benefits achieved by LSS implementation. LSS offers a data-driven methodology which is not provided by lean or six sigma so here author concludes that LSS delivers another advantage than lean or six sigma alone so competitive strength can be increased by adding value-added activities in an organization. So when an LSS model is designed to consider the above benefits in beginning phase of design a model and give a power of competitive strength to that selected organization or sector.

2.6. Success ingredients of LSS

11 papers reported following CSFs (Critical Success Factors) during LSS implementation. Out of 11, 2 papers said CSFs of lean and six sigma methodologies. These authors mentioned CSFs of TQM, lean manufacturing, Kaizen and six sigma[21]. They measures the three CSFs were Commitment from Top management, Investment in training modules and cultural change for conducive entrepreneurial. Assaulted et al.2013 and Naslund (2008) reported CSFs for Lean, BPR, ERP and six sigma programs. They mentioned that CSFs are essential for LSS implementation. These authors also support the Commitment from

top management as CSFs in addition to this Vision and Business plan and organized the conductive culture.

Hilton and Sohal (2012) have mentioned 18 black belt competencies like interpersonal and technical skill should be combining with support from top management and customer relationship as core CSFs for lean and six- sigma implementation programmes. They also reported that trained LSS black belt personnel are challenging to found for LSS implementation. The success of LSS depends upon the vision of black belt trainer, training modules for bottom level and commitment from top management.

During literature review, three papers exclusively reported the CSFs for LSS implementation. Among these three papers, Jayaraman et al. (2012) mentioned nine CSFs for LSS implementation like. Project prioritization, LSS dashboards, top management commitment and black belt competency. Antony et al. (2012) have mentioned seven CSFs include organizational culture, Project prioritization and project selection support and commitment from top management. The contributions of Jayaraman and Teo (2010) are most appreciable by presenting 18 CSFs, and a developed a model for LSS implementation. With above CSFs they added the review, tracking or monitoring the system and effective training programmes for LSS.

Another group of researchers mentioned six CSFs for LSS implementation were training, support from management and customer preferences linked with LSS [45] While Psychogios et al (2012) gave preference to link the LSS with top management. Moreover, Snee (2010) also gave preference to leadership and management support has played key roles in the LSS implementation. The researchers have making great efforts to identify a list of CSFs successful LSS implementation in organizations. During this literature review author conclude that CSFs of TQM, JIT, lean and six-sigma are play a vital role in CSFs of LSS implementation. In addition to above CSFs LSS training, Prioritization and project selection and customer as a key focus for LSS implementation in any organization. In this section, the CSFs of JIT, lean, Six-sigma, TQM and Lean six sigma discussed with more importance of LSS implementation in any organization[32].

2.7. Tools and techniques used for LSS implementation

In this section author identified 50 tools for LSS implementation. Namely VSM[4][18][21][33][59],CED[18][21][33][34][38][60],Pareto analysis[4][18][33][34][38], Visual Management [4][18][38][59], Project Charter[4][33][39], SIPOC[4][18][33][34][39][41],RIW[4][59],COPQ[59],PDCAcycle[34][59],Kanban[59], 5S[33][59],TPM[59], Box plots[59], Control Charts[33][38][59], FMEA[18][21][33][38][59], Brainstorming[33][38], Standardization[33][60][38][59], Mistake Proofing by use of Poka-Yoke[33][38][59], SMED[59], Layout Planning[59], Measurement analysis[33][38][59], Process Capability Analysis[33][38][59], XY Matrix[18], RCA[60], Why-Why Analysis[60][38] [59] , Tree diagram[60], CDEAC[60], Kepper-Tregoe (K-T) approach [60], Partition Diagram[60], CART[60], Test of hypothesis[60], GEMBA [33][60], Takt time analysis[38] , Histograms[38] , Scatter diagram[38] , Workplace management[38] , Just-In-Time[33][38] , Production flow balancing[38] , Kaizen[33][38] , Change management tools[38] , Regression Analysis[33][38] , Hypothesis testing[33][38] , Quality Function Deployment[33][38] , Statistical Process Control[18][38] , Project Management[38] , Analysis of means and Variance[34][38] , KANO analysis[33] , Time trap analysis[33] , Repeatability chart[34].

As LSS is a hybrid methodology by combining Lean and Six- sigma so their tools and techniques can be used for LSS implementation [2][20]. During literature review 15 research papers identified and 50 tools and techniques identity for LSS implementation in any organization. Though few techniques used frequently like VSM, FMEA and cause-effect diagram while few techniques like QFD, KANO analysis, Regression Analysis and time trap analysis used relatively low for LSS implementation. Majority of the researchers employed DMAIC, belt based training, the voice of customer and employee. As more number of tools and techniques available for LSS implementation, so researchers and practitioners employ any tools and techniques for successfully LSS implementation.

2.8. Areas / sectors of LSS applications

In this section,22 research papers identified for discussion of areas and sectors for LSS implementation. Lean manufacturing and Six-sigma found a broad application in worldwide so LSS can also be applied to various sectors .like lean, and six-sigma LSS is newly generated methodology so only 22 research papers identified for areas and sectors of LSS application. It is quite interesting to note that like both these principles, LSS too has found broad applications. Atmaca and Gireness (2013) have reveled 14 areas and sectors suitable for LSS implementation. Majority emphasis on Battery industry, Aircraft industry, Public sector,IT

Sector , Pharmaceutical industry, Call centre and insurance sector. Few researchers were also applied LSS in various sectors like Chen and Lyu (2009) reported LSS in computer industry, Delgado et al.(2010) reported LSS in Financial services, Koning et al. (2010) reported LSS in Publishing company, Barnes and Walker (2010), Psychogios et al. (2012) reported LSS in a communication sector and Barnes and Walker (2010), Psychogios et al. (2012) reported LSS in Healthcare environment.

In the above research papers, researchers mentioned that the success of LSS depends upon the connectivity between DMAIC, waste identification and elimination through VSM and LSS training modules. Researchers also found that the scope of LSS in SMEs are very high but special care required to achieve the specified goal for that SMEs (Kumar et al. (2006)). These authors prepared a generalized framework or model for LSS implementation in small-sized companies. Similarly, Karthi et al. (2011) and Gnanaraj et al. (2012) have presented a research paper combining LSS with ISO 9001:2008 standard. These authors prepared a model using ISO 9001:2008 as ‘L6QMS-2008' model (stands for Lean Six-sigma Quality Management System-2008).

The contextual investigation including the execution of L6QMS-2008 model is introduced in Karthi et al. (2013) Amidst all these exploration attempts, singular creators have revealed inquires about on misusing LSS for achieving particular methodologies. For instance, Byrne et al. (2007) and Hoerl and Gardner (2010) have detailed examinations on applying LSS to accomplish advancement. Similarly, Gupta et al. (2012) have announced the examination on applying LSS for accomplishing intensity. Every one of these explores have uncovered that LSS is powerful in accomplishing diverse objectives in associations. Nonetheless, the viability of accomplishing these objectives through the execution of LSS is to be analyzed. Probably because of the need of looking into toward this path, Gibbons and Burgess (2010) have exhibited the technique for utilizing Overall Equipment Effectiveness (OEE) to quantify the capacity of LSS usage. In like manner, Arumugam and Antony (2012) have detailed research in which 'perception' was utilized as a device to analyze the adequacy of LSS usage. Overall, these perceptions show the requirement for seeking after explores to research the adequacy of applying LSS in various parts and little estimated organizations.

2.9. Barriers/Challenges of LSS implementation

Although many researchers have an opinion to face the challenges during LSS implementation in any organization. In literature, only five research papers report the barriers/challenges in LSS implementation are described below.

Breyfogle III (2010) suggests the use of TOC (Theory of constraints) for bottleneck as primary barriers for performance improvement and identification of such bottleneck during the brainstorming session for LSS implementation in an organization. Psychogios et al. (2012) pointed out three main barriers to the service-oriented organization were lack of awareness and strategical orientation in employees, management and employee culture is not sustainable with LSS. According to Snee (2010),four challenges encountered while LSS implementation were lack of knowledge about LSS and expected higher result from LSS implementation as no involvement from top management and employees, unavailability of roadmap or model showing systematic steps for LSS implementation ,difficulty inaccurate data collection and mindset of management that an organization performs in such a way that LSS implementation is not suitable for their company.

Antony et al. (2012) have drawn the challenges like poor leadership, and lacking in strategic orientation play the crucial role in the non-manufacturing sector like the higher education sector. Above challenge has revealed that the LSS model framework needs to be tested before implementation as a pilot study for its success or suitability in particular sector[25] .

2.10. Conclusion

In this thesis chapter, the researches on Lean Six Sigma have been reported by reviewing the research papers. When searching with the keywords lean, six sigma, Lean six sigma, foundry from various databases available on internet like Google scholar, Springer and Elsevier etc. The number of books and review paper found on Lean Six Sigma stated its different field application and scope. Authors have collected best papers on Lean Six Sigma from the year 2000 to till date from good databases namely Emerald insight, science direct and Springer link. Like TQM, Lean and Six-sigma methodology only 45 papers reported under LSS. The reviewing of these few LSS papers is a limitation of this literature survey. The author put her maximum effort into examining the various seven issues of LSS. In this direction of research, a section of researchers has been striving to implement LSS in several industrial sectors. LSS generalized model adopted for specific sectors and check the compatibility of the model [27]. Although with LSS generalized model, DMAIC and VSM are used to eliminating wastes from an organization while implementing Lean Six-Sigma [9]. This approach was followed to implement LSS in several manufacturing and service sectors. Few researchers pointed out that LSS has a scope in many industrial and non-industrial sectors, but it applied in very fewer organizations [23]. LSS offers a large number of financial and non-financial benefits to an organization [42] . From this review, the author identifies a list of sectors like Foundry, shipbuilding industry, Textile industry, Pump sector and electronics sector in which LSS should be implemented with an LSS framework /model.

Further in Indian SME's 17 papers reported on Lean Six Sigma from science direct, Inderscience, Taylor Francis and emerald publication .out of 17 papers only 8 papers reporting the LSS implementation in Indian SME's. In Indian SME'S papers stated work is done in various sectors like cylinder frames manufacturing unit [25], Automobile accessories manufacturing unit [38], Rotary switches manufacturing organisation (Vinodh et al.2012,Automotive valve manufacturing organization(Swarnakar et al.2016),Aircraft Maintenance(Karunakaran 2016) and improvement of claim processing time(Mukhopadhyay and Ghosh 2013).Gujarat state satisfied the significant need of automobile component and engine all over India and World. So author finds the application of Lean Six Sigma in Foundry sector of Gujarat by developing a model and implements the model in several foundries and investigates the results of LSS in the foundry. In foundry maximization of waste on the floor so the better result can be achieved with proper directional training and monitoring waste on a floor and sources of the primary defect in casting can be identified by continuous monitoring the system as well workers as 80 percent of problem occurs due to 20 percent of causes. The author published a literature review paper (available in the list of papers) of lean six sigma to identify this research gap in the foundry.

Further a questioner (Appendix A) is prepared, and the pilot survey is conducted by the author in various foundries of Gujarat by personal conversation with managing director, senior personnel of the full-time employee to find the best outcome of the survey. The questioner is authenticated by lean six sigma black belt practitioner and verified by academic researchers as well. In the context of drawing this inference, the doctoral work is presented in this thesis was carried out to examine the theoretical and practical aspects of implementing LSS in foundries.

Considering the need of LSS in the foundry, it was decided to investigate the implications of practically implementing LSS in the foundry sector. Moreover, questioner is prepared to identify the current scenario of foundry and pilot survey was conducted .Survey also revealed that lean six sigma and foundry are unknown to each other, and there is a big scope of LSS in the foundry as company owner shows their interest in implementing LSS in their foundry and invite author for the same. Subsequently, these investigations were conducted by implementing LSS in three different foundries.

CHAPTER 3

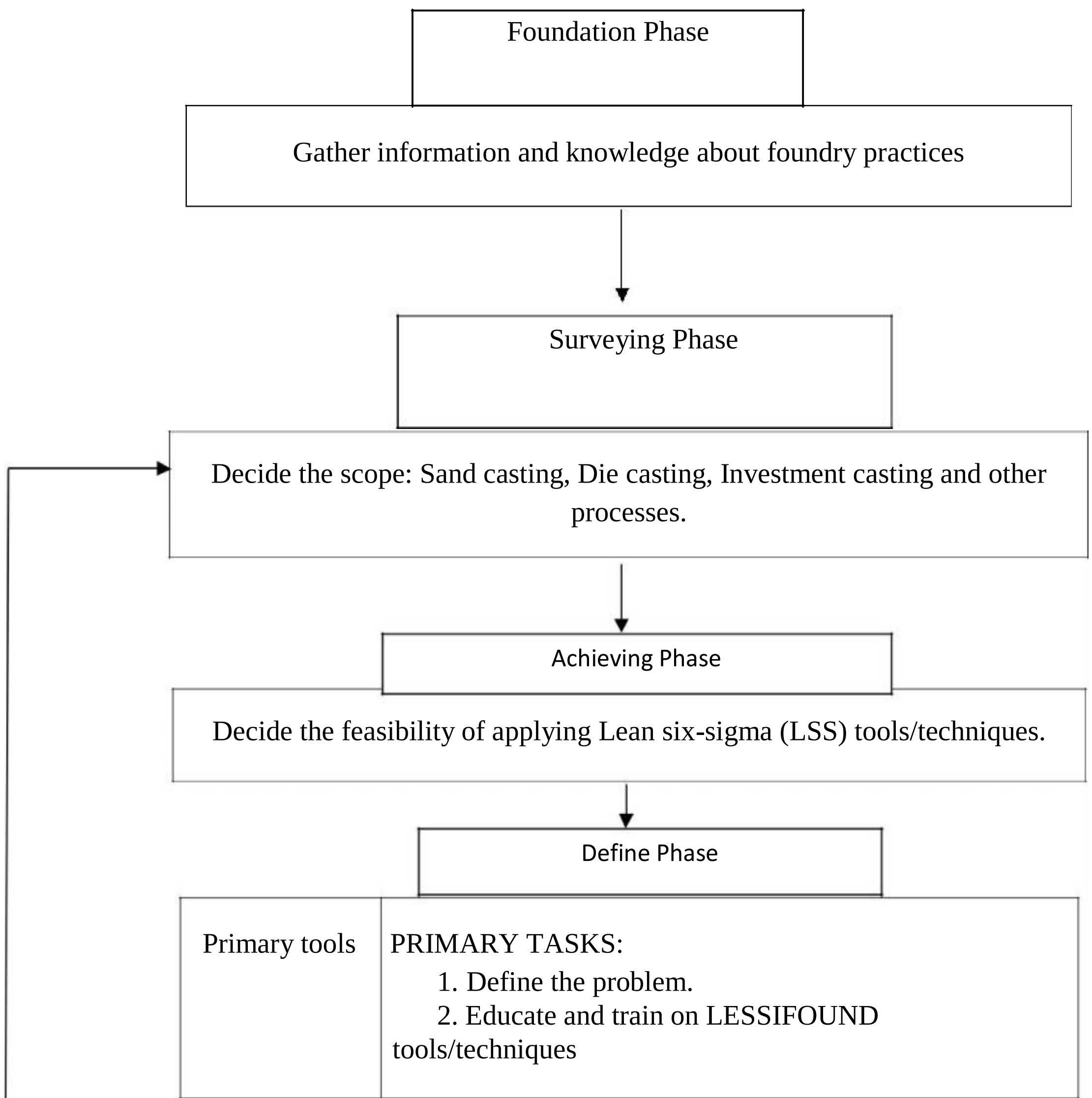
LESSIFOUND: A Model for Implementing Lean Six Sigma in Foundries

3.1 Introduction

As mentioned in the previous chapter, the results of conducting literature review during the beginning phase of the doctoral work being reported here revealed the need for developing the theoretical and practical aspects of implementing LSS in foundries. The theoretical perspective of studying the implementation of LSS in foundries was carried out in two stages. In the first stage, the theoretical knowledge gained by conducting the literature review was utilized to design LESSIFOUND model. In the second stage, a hypothetical study was virtually carried out to proposition the steps of LESSIFOUND model. These theoretical works carried out during the doctoral work being reported here are presented in this chapter.

3.2 Designing of LESSIFOUND

The theoretical knowledge gained by conducting the literature review published in this paper resulted in the identification of two information. The first information is that while implementing LSS, as many as 53 tools and techniques have been used. The second information is that the Six-Sigma's DMAIC phases are applied with the inclusion of lean tools and methods while executing LSS projects. A critical study of this information with references to foundry practices indicated that such execution practices could not be carried out in contemporary foundries. This is due to the reason that the foundry industry is yet to nourish the benefits of implementing LSS. Hence, besides the conventional execution phases of LSS, the preparatory phases are required to the applied. A critical study about the foundry practices indicated that three such phases are necessary to the implemented in the contemporary foundries. The first such phase should lead to the laying of foundation on implementing LSS by studying the practices followed in the own foundry. The second phase should facilitate the surveying of the foundry method applied and deciding the scope of implementing LSS. In the third phase, the feasibility of implementing the LSS tools is estimated. At the end of this third phase, the tools and techniques are to the chosen for performing the same in the respective foundry is to be carried out. Thus, these three phases facilitate the preliminary preparation for applying the LSS in the respective foundry. After making this preliminary preparation, the DMAIC phases of LSS technique are required to be implemented in the foundry. After the completion of the first cycle of implementation, the second cycle of implementing LSS has to begin from the surveying phase. The theoretical aspects thus formulated by the information and knowledge gained by conducting the literature reviews were used to design the LESSIFOUND model. The LESSIFOUND model therefore designed by incorporating the above eight phases is pictorially depicted in Figure 3.1.



Toolbox 1 to 53 tools	SECONDARY TASKS: Identify the problem areas Identify the customer requirements
	CRITICAL OUTCOME: Development of Problem statement

↓

Measure Phase

PRIMARY TASK: Measure the performance in the problem areas.

SECONDARY TASK:

a) Calculate the sigma level
b) Identify the critical to quality parameters
c) Calculate the waste level

CRITICAL OUTCOME: Determination of overall current performance

↓

Analyse Phase

Toolbox	PRIMARY TASK: Analyse the problem
1 to 53 tools	SECONDARY TASKS: a) Determine the causes of rejections b) Determine the reason for lower sigma level c) Determine the reason for the occurrence of wastes
	CRITICAL OUTCOME: Determination of causes, effects, reasoning and solutions

↓

Improve Phase

PRIMARY TASK: Improve

SECONDARY TASKS:

a) Develop proposals for increasing sigma level
b) Develop proposals for eliminating wastes
c) Determine the integrated proposal for increasing sigma level and eliminating wastes
d) Implementation of the integrated proposal

CRITICAL OUTCOME: Successful implementation of the integrated proposal

↓

Control Phase

PRIMARY TASK: Control

SECONDARY TASKS:

a) Control the procedures
b) Control the documents
c) Control the instructions
d) Control the processes

CRITICAL OUTCOME: Sustainable execution of the integrated proposal

↓

Assess the level of acquiring core competencies

Figure.3.1 Conceptual framework of LESSIFOUND model

The conceptual framework of LESSIFOUND presented in Figure 3.1 is required to be implemented in 13 steps. These steps and the activities carried out under them are briefly given below.

Steps of LESSIFOUND model

STEP 1: Gathering of foundry practices.

Foundry field has witnessed the emergences of numerous methods and practices. In this step, these method and practices are required to the studied by referring to books, research articles and knowledge posted on the World Wide Web.

STEP 2: Decide the scope of LESSIFOUND concerning processes like Sand casting, Die casting, Investment casting and other foundry practices.

In a foundry, several processes like sand casting, die casting and investment casting are used to produce castings. In this step, the step the scope of applying LESSIFOUND model on the specific process needs to be decided with the consultation of the top management.

STEP 3: Map the candidate process in the foundry.

In this step, the stages followed in the foundry for carrying out the candidate process need to be studied. Then, these steps are to be mapped by using either block diagrams or flowchart.

STEP 4: Determining the feasibility of applying LESSIFOUND tools and techniques in the foundry.

In this stage, the features of 53 tools and techniques employed in the LSS field need to be studied. Then, the suitability of applying them in the foundry is required to be analyzed. Finally, the most feasible LSS tools and techniques are chosen for implementation in the first cycle of LESSIFOUND model.

STEP 5: Deciding the area and team for applying LESSIFOUND.

The area in which the chosen process applied in the foundry is required to be visited. If the area is small with one unit, then the first cycle of LESSIFOUND project may be applied in this area. In case the area is abundant with several units, the most feasible unit is chosen for implementing the first cycle of LESSIFOUND model a team of members possessing appropriate knowledge and skill is required to be formed. Finally, the leader of this team is also required to be chosen.

STEP 6: Impart training and education on LESSIFOUND tools and techniques.

In this step, the training and educational needs for implementing LESSIFOUND tools and techniques are required to be identified. These needs are required to be documented in the forms of a training and educational manual. By referring to this manual, team leader and members are required to undergo training and education on LESSIFOUND tools and techniques.

STEP 7: Defining the problem.

Now at this stage, the team leader and members are equipped with the necessary skills and knowledge to solve the problem, so that the sigma level quality is enhanced through the elimination of wastes. In this step, the team leader and member identified the problem. After studying this problem, the same is defined by the team leader by preparing the problem statement.

STEP 8: Measuring the performance in the problem areas.

In this step, the team leader prepares the metrics for measuring the performance in the problem areas. The scope of these metrics should include sigma level quality and quantum of wastes. By using these metrics, the team members measured the sigma level quality and quantum of wastes in the problem areas.

STEP 9: Analysing the problem.

In this step, the team leader and its members apply analysis tools like brainstorming and ‘cause and effect diagram’ to analyse the problem. In this step, the causes of low sigma level performance and high quantum of wastes are identified.

STEP 10: Improving the performance.

The team leader and members apply tools like brainstorming and affinity diagram to offer the solution for overcoming the causes that led to low-level sigma performance and high quantum of wastes. These solutions should theoretically indicate the degree of performance improved to be achieved on the implementation.

STEP 11: Implementing the system.

In this step, the solutions generated are encapsulated in the form of a system. Then this system should be subjected to implementation in the chosen area.

STEP 12: Controlling the implementation of the system.

In this step, the team leader and members develop instruments for controlling the implementation of the solutions. For example, the team leader and members may decide to carry out an internal audit for ensuring that the solutions are implemented smoothly in the foundry.

STEP 13: Assessing the level of acquiring core-competencies.

In this step, the metrics used while carrying out step 8 need to be used again to check whether the implementation of the above 12 steps of LESSIFOUND model has resulted in increasing sigma level and reduction in wastes. Besides, suitable metrics are required to be used to assess whether the implementation of the above steps of LESSIFOUND model has enabled the foundry to acquire core competencies.

After completing the thirteen steps, the used cycles of implementing LESSIFOUND model has to be started from step 2.The duration of each cycle of LESSIFOUND model may vary from 6 months to 1 year depending upon the chosen area and problem. The cycles of LESSIFOUND model shall be continued first to spread the execution of LESSIFOUND model in all areas of the foundry, and the subsequent cycle shall be employed to strengthen the implementation of LESSIFOUND model in the foundry. A foundry implementing several cycles of LESSIFOUND model will perform at Six-Sigma level quality and will eliminate wastes in all the areas.

3.3. Hypothetical case study

The working of LESSIFOUND is illustrated here by presenting a hypothetical case study. In the hypothetical company that is being considered here, was started in the year 1950. In the beginning, the sand casting was used to produce cast components that were used by pump manufacturers. In the later period, other foundry practices like die casting and investment casting were adopted in this foundry. At the beginning of starting this foundry, 100 employees were working. Today in this foundry 2000 employees are working. Though this foundry can sustain by supplying cast components to the companies which are situated nearer to this foundry, the progress of this foundry has been very slow in the past one decade. This is due to the main reason that the wastages were high and defectives produced were also high. In this background, the management of this foundry appointed a consultant to apply LESSIFOUND exclusively and overcome the problem of wastages and high rejections. The steps carried out subsequently under the leadership of the consultant of the consultant of

LESSIFOUND (hereafter referred to as CGM) is illustrated below.

3.3.1 STEP 1: *Gathering of foundry knowledge*

The CGM began to refer the books on foundry practices to gather knowledge about different types of foundry processes. Furthermore, the CGM studies the research papers published in the leading journals to gather knowledge about the state-of-art foundry practices. This exercise enhanced the knowledge level of CGM, which could be used to improve the foundry practices adopted in the foundry.

3.3.2. STEP 2: *Deciding the scope of LESSIFOUND application*

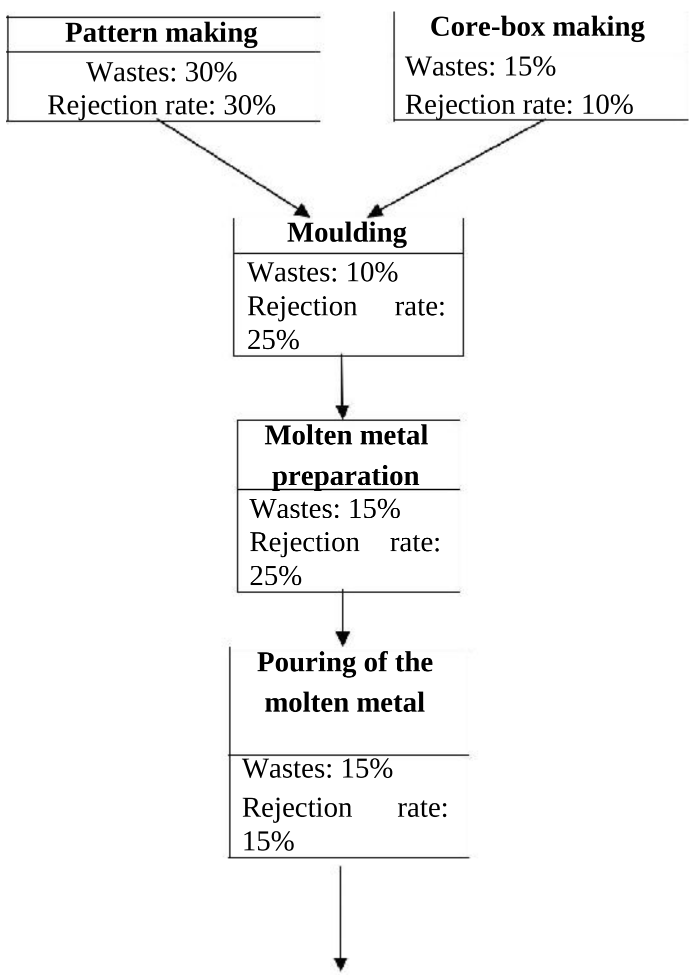
The CGM understands that about 50 foundries presented are widely adopted in the world. Only three foundry processes namely Sand casting, Die casting and Investment casting are adopted in the foundry. In this background, the CGM gathers data regarding the occurrence of wastes and rejection rate during the past six months while executing the three foundry processes. To carry out this exercise, the CGM referred the past records to assess the waste level. As no records were available to gather data about the occurrence of wastes, the CGM interviewed the supervisors and senior operators. The CGM takes one week to complete this exercise. In the end, the CGM finds that the occurrence of wastes and rejection rates are highest in the case of the sand casting process. In the context of this finding, the CGM decides to apply LESSIFOUND in the foundry while executing the sand casting process. In other words, the scope of LESSIFOUND in the foundry was decided to apply it on the sand casting process.

3.3.3. STEP 3: *Mapping the candidate process*

The CGM visits the locations in the foundry to study the sand casting process carried out in practice. During this exercise, the CGM traces the path followed in this foundry to produce the casting of a pump housing which was specially ordered by a client. The CGM records the activities including pattern making, mould making, metal pouring, solidifying and cleaning which are followed in the foundry to produce this casting. After gathering this information, the CGM draws the map shown in Figure 3.2 to map the processes in the foundry. As shown, in this map the CGM notes the occurrence of wastes and rejection of defectives under each process.

3.3.4. STEP 4: *Determining the feasibility of applying LESSIFOUND tools and techniques*

By referring to the map developed in the previous steps, the CGM lists the tools and techniques that could be applied to overcome wastages and rejection rates under each stage of the processes. With this map in hand, the CGM convenes a meeting of supervisors and operators to discuss the feasibility of applying the tools and techniques specified under each stage of the processes. During this meeting, the feasibility of applying these tools and techniques is discussed. Particularly the capability of operators in applying the chosen tools and techniques and practical benefits of applying them, in reality, were considered to decide the feasibility of applying LESSIFOUND tools. After considering these factors, four tools and techniques were removed from the consideration. Now CGM consults the top management about adopting the tools and techniques to overcome the occurrence of wastes and defectives under each stage of the processes. The management agrees to allow the application of all tools and techniques except one. That tool is removed from the consideration.



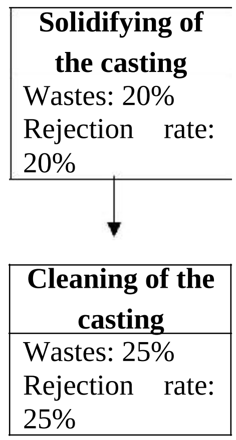


Figure:3.2 Map of sand casting

3.3.5 STEP 5: *Deciding the team and area of applying LESSIFOUND*

Under this step, the CGM examines the stage of applying LESSIFOUND. After studying the waste level and rejection rate, the CGM decides to apply LESSIFOUND in pattern making area. Subsequently, the CGM invites supervisors and operators who are interested in involving in applying LESSIFOUND in the pattern making area. In response to this invitation, two supervisors and six operators volunteer to become team members of LESSIFOUND. The CGM interviews these team members. The CGM develops confidence that it is possible to apply LESSIFOUND in the pattern making area and overcome the occurrence of wastes and rejection of the patterns. The CGM informs the top management about the formation of this LESSIFOUND team. The management approves the formation of this LESSIFOUND team and carrying out the subsequent steps.

3.3.6 STEP 6: *Imparting training and education*

The CGM studies the chosen LESSIFOUND tools and techniques by referring to the case studies reported by the researchers and practitioners. After gathering this knowledge, the CGM designs training modules on these chosen LESSIFOUND tools and techniques. By making use of these training modules, the CGM trains the team members to apply the chosen LESSIFOUND tools and techniques in practice.

3.3.7 STEP 7: *Defining the problem*

Under this step, the CGM discusses with the LESSIFOUND team members to choose the problem. The LESSIFOUND team members inform that the occurrence of the high level of wastes and rejection rate is due to the inappropriate shrinkage allowance assigned during the designing of patterns. Thus this problem was defined, and the project charter was developed by the CGM and LESSIFOUND team members. This project charter is shown in Figure 3.3.

Date of starting the project: July 1, 2014
Date of completing the project: September 3, 2014
Project deliverables: Waste elimination and zero defect in pattern making

LESSIFOUND Project

Project number: 1
Project title: Quality improvement in pattern making (QII PM)
Team leader: Mr A
Team members: Mr X, Mr Y, Mr Z, Mr P
Problem definition: Assigning inappropriate shrinkage allowance leads to the occurrence of higher wastes and rejection in pattern making.
Project duration: 3 months

Figure 3.3. Project charter

3.3.8. STEP 8: *Measuring the performance*

While executing this stage, under the direction of the CGM, the team members assess the waste level under seven categories that occurred due to the mistake in giving proper shrinkage allowance in the patterns. These seven categories are Overproduction, Defects, Delay, Unnecessary motion, Transportation …… and…..... Subsequently, the number of castings rejected due to the existence of this problem in the foundry is determined by the LESSIFOUND team members. Using this data, the CGM and LESSIFOUND team members find that the sigma level of producing the castings in the foundry as 2.8. The calculation details are shown below:

- Number of patterns observed = 7

Number of patterns rejected = X

Number of CTQ parameters = 2

Defects per million opportunities = X÷Y×10,10,000

From the six-sigma Table, the sigma level is found to be 2%

After making these measurements, the CGM and LESSIFOUND team members fix the target by overcoming the defined problem.

3.3.9.STEP 9: ***Analysing the problem***

The CGM and LESSIFOUND team members carry out the Why-why analysis to determine the cause of occurrence of the defined problem. The CGM and LESSIFOUND team members find that the absence of information about the material to be cast, absence of a chart to decide the shrinkage allowance and inadequate training of pattern makers are the causes that cause the defined problem.

3.3.10. STEP 10: ***Improving by providing solutions***

The CGM and LESSIFOUND team members discuss providing solutions against the causes identified in the previous stage. After thorough discussion, the CGM and LESSIFOUND team members suggest preparing a ‘Material information form' which should contain the exact code of the material, composition and properties of the materials. Second, the CGM and LESSIFOUND team members suggest preparing a chart to indicate the shrinkage allowance to be given in the patterns against the materials and shapes. Third, the CGM and LESSIFOUND team members suggested the imparting of on the job training by availing the service of a senior most pattern maker.

3.3.11. STEP 11: ***Implementing the system***

The CGM and LESSIFOUND team members designed a pattern making the form which should contain relevant information including that of materials. This form is shown below :

Serial number	Date	Code of the material	Composition	Signature of the works manager

Figure 3.4 Pattern making form

This form should be endorsed by the works manager. The supervisor is instructed to initiate the designing of patterns only after receiving the completely filled-in pattern making the form.

Second, the CGM and LESSIFOUND team members prepare a chart containing information about the shrinkage allowance to be assigned against the materials and shapes. The supervisor is instructed to indicate the serial number referred in this chart in the pattern drawing. The CGM and LESSIFOUND team members develop a chart containing the training requirements. This chart is given to the senior most pattern maker who has to indicate the training needs of the individual pattern makers. Thus the system for implementing the solutions is developed and installed by the CGM and LESSIFOUND team members.

3.3.12.STEP 12: *Controlling the implementation of the system*

The CGM and LESSIFOUND team members prepare an audit sheet to check the continuance of the system installed in the previous step. The CGM and LESSIFOUND team members conduct the audit on the second Saturday of the month. When deviations are found, the CGM and LESSIFOUND team members take swift actions to restore the status queue.

3.3.13.STEP 13: *Assess the level of acquiring core-competencies*

The CGM appraises the top management about the implementation of solutions. The top management receives reports from different sections about the occurrence of wastes and rejection of castings. From these reports, the top management understands that there has been nearly no wastages and rejections due to the installation of the system of LESSIFOUND. The customer who receives the first consignment also informs that the quality of castings is superior in comparison to those are supplied by other foundries. These observations indicate that the application of LESSIFOUND enables the foundry to acquire core-competencies.

3.4 Conclusion

The results of conducting the literature review reported in the second chapter of this thesis revealed the need of developing an exclusive model for implementing LSS in foundries. To meet this need, the LESSIFOUND model presented in this chapter was designed. Further, the results of the above literature review indicated that a strong theoretical foundation is to be laid before investigating the practical implementation feasibility of implementing LESSIFOUND model. Accordingly, the 13 step implementation framework of LESSIFOUND model presented in this chapter was designed. To theoretically anticipate the implementation of this methodology, a hypothetically case study as implementing this methodology was developed. With these theoretical foundations in hand, the investigations on implementing LESSIFOUND model were practically carried out in real time environment in three foundries. These investigations are reported in the following three chapters.

CHAPTER-4

Investigation on Implementing LESSIFOUND in CO_2 Casting Based Sand Casting Process

4.1 Introduction

The technical concepts of LESSIFOUND developed during the preliminary phase of the doctoral work being reported here provided the benchmark guidelines for implementing LESSIFOUND in foundries. With these theoretical guidelines, investigations were carried out to examine the practicality of LESSIFOUND model in sand casting foundries. While pursuing this practical part of the doctoral work, studies on implementing LESSIFOUND was carried out in three sand casting foundries situated in the Gujarat state of India. These investigations are reported in this chapter and the subsequent two chapters. In this chapter, the investigation on implementing LESSIFOUND is a foundry in which the castings are produced through sand casting method involving a co2 process. The background of this foundry, the steps followed to produce the castings and the efforts made to implement the 13 steps of LESSIFOUND model are presented in this chapter.

4.2 Background of the foundry

The investigation on being reported here was carried in a foundry by name *'German Techno Cast'* (This foundry will hereafter be referred to as *GTC*). GTC is situated in Ahmedabad city of India. The front portion of the GTC is shown in Figure 4.1.

Figure 4.1. The front portion of GTC

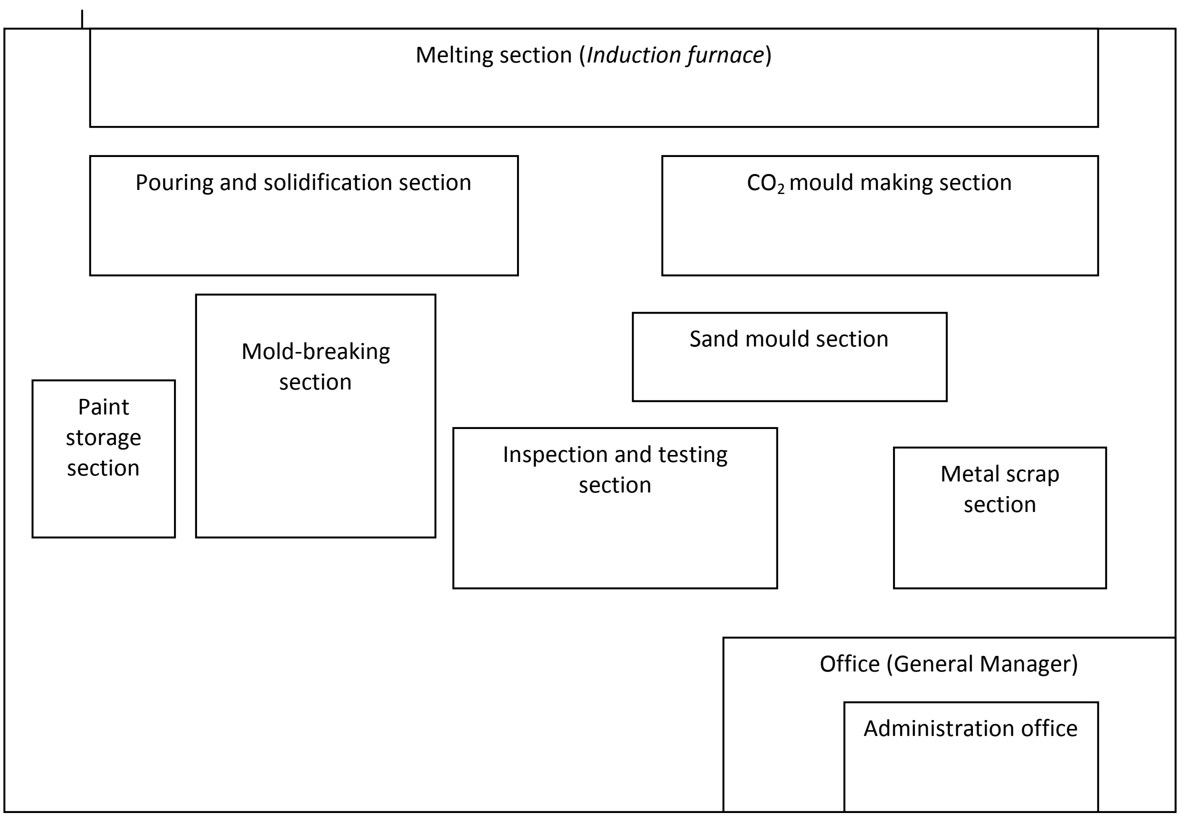


Figure 4.2. Plant layout of GTC

The plant layout of GTC is shown in Figure 4.2. As shown, it consists of eight departments. In one end, the administrative office is located. In the other end, the melting section is located. In this section, the induction furnace is located. GTC was started in the year 2008 with employee strength ten. Currently, 40 employees are working in GTC. The organisational structure of GTC is shown in Figure 4.3.

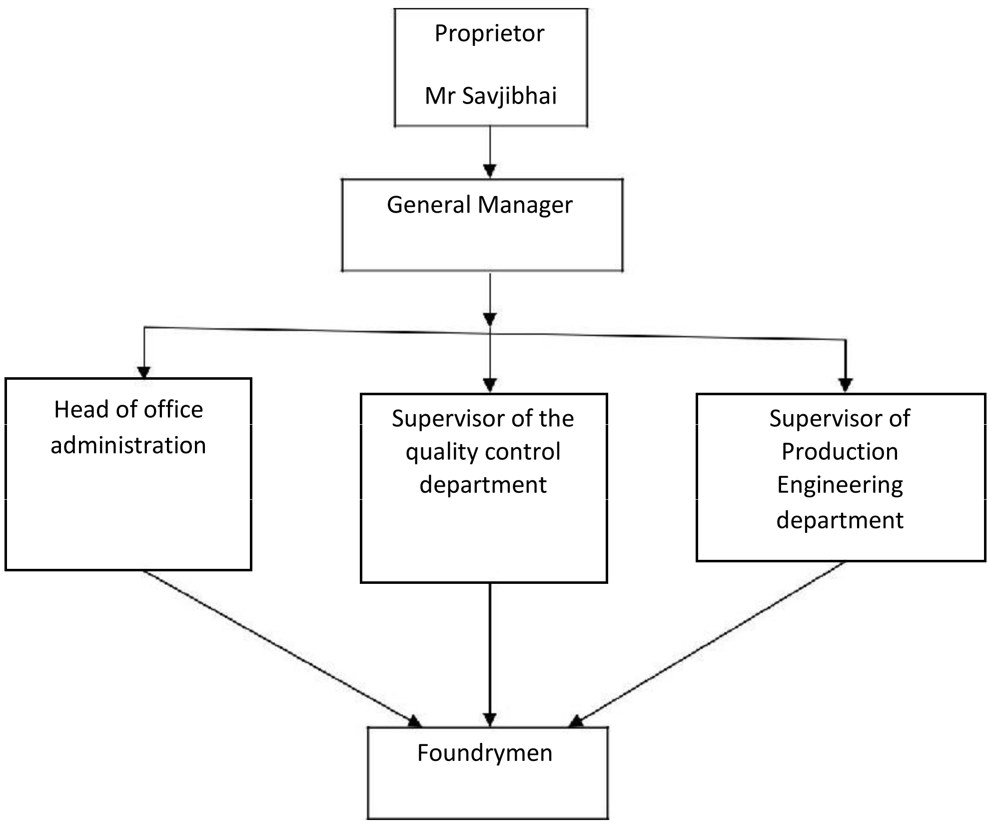


Figure 4.3. The organisational structure of GTC

As shown, GTC is owned by its proprietor Mr.Savjibhai. Due to his poor health, Mr.Savjibhai is unable to manage GTC. Hence, currently, GTC is managed by *Mr Deepchand Patel*, who holds a bachelors degree in Mechanical Engineering. Under the guidance of general manager, head of the administration and supervisors of quality control and production engineering departments manage the foundry activities of GTC. These three managerial employees instruct the foundry men to execute the jobs. In GTC, the sand casting method is adopted to produce the castings of parts which are used in the mining industry and sugar mills. Further, the castings of transmission parts like gears and couplings are produced in GTC. The overall view of the foundry shop of GTC in which sand casting is carried out is shown in Figure 4.4.

Figure 4.4. Overall view of foundry shop of GTC

In GTC, an induction melting furnace is installed to produce castings weighing up to 1500 kilograms(kg). The photograph of this induction furnace is shown in Figure 4.5. The castings produced in GTC are of ISO 1030 grades and ASTM A216 WCB grade. The conventional practices are followed to produce castings and inspect the same in GTC. There have been no modern concepts like TPM and Six-sigma implemented in GTC. The quality control practices have been conventional and ISO 9001 based quality management system has also not been implemented in GTC. No castings of GTC are exported directly to any country.

Figure 4.5. Induction furnaces used in GTC

During the recent years, problems in improving quality and increasing production to match with competitive situations prevail in the foundry arena. In this background, GTC is currently considering the implementation of Enterprise Resource Planning (ERP) and purchasing a spectrometer and hardness tester. A considerable number of customers have been machining the parts supplied by GTC and exporting them to other countries. In this background, the efforts were made to implement LESSIFOUND in GTC. To begin with, the author of this thesis was recognized as the ‘Consultant General Manager’ (CGM), to coordinate the implementation of LESSIFOUND steps in GTC. In the beginning, the CGM met the Managing Director of GTC and exposed to him the LESSIFOUND model. The photograph shot during one of these sessions is shown in Figure 4.6. The details of activities carried out under these steps are described in the following sub-sections.

Figure 4.6. The CGM explains the LESSIFOUND model to the Managing Director of GTC

4.3. Implementation of LESSIFOUND Model

The activities carried out to implement the13 steps of LESSIFOUND model in GTC are described in the following subsections.

4.3.1 Step 1: Gathering of foundry knowledge

The CGM began to refer the books on foundry practices to gather knowledge about different types of foundry processes like sand casting, shell mould casting, centrifugal casting,

co_2 casting, die casting etc. with their characteristic for manufacturing a casting product. Furthermore, the CGM study the research papers published in the leading journals to gather knowledge about the state-of-art foundry practices. This exercise enhanced the knowledge level of CGM, which could be used to improve the foundry practices adopted in the foundry. In GTC, the co_2 casting process is employed to cast component.

4.3.2 Step2: Deciding the scope of LESSIFOUND application

The CGM understood that as many as 50 types of state-of-the-art research practices are adopted in the world's leading foundries. In GTC, only sand casting using CO_2 moulding is just being adopted. Hence the title of this chapter implies, the investigation being reported here was listed to examine the application of LESSIFOUND model in GTC in the scope of CO_2 moulding based sand casting process. After thus deciding the scope of the application of LESSIFOUND, the CGM studied the steps followed to carry out CO_2 moulding based sand casting process in GTC. The information thus gathered by the CGM is depicted in the form of the block diagram shown in Figure 4.7. As shown, if found necessary cores are required to be made to cast components with hollow sections. Then, moulds are made by making use of the patterns. A photograph shot when the moulds were made in GTC is shown in Figure 4.8. Subsequently, colour coating and CO_2 vent holes are made in the mould.

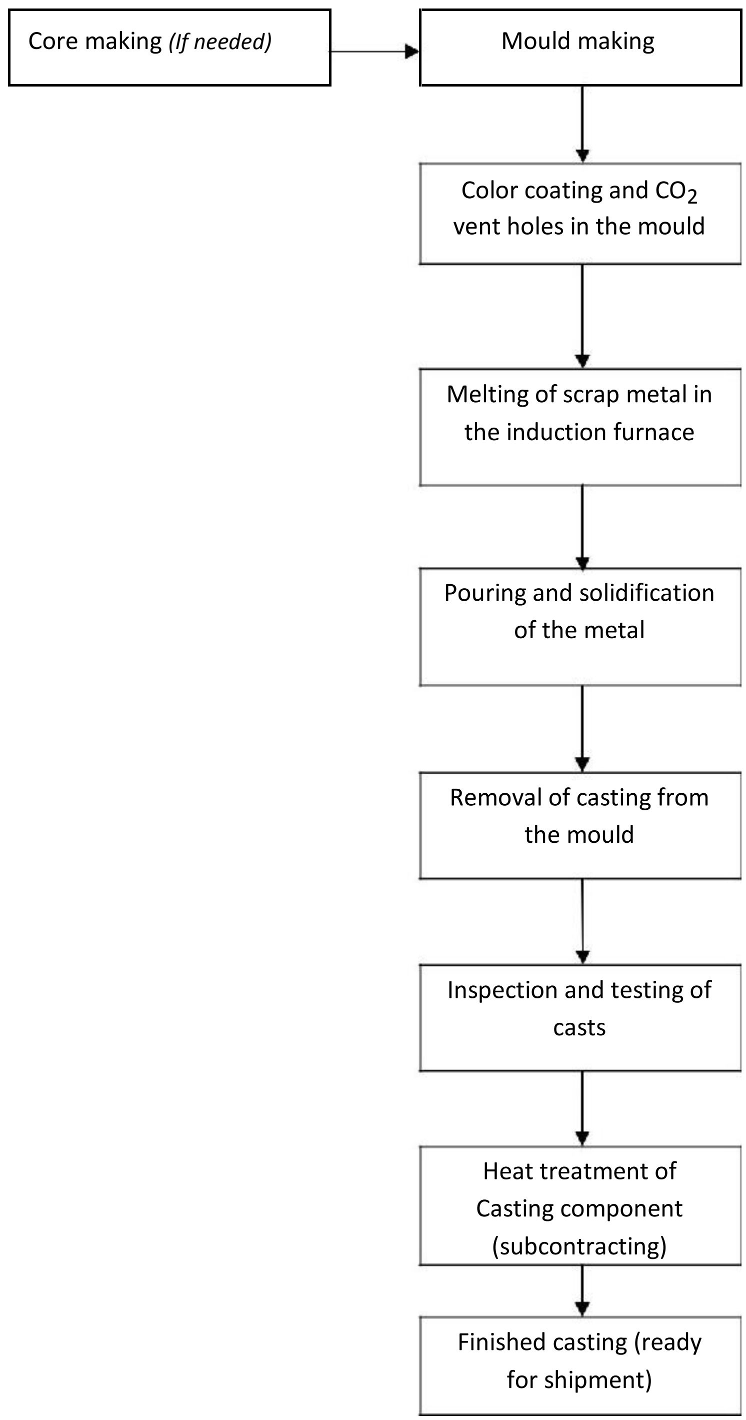


Figure 4.7 Steps of CO_2 casting process adopted in GTC

Figure 4.8. Mould making in GTC

Figure 4.9. Applying Color coating on the moulds in GTC

The photograph shot during the execution of the colour coating process in GTC is shown in Figure 4.9. Vent holes made in a mould in GTC are shown in the photograph presented in Figure 4.10.

Figure 4.10. Vent holes made in a mould in GTC

Figure 4.11. CO_2 moulding process in GTC

The photograph shot when CO_2 moulding process was carried out in GTC is shown in Figure 4.11. Simultaneously, the metal is molten in the induction furnace. Subsequently, the molten metal is poured into the cavity. After elapsing certain time, the solidification of metal takes place. Once the solidification is completed, the castings are removed from the mould by breaking the same. The photograph shown in Figure 4.12 shows the broken pieces of moulds found in GTC. The burrs and protrusions found in the castings are removed using grinding operation in GTC. A photograph shot while carrying out such grinding operation in GTC is shown in Figure 4.13.

Figure 4.12. Broken mould pieces found in GTC

Figure 4.13. Grinding operation carried out in GTC to remove burrs and protrusions in the castings.

Then the castings are subjected to inspection and testing. A photograph shot while carrying out the inspection and testing of finished cast components in GTC is shown in Figure 4.14. The defect-free castings are sent for carrying out heat treatment. The heat treated castings are now ready for shipment. In Figure 4.15, a photograph showing a sample of finished cast components kept ready for shipment in GTC is presented. As the components cast in GTC are heavy, the material handling using overhead cranes is carried out frequently. The photograph showing such material handling in GTC is shown in Figure 4.16. The CGM discussed with GM about the CO_2 casting process. According to the GM, no wastages are encountered while making pattern, cores and moulding boxes. Since the cast components are heavy, the rejection of a component made using CO_2 process results in a loss of Indian National Rupees (INR) 1 lakh in GTC.

Figure 4.14. Inspection and testing of finished cast component conducted in GTC

Figure 4.15. Finished casting components kept ready for shipment in GTC.

Figure 4.16. Material handling in GTC using the overhead crane

4.3.3.Step 3: Mapping the candidate process

The CGM visited the locations in the foundry to study the sand casting process carried out in practice. During this exercise, the CGM traced the path followed in this foundry to produce the casting of an ingot mould which was specially ordered by a client. The CGM recorded the activities including pattern making, mould making, metal pouring, solidifying and cleaning which are followed in the foundry to produce this casting. After gathering this information, the CGM draw the map shown in Figure 4.17 to map the processes carried out in GTC. As shown in this map, the CGM notes the occurrence of wastes and rejection of defectives under each process.

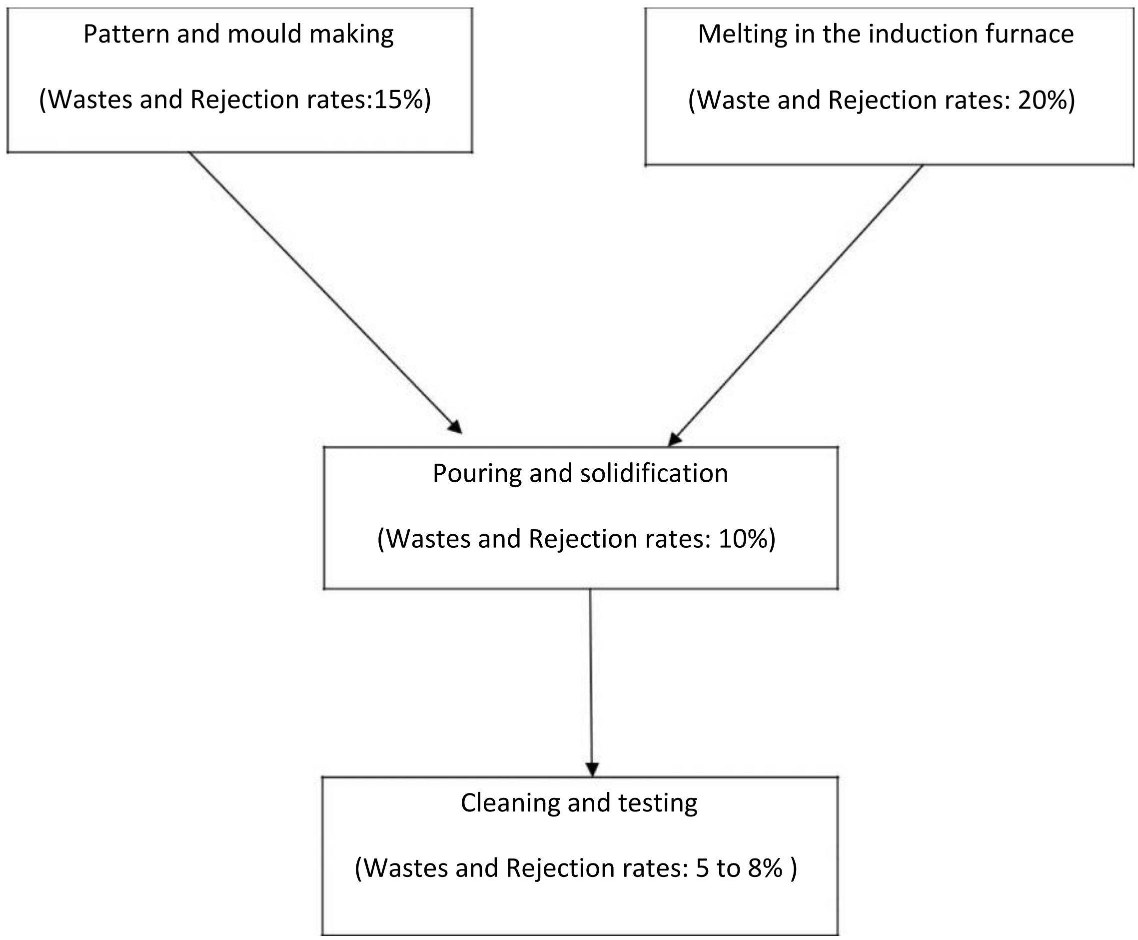


Figure 4.17. Mapping the processes in GTC

4.3.4. Step 4: Determining the feasibility of applying LESSIFOUND tools and techniques

By referring to the map developed in the previous step, the CGM listed the tools and techniques that could be applied to overcome wastes and rejection rates under each process. With this map in hand, the CGM convened a meeting of supervisors and operators to discuss the feasibility of applying the tools and techniques specified under each process. During this meeting, the feasibility of applying these tools and techniques is discussed. Particularly the capability of operators in applying the chosen tools and techniques and practical benefits of applying them, in reality, were considered to decide the feasibility of applying LESSIFOUND tools. After considering these factors, four tools and techniques were chosen for consideration. Now CGM consulted the top management about adopting the tools and techniques to overcome occurrence of wastes and defectives under each process. The management agrees to allow the application of all tools and techniques except one. That tool was removed from the consideration.

4.3.5. Step 5: Deciding the team and area of applying LESSIFOUND

Under this step, the CGM examine the stage of applying LESSIFOUND. After studying the waste level and rejection rate, the CGM decided to apply LESSIFOUND in pattern making area. Subsequently, the CGM invited supervisors and operators who were interested in involving through while applying LESSIFOUND in the pattern making area. In response to this invitation, one supervisor and six operators volunteer to become team members of LESSIFOUND. The CGM interviewed these team members. The CGM developed confidence that it would be possible to apply LESSIFOUND in the pattern making area and overcome the occurrence of wastes and rejection of the patterns. The CGM informs the top management about the formation of this LESSIFOUND team. The management approved the formation of this LESSIFOUND team and permitted to carry out the project presented in Table 4.1.

Table4.1.Project approved by the management for implementing at GTC

- **Project number:1**
- **Project Title: Quality Improvement in pattern and Mould making**
- **Team Leader: Darshana Kishorbhai Dave**
- **Team Members: Mr.Nayan Patel (M.D.), Mr Hiren Patel (Admin Head), Mr Suresh Vyas (Q.C. Head), Mr Kaushal Patil (Production head)**
- **Project Duration:4 Months**

4.2.6. Step 6: *Imparting training and education*

The CGM studied the chosen LESSIFOUND tools and techniques by referring to the case studies reported by the researchers and practitioners. After gathering this knowledge, the CGM designed training modules on these chosen LESSIFOUND tools and techniques. By making use of these training modules, the CGM trained the team members to apply the chosen LESSIFOUND tools and techniques in practice.

4.3.7. Step 7: Defining the problem

Under this step, the CGM discussed with the LESSIFOUND team members to determine the problem. The LESSIFOUND team members informed that the occurrence of the high level of wastes and rejection rate is due to the inappropriate shrinkage allowance assigned during the designing of patterns. Thus, this problem was defined, and the CGM and LESSIFOUND team members developed the project charter. This project charter is shown in Figure 4.18.

LESSIFOUND Project

Project number: 1

Project title: Quality improvement in pattern making (QII PM)

Team leader: DARSHANA DAVE

Team members: **Mr.Nayan Patel(M.D.), Mr Hiren Patel(Admin Head), Mr.Suresh Vyas(Q.C. Head), Mr Kaushal Patil (Production head)**

Problem definition: Assigning inappropriate shrinkage allowance leads to the occurrence of higher wastes and rejection in pattern making.

Project duration: 3 months

Date of starting the project: July 1, 2014

Date of completing the project: September 3, 2014

Project deliverables: Waste elimination and zero defect in pattern making and final casting product

Figure 4.18. Project charter

While manufacturing casting of a water cooler body of the plastic extrusion machine, maximum Possibility of rejection from last 5 year. This is the defect that we identify and try to resolve with LSS. (D-M-A-I-C). Identify the Problem in GTC: Defect-free sand casting product should be produced with no rejection.

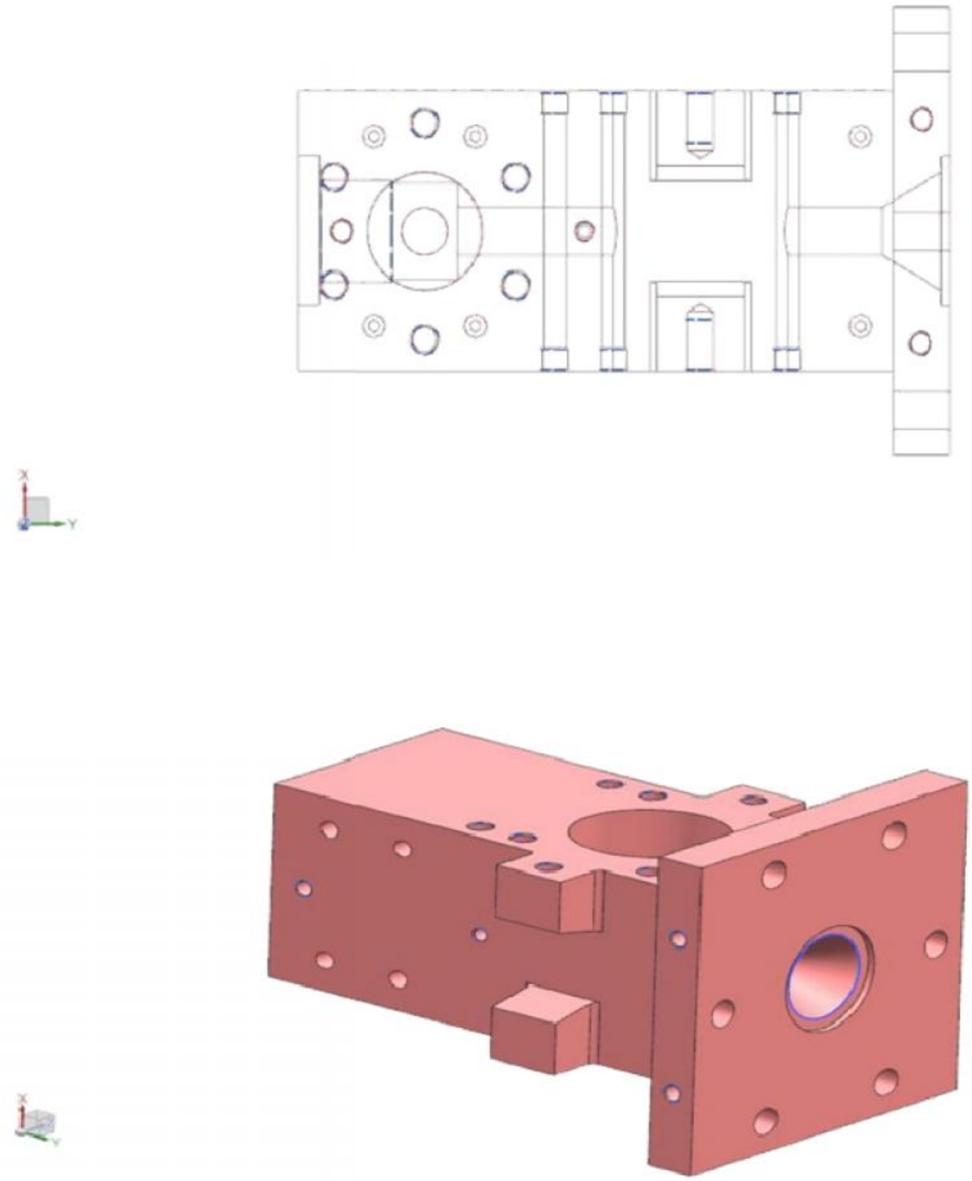


***Figure 4.17. Design and Modeling of W*ater Cooler Body of Plastic Extrusion Machine**

4.3.8. Step 8: Measuring the performance

While executing this stage, under the direction of the CGM, the team members assessed the waste level under seven categories that occurred due to the mistake in giving proper shrinkage allowance in the patterns. These seven categories are overproduction, defects, delay, unnecessary motion, transportation, inappropriate processing and unnecessary inventory. Subsequently, the number of castings rejected due to the existence of this problem in GTC was determined by the LESSIFOUND team members. Using this data, the CGM and LESSIFOUND team members found that the sigma level of producing the castings in the foundry was 3.7. The calculation details are shown below:

Total number of casting component from 15th November 2014 to 5th March 2015: 230

Number of Defects found during /after casting body = 19

Identification of defects Sources: 7

$$DPMO = \frac{\text{total no. of defects detected}}{\text{Number of units produced* opportunities of defect per unit}}$$

$$= \frac{19*1000000}{230*7}$$

$$=11801$$

Six Sigma level =3.76 σ

After making these measurements, the CGM and LESSIFOUND team members fix the target by overcoming the defined problem.

Area: Foundry

Customer requirement: Defect-free casting product

DPMO (defect per million opportunities): during /after CO_2 casting process carried out

4.3.9. Step 9: Analysing the problem

The CGM and LESSIFOUND team members carried out the Why-why analysis to determine the cause of occurrence of the defined problem. The CGM and LESSIFOUND team members found that the absence of information about the material to be cast, the absence of a chart to decide the shrinkage allowance and inadequate training of pattern makers are the causes that caused the defined problem. Further analysis indicates the causes and number of frequency of occurrence of the some. These details are presented in Table 4.2. After making several visits, the causes and sources of defect were identified. This cause and effect diagram is shown in Figure 4.18.

Table 4.2. Causes and the frequency of occurrence (Before LSS)

Serial Number	***Causes***	***Frequency***
1	Material	4
2	Co_2 Molding problem	3
3	Furnace problem	2
4	Improper fettling operation	2
5	Improper sand ramming	6
6	Power breakdown and shutdown	1
7	Others	1
	Total	**19**

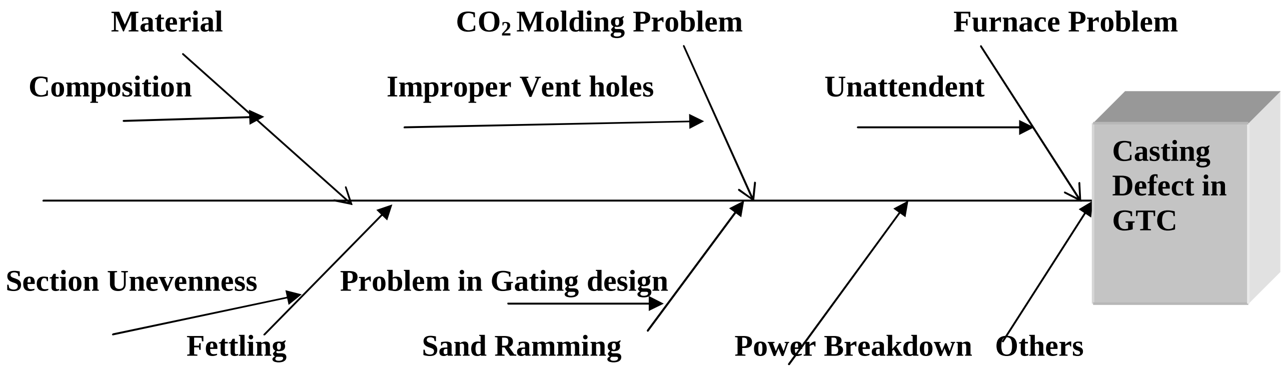


***Figure 4.18. Cause-Effect Diagram for Identification of sources of the defect in W*ater Cooler body of Plastic Extrusion Machine**

4.3.10. Step 10: Improving the performance

The CGM and LESSIFOUND team members discussed providing solutions against the causes identified in the previous step. After thorough discussion, the CGM and LESSIFOUND team members suggested preparing a 'Material information form' which should contain the exact code of the material, composition and properties of the materials. Second, the CGM and LESSIFOUND team members suggested preparing a chart to indicate the shrinkage allowance to be given in the patterns against the materials and shapes. Third, the CGM and LESSIFOUND team members suggested imparting on the job training by availing the service of a senior pattern maker. The overall reduction in defects was intimated to decrease from 19 to 12 .Material defects can be reduced by 50 %, sand ramming and moulding defects can be reduced by 30 to 40%.

Based on the above data again, the revised sigma level after the improvement in the casting process was calculated. The details of this calculation are presented below.

Total number of component cast from 15th March 2015 to 5th September 2015: 330

Number of Defects found during /after casting body: 12

Table. 4.3. Causes and the frequency of occurrence (After LSS)

Serial Number	***Causes***	***Frequency***
1	Material	2
2	Co_2 Molding Problem	2
3	Furnace problem	1
4	Improper fettling operation	1
5	Improper sand ramming	4
6	Power breakdown and shutdown	1
7	Others	1
	Total	**12**

Identification of defects Sources: 7

$$\text{DPMO} = \frac{\text{Total number of defects detected}}{\text{Number of units produced} \times \text{opportunities of defect per unit}}$$

$$= \frac{12 \times 100000}{330 \times 7}$$

$$=5194.80$$

Sigma level =4.06 σ

It can be recalled that under step 8, it was mentioned that the current sigma level is 3.76.the value is about to increase to 4.06 on implementing the system by solutions which are mentioned above.

4.3.11. Step 11: Implementing the solutions

The CGM and LESSIFOUND team members designed a pattern making a form which should contain relevant information including that of materials. This form is shown in Figure 4.19.

Serial number	Date	Code of the material	Composition	Signature of the works manager

Figure 4.19. Pattern making form

This form should be endorsed by the works manager. The supervisor was instructed to initiate the designing of patterns only after receiving the completely filled-in pattern making a form. Second, the CGM and LESSIFOUND team members prepared a chart containing information about the shrinkage allowance to be assigned against the materials and shapes. The supervisor is instructed to indicate the serial number referred in this chart in the pattern drawing. The CGM and LESSIFOUND team members developed a chart containing the training requirements. This chart was given to the senior pattern maker who had to indicate the training needs of the individual pattern makers. Thus, the system for implementing the solutions was developed and installed by the CGM and LESSIFOUND team members.

4.3.12. Step 12: Controlling the implementation of the system

The CGM and LESSIFOUND team members prepared an audit sheet to check the continuance of the system installed in the previous step. The CGM and LESSIFOUND team members conducted the audit on the second Saturday of the month. When deviations were found, the CGM and LESSIFOUND team members took swift actions to restore the status queue.

4.3.13. Step 13: Assess the level of acquiring core-competencies

The CGM appraised the top management about the implementation of solutions. The top management received reports from different sections about the occurrence of wastes and rejection of castings. From these reports, the top management understood that there had been nearly no wastages and rejections due to the installation of the system of LESSIFOUND. Other foundries supply the customer who received the first consignment of the casting water cooler body also informed that the quality of castings is superior in comparison to those .these observations indicate that the application of LESSIFOUND enables the GTC to acquire core-competencies. These observations coincided with the increase in sigma level. The details of this increase in sigma level are presented below.

Before applying six sigma: the six sigma level =3.76σ

After applying six sigma: Six Sigma level =4.06

σ Improvement in sigma level=0.84 σ

4.4. Results and discussion

The above increase in sigma value indicates that the implementing subsequent cycles of LESSIFOUND model will increase the sigma level performance of co2 based sand casting process adopted in GTC. CGM found difficulty in step 5, 6, 12 and 13 to implement LESSIFOUND while stage 7 to 10 easy stages of LESSIFOUND. Challenges involved in implementing LESSIFOUND in foundries. Majority of foundry data not available and they are unable to give the necessary data because they have not much information related to lean and six sigma technology. Investors of small-scale foundry industry are capable of accommodating the LSS MODEL, but they are afraid to shake their foundry secrets in researchers as well as common practitioners of same manufacturing component.

4.5 Conclusion

During the past five decades, the world has been witnessing the adoption of lean manufacturing paradigm and Six-Sigma concept in several industries. In the literature arena, there have been several reports of nourishing benefits by implementing lean manufacturing paradigm and Six-Sigma concept. As a result, researchers have been advocating the combining of lean manufacturing paradigm and Six-Sigma concept under the technique lean six –sigma. Meanwhile, few reports of implementing lean six-sigma in few industries have appeared in the literature arena. These reports also have indicated that the implementation of Lean six –sigma facilitates the companies to acquire competitive strength. Despite these favorable reports lean six-sigma is yet to find applications in several industries. As mentioned in the first chapter of this thesis, the foundry is one which the application of lean six-sigma is however to see its application. In the background of this current shuttle, the investigation reported in this chapter gave valuable insight into the implementation of lean six-sigma by following the 13 steps of LESSIFOUND model. Although no approaches like TQM and TPM were implemented in the GTC, the MD of GTC and the team members of the LESSIFOUND project could nourish the activities to be carried out under the 13 steps of LESSIFOUND model. One cycle of the completion of the implementation of the LESSIFOUND model in GTC was marked by the increase of sigma level by 0.84. The overall experience of the completion of implementing one cycle of LESSIFOUND model indicated that this model could be used as a catalyst for triggering foundry industry to achieve waste elimination and defect manufacturing in producing cast components. Since no continuous quality improvement approaches were employed in GTC, little difficulties were experienced while implementing certain steps of LESSIFOUND model in which case gathering of the appropriate data played crucial roles. These difficulties are discussed in chapter 7. In the backgrounds of encouraging experiences, two more investigations on the practicality of LESSIFOUND model were conducted in two different foundries. These investigations are reported in the following two chapters.

CHAPTER-5

Implementation of lean six-sigma in sand casting process: An implementation study in a factory

5.1 Implementation study

The practicality of LESSIFOUND model was studied by making efforts to implement it in a foundry by name 'Sanjay casting(Ind.) PVT.LTD'(This foundry will hereafter be referred to as SF). SF is situated in Bhavnagar city of India. The front portion of the SF is shown in Figure 5.1.

Figure 5.1. The front portion of SF

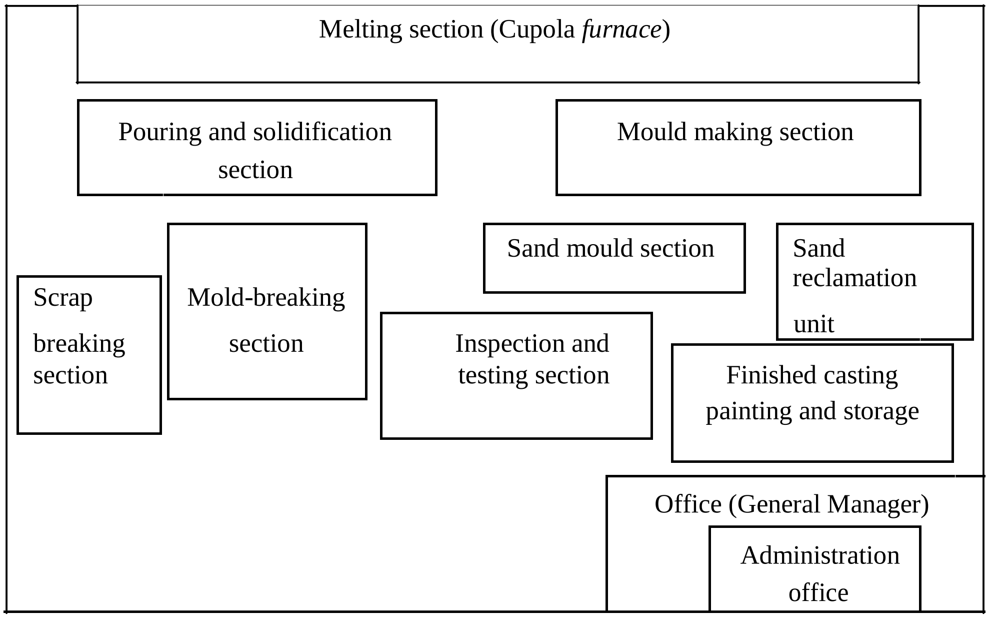


Figure 5.2. Plant layout of SF

The plant layout of SF is shown in Figure 5.2. As shown, it consists of ten departments. In one end, the administrative office is located. In the other end, the melting section is located. In this section, the cupola furnace is located. SF was started in the year *1976 with* employee strength four. Currently, 200 employees are working in SF. The organizational structure of SF is shown in Figure 5.3. SF is owned by its proprietor *Mr Harshadrai Rathod*. Due to his poor health, and age problem Mr.*Harshadrai Rathod* is unable to manage SF. From 1991, SF is managed by Managing Director's Mr Sanjaybhai Rathod and Deepakbhai H. Rathod.The group has blossomed into a major player not only in India but overseas market also.*Mr.* Sanjay Rathod, who holds a Diploma degree in Mechanical Engineering. He and his brother Deepakbhai H. Rathod put continuous effort to established two more units of SF as Sanjay casting(Ind.) PVT.LTD(100%Export Oriented Unit) and Sanjay Iron & steel Industries in Bhavnagar. Under the guidance of general manager, head of the administration and supervisors of quality control and production engineering departments manage the foundry activities of SF. These three managerial employees instruct the foundry men to execute the jobs. Sanjay group is committed to maintaining its position as a leading manufacturer & supplier of quality Cast Iron Ingot Moulds and other products in Indian and overseas markets. Sand casting is followed to produce the castings of parts which are used in rolling mill and slag pot in foundry industries. Further, from a small turnover of INR 11 Million during 1991-92 the group has witnessed substantial growth, and the turnover in 2006-07 has reached INR 400 Million.

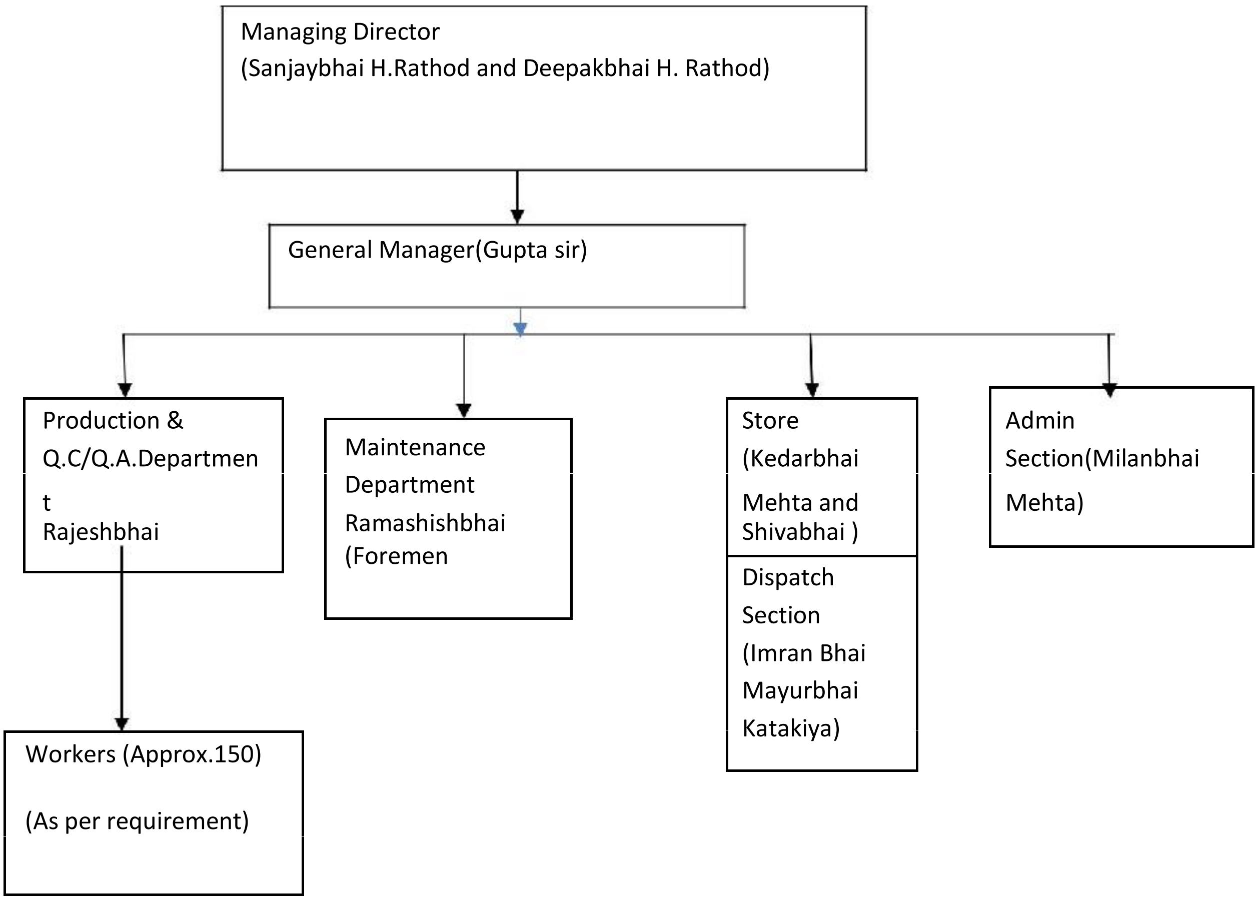


Figure 5.3. The organizational structure of SF

The group is regularly exporting to African & Asian countries and has ambitious marketing plans to export in the European countries and the USA. Figure 5.5 and 5.6 shows various certificates from an export house and SME Business Excellence Award and Western Region Award.

Figure 5.4. Certificate of Export House

***Figure 5.5.* SME Business Excellence Award and Western Region Award**

In SF, a Cupola furnace is installed to produce castings weighing up to 1500 kgms. The photograph of this Cupola furnace is shown in Figure 5.6. A regular interval for checking the work sample on spectrometer machine as shown in figure 5.7 and 5.8. After the approval from QA department head, Mr Hardikbhai Vyas metal will be poured in to mould. The castings produced in SF are of Cast Iron Ingot Moulds and other Castings products like the bottom plate, slag pot, centre column for Steel Plants & Rolling Mills & processing of Ferrous & Non-Ferrous Scrap. The conventional practices are followed to produce castings and inspect the same in SF.

There have been no modern concepts like TPM and Six-sigma implemented in SF. The quality control practices have been conventional, and ISO 9001 based quality management system has also not been implemented in SF. *Future they will be applied for ISO 9001 certification. Their* castings are exported directly to many countries. List of these countries are:

- Africa
- Saudi Arabia
- Iran
- Dubai
- Bahrain
- Abu Dhabi
- North America
- West Indies
- South Africa

Figure 5.6 Cupola furnaces used in SF

Figure: 5.7 Spectrometer test Apparatus

Figure: 5.8 Spectrometer test on the piece

During the recent years, problems in improving quality and increasing production to match with competitive situations prevail in the foundry arena. In this background, SF is currently considering the implementation of ERP (Enterprise Resource Planning) and purchasing a spectrometer. SANJAY CASTINGS (India) PVT LTD is established as a 100% Export Oriented Unit. These companies have established themselves very well in the market and have become significant players in both domestic as well as export markets. In this background, the efforts were made to implement LESSIFOUND in SF.

To begin with, the first author of this paper was recognized as the 'Consultant General Manager' (CGM), to coordinate the implementation of LESSIFOUND steps in SF. In the beginning, the CGM met the Managing Director of SF and exposed to him the LESSIFOUND model. The photograph shot down during one of these sessions is shown in Figure 5.9. The details of activities carried out under these steps are described in the following sub-sections.

Figure 5.9. The CGM explains the LESSIFOUND model to the Managing Director of SF

5.2. Implementation of LESSIFOUND Model

CGM developed a 13 step model summarized as below:

STEP 1: Gather information and knowledge about foundry practices.

STEP 2: Decide the scope of a model concerning processes like Sand casting, Die casting, Investment casting and other foundry practices.

STEP 3: Map the candidate process in the company.

STEP 4: Determine the feasibility of applying model 53 tools and techniques in the foundry. (Shown in the Literature review paper)

STEP 5: Decide the area and team for implementing the model.

STEP 6: Impart training and education on model tools and techniques.

STEP 7: Define the problem.

STEP 8: Measure the performance in the problem areas.

STEP 9: Analyze the problem.

STEP 10: Improve the performance.

STEP 11: Implement the system.

STEP 12: Control the implementation of the system.

STEP 13: Assess the level of acquiring core-competencies.

CGM implemented 13 step model in SF as discussed below:

5.2.1. Step 1: Gathering of foundry knowledge

SF produces Cast Iron Ingot Moulds as a primary product. They purchase raw material from their supplier of Ingot mould as scrap rate after their 100 times used for producing ingot .they melt these ingot moulds in cupola and then produces Cast Iron Ingot Moulds again .whenever demand of Cast Iron Ingot Mould was high, in case of big order from other countries then they purchase raw material as scrap rate from Alang ship breaking yard also. Approximate weight of these product 600 to 700 kg/Ingot. Average production of ingot mould approx. 70 to 75 pieces and six days working in a week so monthly they produce 1700 ingot mould .2 core required in every mould so daily they prepared 140 to 150 core. Core sizes may differ according to finished Ingot mould required as per purchase order. On the average regular size of core required was 3.5 to 4.5-inch cross-section and 68-inch length prepared. 140 to 150 core of high size prepared every day .however currently they produced another 6 to 10 pieces of core size 5 to 6-inch cross-section and 48 inches in length. Same foundry men prepare the mould and core.

They prepared the core in 4 rows in which 1st raw contains 52 cores,2nd raw contains 62 cores, 3rd raw contains 30 cores of regular size and in 3rd raw six core of 48-inch length. Every day after 12.00.p.m. workers prepared the mould cavity with core insertation and stacking the mould in a raw for next day morning for pouring session and another worker carried out Knock out operation on previous day poured mould. Parallel activity related to mould preparation through sand reclamation unit and braking of used ingot mould through a machine and Magnetic separator crane used to identify magnetic particles from scrap. Finished casting is paint and ready for shipment.

Current turnover of the company is approximately 120 crores. Cupola charges in the early morning at about 3.00 a.m. and continues till 5.00 p.m. After each hour sample should be inspected by the spectrometer and after assurance from Q.A. departments they pour the molten metal into the mould. In spectrometer test each sample contains proportion of carbon 3.25 to 3.6% , Manganese 0.8 to 1% ,Silicon 1.9 to 2.2% ,Sulphur 0.3 to 0.5%, Phosphorus 0.03 to 0.05%. Then poring will be initiated else changes will be initiated into cupola charges according to requirement. Pouring capacity of the unit is 50 tons per day. A general daily requirement of workers on the shop floor is core, pouring and mould making 10-10 -10 workers, mould matching and setting 12 workers, mould preparation by 15 workers and mould repairing section 10 workers. Melting and pouring carried out in 3 rows. 1st raw contains 15 mould box, 2nd raw contains 42 mould and 3rd raw contains 18 moulds. Graphite coating is compulsory on every core and mould by changing the graphite grade for both. In core 90-95 graphite grade and mould 70 - 75 graphite grade required to mix with water. Graphite grade is available in a container of 50 kg. Minimum 2 container of graphite grade utilized in a day. Graphite should be properly melted in a tank for at least one week, and then they used this mixture for graphite coating in mould and core for a better surface finish. In graphite coating 30-litre water required for mould and core finishing process. In sand moulding, 70% reused sand mixed with 30% fresh sand with a mixture of bentonite and S Coke for mould strength and bonding purpose. Such prepared sand mixture fills 160 moulds by three units sand reamer machine. Shake out the operation of 160 moulds carried out in next day by using an overhead crane and hand hammer only. Riser, core and extra metal removed from the final casting piece. Minimum time required for cleaning and removal of a riser is about 15 to 20 minutes per mould. After cleaning operation grinding operation is carried out on every casting by

1 to 2 mm cross section and 1 to 1.5-inch length cutting on the special-purpose machine. In SF, 5 special purpose machines available so daily 15 casting pieces cut on every machine as handle side remain as it is only another side cutting on every casting.

5.2.2. Step 2: Deciding the scope of LESSIFOUND application

The CGM understands that many types of casting practices available in leading foundries like Sand casting, Shell moulding, Continuous casting, Forge casting, Permanent mould casting etc. In SF, only sand casting using Permanent moulding is only being adopted. Hence the scope of application of LESSIFOUND in SF was its application in Permanent moulding based sand casting process. After thus deciding the scope of the application of LESSIFOUND, the CGM studied the steps followed to carry out Permanent moulding based sand casting process followed in SF. following Activity Chart shows the number of activity and duration for each activity. Total time required for casting ingot Billet is seven days graphically as shown below in figure 5.10. The steps followed to produces Cast Iron Ingot Mould shown by the CGM is in Figure 5.11 is a block diagram. As shown, Core making and core backing carried out in the separate section as shown in Figure 5.12 and Figure 5.13. According to order size number of core, production may vary from 120 to 150.bigger size fan required for cooling the core. Then Graphite coating is done on all the core and next day backed the core in an oven for strengthening purpose of a core. Moulds were made by making use of these two cores. Mould was prepared into two half and then join these two half. Then graphite coating on the mould and places the mould into the oven for backing purpose as the shot in Figure 5.14 and Figure 5.15.Mould was prepared into two half and then join these two half as final mould and stacking all these mould assemblies in 3 or 4 raw for next day pouring.

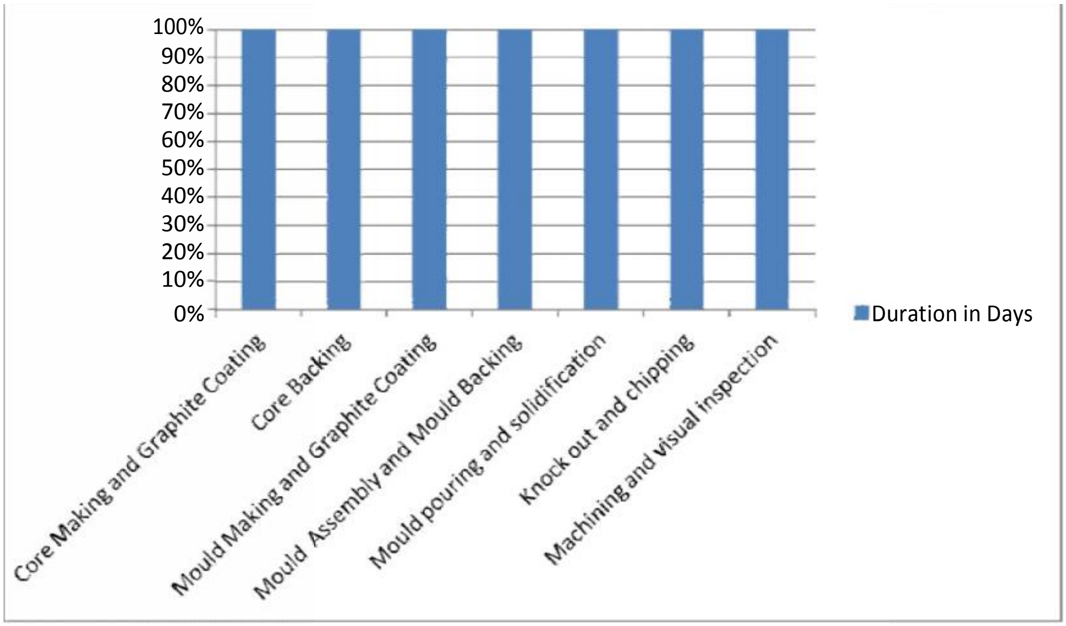


Figure 5.10. **Total Time Required for making Casting Ingot Billet**

1.Core making and Graphite coating– One day

2.Core backing- One day

3.Mould making and Graphite coating –One day

4.Mould assembly and mould backing-One day

5.Mould Pouring and solidification-One day

6. Knock out and chipping-One day

7.Machining and visual inspection -One day

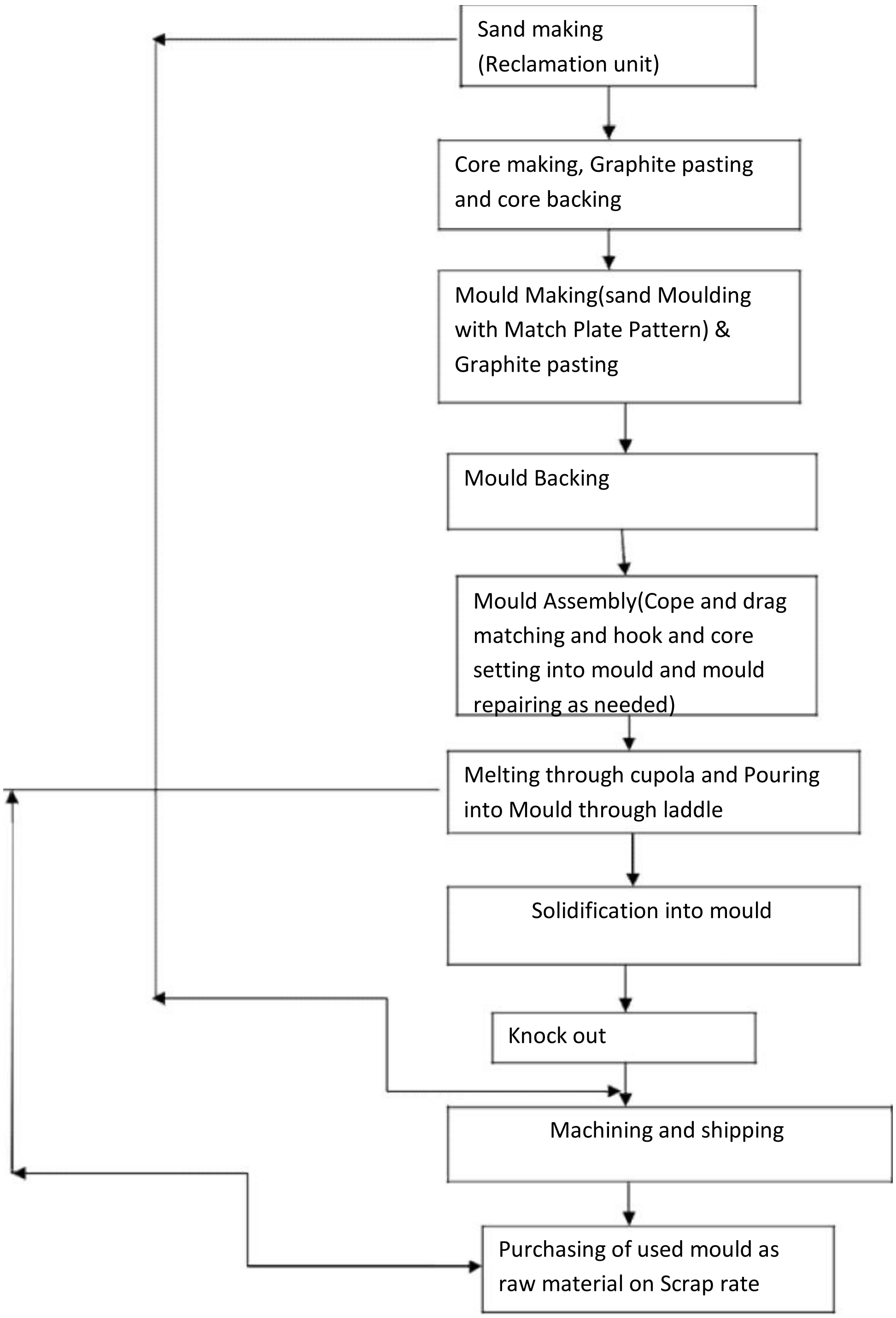


Figure 5.11 Steps of sand casting process adopted in SF

Figure 5.12. Series of Mould and core making in SF

Figure 5.13.Mould making on Match plate pattern

Figure 5.14. Mould backing Oven in SF

Figure: 5.15 Partial view of Mould backing

Figure: 5.16 Types of Mould

Variety of permanent mould available according to their size. Figure 5.16. shows sizes of the ingot mould. A photograph shot when the moulds were repaired, and coating made in SF is as shown in Figure 5.17. Subsequently Finished mould as shown in Figure 5.18.

Figure: 5.17 Mould Repairing and Graphite Coating In SF

Figure: 5.18 Finished mould

Now handling of the mould through overhead crane into the oven for backing purpose as shown in Figure 5.19. After backing into the oven the mould assembly placed in a raw wise for next day pouring as shown in Figure 5.20 as title stacking of mould.

Figure: 5.19 Handling of the mould into mould backing

Figure: 5.20 Stacking of Mould

After stacking of mould into a line next day morning charge the cupola furnace and pouring molten metal through overhead crane and translate ladle as shown in Figure 5.21. Solidification time required for these casting is about 24 hours. Figure 5.22 shows solidification into mould and backside of these core making process will continue. So next day afternoon knock out operation will carried out in damp to avoid an accident and in an isolated region and NO entry zone.

Figure: 5.21 Pouring into Mould

Figure: 5.22 Solidification into mould and backside Core Making Process

Figure: 5.23 Cleaning of casting

Figure: 5.24 Finishing of casting on lathe machine

Figure 5.23 shows a cleaning of casting ingot while figure 5.24 shows a finishing of casting ingot**.** Figure 5.25 shows a section of storage of finished casting. Sand used for casting can be reused after reclamation technique. Figure 5.26 shows a sand reclamation unit.

Figure: 5.25 Storage of Finished casting

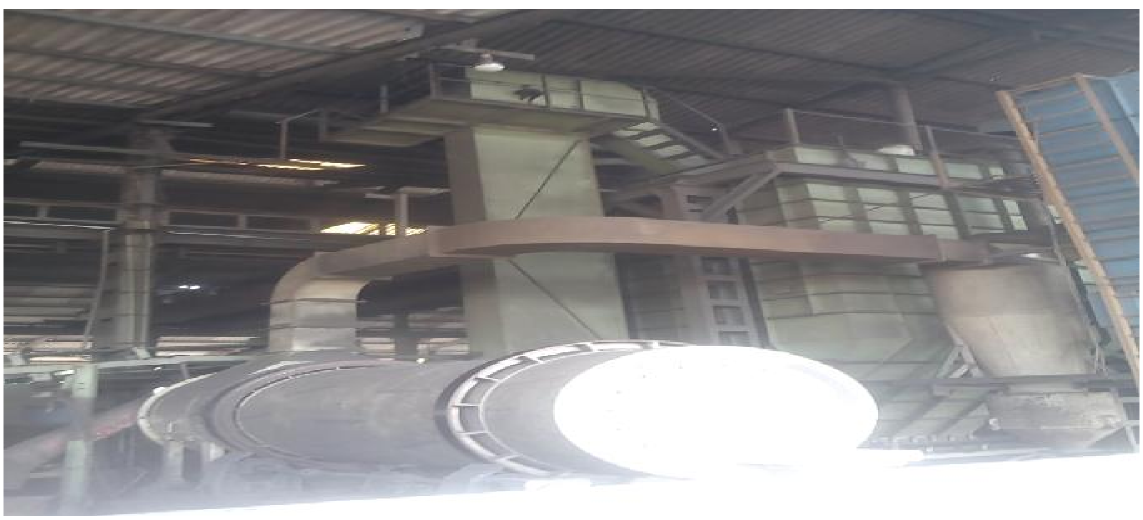


Figure: 5.26 Sand Reclamation unit

Figure: 5.27 Magnetic Separate overhead Crane

Figure: 5.28 Broken pieces of ingot mould/ scrap for charging material in Cupola furnace

Figure 5.27 shows a magnetic separator overhead crane used in SF. Figure 5.28 shows a broken piece of scrap ingot used as charging material in the cupola furnace. CGM

Frequently visited SF and one shot of communication with production head Mr Hardikbhai Vyas as the shot in Figure 5.29.

Figure: 5.29Communication of CGM with Production head

5.2.3.Step 3: Mapping the candidate process

In this step, CGM takes the several visits of the SF.SF manufactures a casting ingot billet according to order size using a sand casting process using various steps like core making, mould making, insertion of the core into the mould, graphite coating on core and mould making, core and mould backing section, melting and pouring section, shake up, cleaning and testing section. Two cores required in casting ingot billet. CGM visits the various section and locations in the foundry to study the sand casting process carried out in practice and mapping the processes in SF. As shown, in Figure 5.30 map the CGM notes the occurrence of wastes and rejection of defectives under each process.

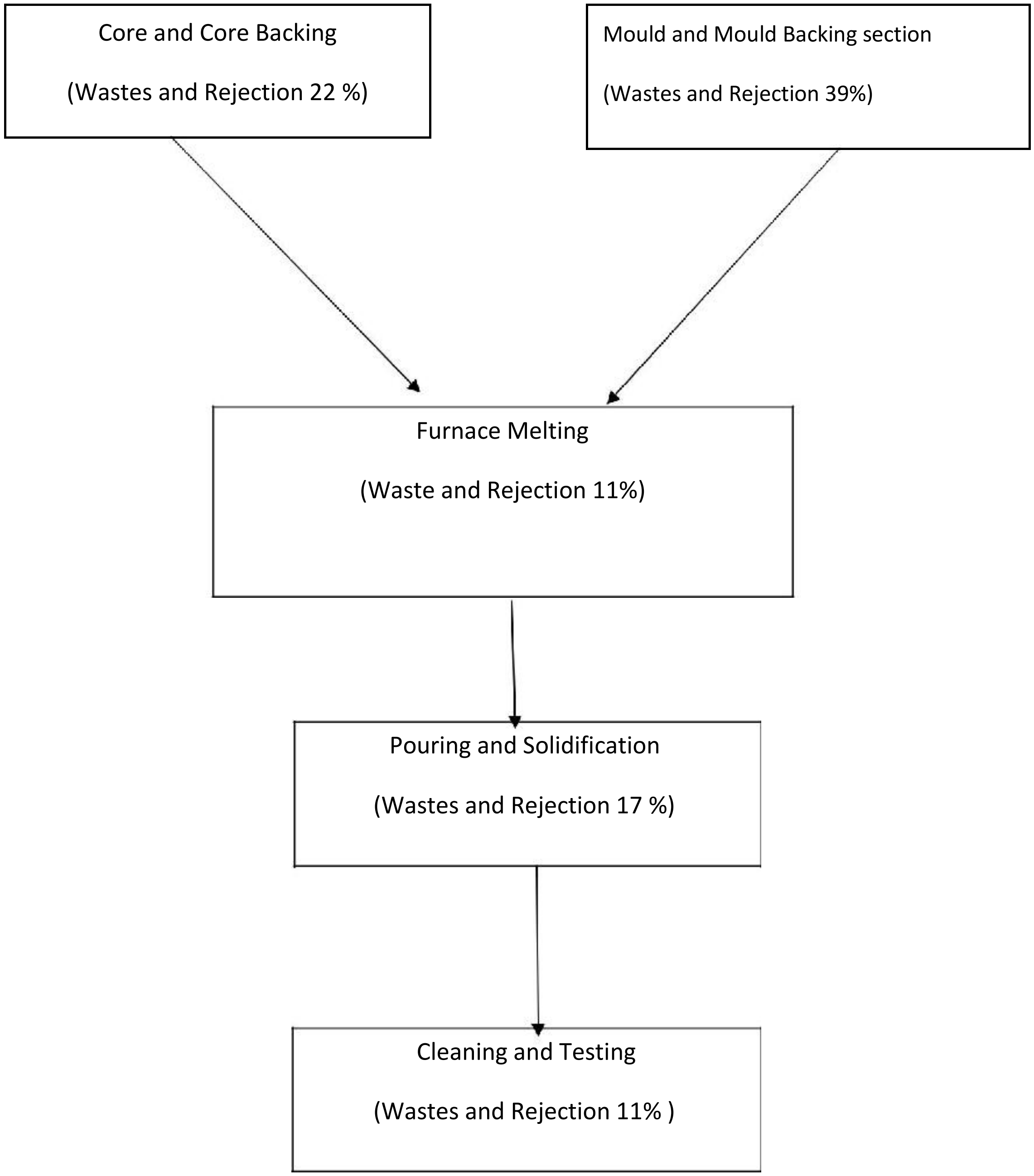


Figure 5.30. Mapping the processes in SF

5.2.4. Step 4: Determining the feasibility of applying LESSIFOUND tools and techniques

Based on a 3rd step CGM makes several meeting with General manager Mr Gupta sir and managing director Mr Sanjaybhai to identify the scope of implement LESSIFOUND model in SF. Finally, top management allows CGM to implement LESSIFOUND model in SF by using D-M-A-I-C approach, Cause-effect diagram only. During this meeting, the feasibility of applying these tools and techniques is discussed.

5.2.5. Step 5: Deciding the team and area of applying LESSIFOUND

Under this step, the CGM invites the team members for LESSIFOUND model from the shop floor, middle management and top management. Four operators, two head of the department, 1 General manager and 1 MD become members of LESSIFOUND team.CGM forms this team and approves this team from top management. Then M.D. Sanjaybhai Rathod approves the formation of this LESSIFOUND team and then CGM and LESSIFOUND team carrying out the subsequent steps.

- **Project number:1**
- **Project Title: Quality Improvement in core and Mould making**
- **Team Leader: Darshana Kishorbhai Dave**
- **Team Members: Mr Sanjaybhai Rathod(M.D.), Mr Gupta (General Manager), MrRamashishbhai (Maintenance Head), Mr Milanbhai Mehta (Admin's head)**
- **Project Duration:4 Months**

5.2.6.Step 6: *Imparting training and education*

Under this step, CGM gives training to entire LESSIFOUND team by referring case studies reported by the various researchers and practitioners in literature arena.CGM design a different short-term training program in the foundry for awareness of LESSIFOUND model.

5.2.7. Step 7: Defining the problem

Under this step, the CGM discusses with the LESSIFOUND team members to choose the problem. The LESSIFOUND team members inform that the occurrence of the high level of wastes and rejection rate is due to the inappropriate moulding method and core making method assigned during the permanent mould. Thus this problem was defined, and the CGM and LESSIFOUND team members developed the project charter. This project charter is shown in Figure 5.31 Identify the Problem in SF: Defect-free sand casting product should be produced with zero defect.

Date of starting the project: July 1, 2014
Date of completing the project: September 3, 2014
Project deliverables: Waste elimination and zero defect in core and mould making

LESSIFOUND Project

Project number: 1
Project title: Quality improvement in core and mould making
Team leader: DARSHANA DAVE
Team members: **Mr Sanjaybhai Rathod(M.D.), Mr Gupta(General Manager), Mr.Ramashishbhai (Maintenance Head), Mr Milanbhai Mehta (Admin's head)**
Problem definition: Assigning inappropriate moulding and core making method leads to the occurrence of higher wastes and rejection in mould making and core making process. *Project duration*: 3 months

Figure 5.31. Project charter

During manufacture of a casting of Ingot Mould rejection is very high. This is a defect that we identify and try to resolve with LSS.(D-M-A-I-C). Figure 5.32 shows the detail drawing of Ingot Mould design.

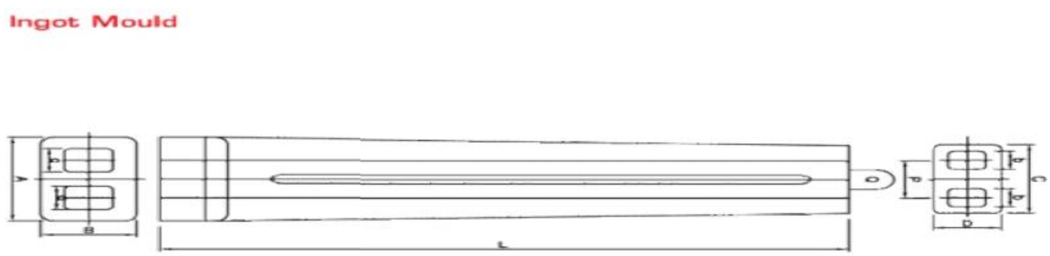


Figure 5.32. Ingot Mould

Table 5.1 shows the specification and size of ingot moulds produced by SF.

Table: 5.1 Specification Table of Ingot Mould

Sr.No.	Size	Centre(P)	Length(L)	Hole (a)	Hole (b)
01	2 ½’X3 ½”x60”	170	1525	89	64
02	3”X4”X54”	170	1372	102	76
03	3”X4”X54”	220	1372	102	76
04	3”X4”X60”	170	1525	102	76
05	3”X4”X60”	220	1525	102	76
06	3 ¼”X4 ¼”X60”	170	1525	108	82
07	3 ¼”X4 ¼”X60”	220	1525	108	82
08	3 ½”X4 ½”X54”	220	1372	115	90
09	3 ½’X4 ½” X	220	1525	115	90

	60”				
10	4”X5”X54”	235	1372	127	100
11	4”X5”X60”	235	1525	127	100
12	4 ½”X5 ½”X60”	220	1525	140	114
13	5”X6’X54”	220	1372	152	127
14	5”X6”X60”	220	1525	152	127
15	5 ½”X6 ½”X54”	220	1372	165	140

5.2.8. Step 8: Measuring the performance

Under this stage, the CGM and the team members assess the waste level during core making and core backing and mould making and mould backing section. Using this data, the CGM and LESSIFOUND team members find that the sigma level of producing the castings in the foundry as 4.75σ. The calculation details are shown below:

After making these measurements, the CGM and LESSIFOUND team members fix the target by overcoming the defined problem.

- Area: Foundry
- Customer requirement: Defect-free casting product
- DPMO (defect per million opportunities): during /after sand casting process carried out
- Total number of casting component from 15th November 2014 to 5th March 2015: 6500
- Number of Defects found during /after casting body of 18

Identification of defects Sources:5

$$DPMO = \frac{\text{Total no.of defects detected}}{\text{No.of units produced* opportunities of defect per unit.}}$$

$$= \frac{18*1000000}{6500 *5}$$

$$=553.84$$

Six Sigma level =4.75σ

5.2.9.Step 9: Analyse the problem

Under this step, CGM and team members of LESSIFOUND analyse the defect identify during mould and core making and backing section. Improper oven time causes cracks in core and mould. Even low backed mould failure during pouring also. Every day 2 to 3 mould breakdown and molten metal moved outside from mould. This was very risky. For safety, the CGM and LESSIFOUND team members allocate two workers during pouring with moulding sand as of when moulding flask open they immediately fill that cavity. Team carry out the Cause-Effect analysis to determine the cause of occurrence of the defined problem. The CGM and LESSIFOUND team members find that the Furnace problem, Improper fettling operation, New operators, Shifts are the main causes that cause the defect in casting. Detailed analysis of causes and number of frequency of occurring the defects are mainly five as shown below. Figure 5.33 shows the proportion of defect. Figure 5.34 shows a Cause-Effect Diagram for Identification of sources of a defect in Ingot Mould. During the site visit, we identify the following five types of defects and frequency of defects as shown in table 5.2.

Table 5.2. Causes and the frequency of occurrence (Before LSS)

Sr.No.	Causes	Frequency
1	Core Making	4
2	Moulding	7
3	Furnace problem	2
4	Improper fettling operation	3
5	Others	2
	Total	18

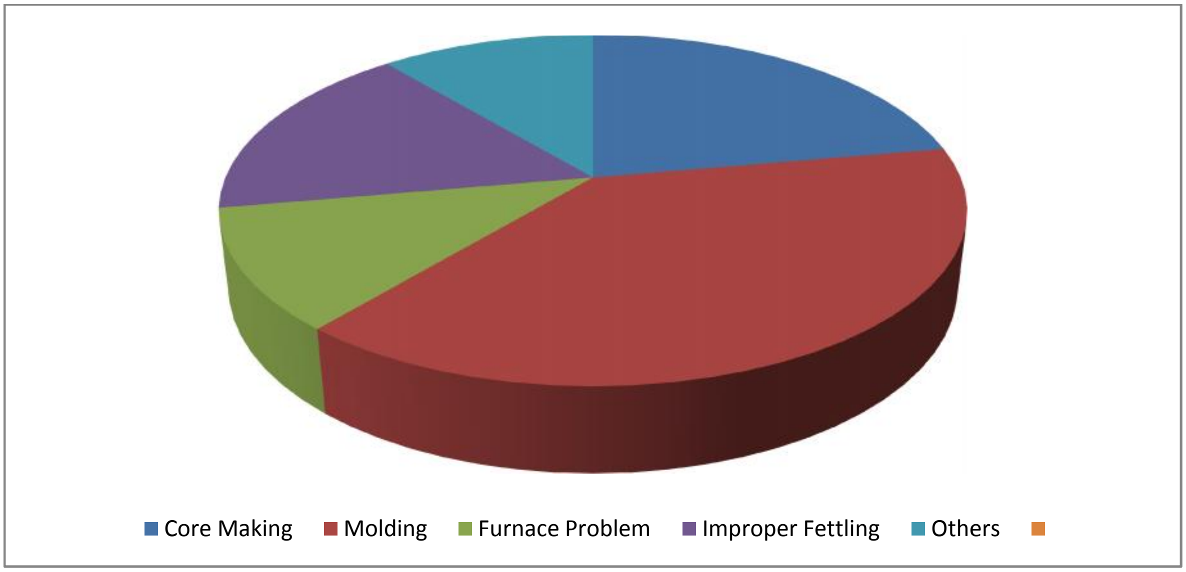


Figure 5.33. Proportion of Defect(Before LSS)

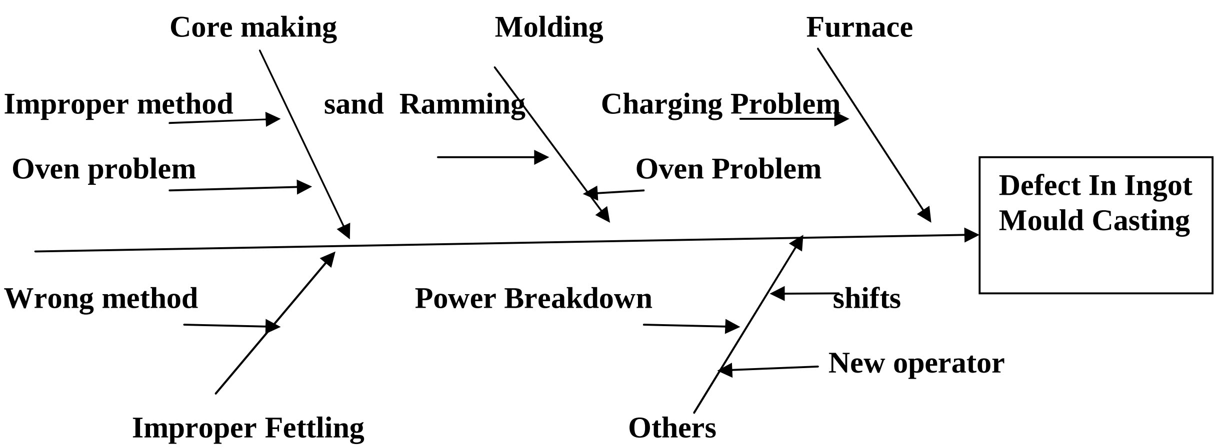


Figure 5.34. Cause-Effect Diagram for Identification of sources of a defect in Ingot Mould

5.2.10. Step 10: Improve by providing solutions

The CGM and LESSIFOUND team members discuss providing solutions against the causes identified in the previous stage. After thorough discussion, the CGM and LESSIFOUND team members suggest training new operators through various innovative method. Management put few senior operators daily for trained new operators after regular shifts. Furthermore, the CGM and LESSIFOUND team members suggested more workers on mould and core backing section instead of the single operator. Due to the heavy load that operator forgets the exact time for removal of core and mould from the oven. So few cores and moulds are too much backed and few cores and mould half backed than required. With above two suggestion management put two operators on mould backing and one operator on the core backing section for better result and minimization of core and mould defects. Third, the CGM and LESSIFOUND team members suggested the need for generators for a power back up.

Table 5.3. Causes and the frequency of occurrence(After LSS)

Sr.No.	Causes	Frequency
1	Core Making	1
2	Moulding	2
3	Furnace problem	1
4	Improper fettling operation	1
5	Others	1
	Total	06

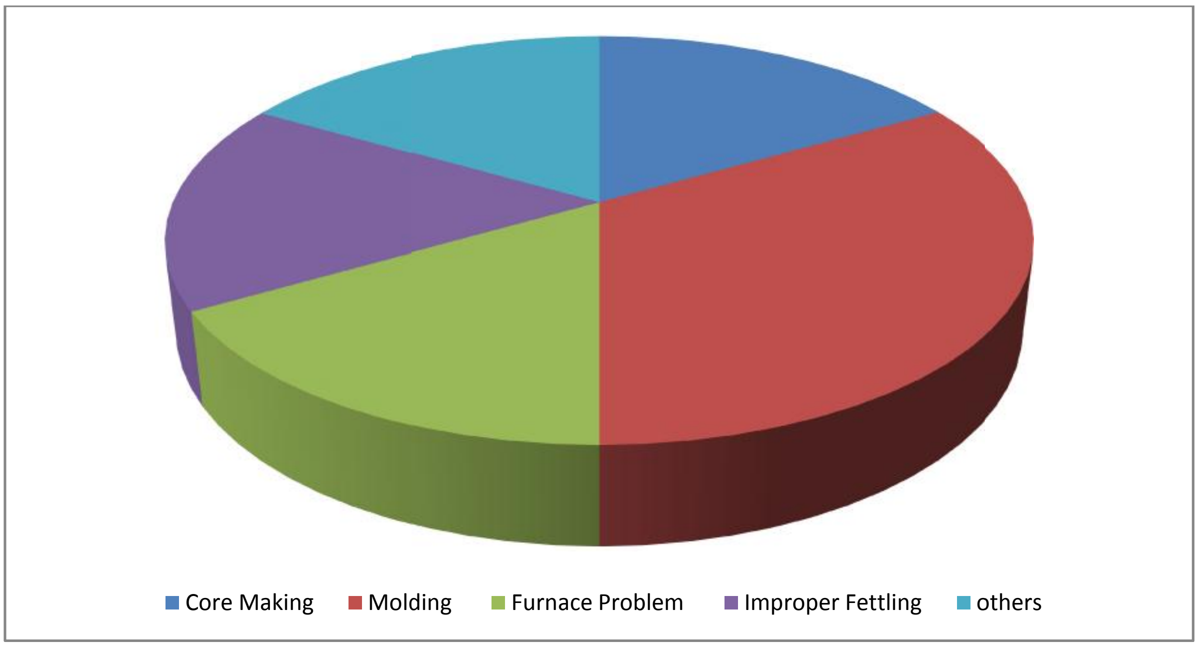


Figure:5.35. Proportion Of Defect(After LSS)

- Total number of casting component from 5th March 2015 to 5th and July 2015: 7440
- Number of Defects found during /after casting body of : 06
- Identification of defects Sources:5

$$DPMO = \frac{\text{total no.of defects detected}}{\text{No.of units produced* opportunities of defect per unit.}}$$

$$= \frac{06*1000000}{7440 *5}$$

$$=161.29$$

Six Sigma level =5.10σ

Overall improvement in defects identification and reduction in defects from 18 to 6 .core defects can be reduced by 25 %, and ramming and moulding defects also reduced by 28%, Cupola furnace problem reduced by 50%, fettling defects reduced by 33% and other defect reduced by 50 %. Figure 5.34 shows the number of defects identified during the improve phase of LESSIFOUND model. Figure 5.35 shows by using proper tools and techniques, defects can be reduced from 18 to 6. In this Step, we improve the sigma level from 4.75 to 5.10, so we keep the training and try to maintain the same level in future also.

5.2.11.Step 11: Implementing the solutions

The CGM and LESSIFOUND team members implement the suggestion to entire foundry through a training session. They also maintain a daily sheet for identification of wastes and defects and make the audit on last Sunday of every month as shown below in Figure 5.36. When deviations are found, the CGM and LESSIFOUND team members take swift actions to restore the status queue.

Sr.No.	Date	Number of Casting Produced	Number of Defects Identified	General Manager Comments about sources of defect and signature

Figure 5.36 Daily Check Sheet

5.2.12.Step 12: Controlling the implementation of the system

The CGM and LESSIFOUND team members prepared an audit sheet to check the continuance of the system installed in the previous step. The CGM and LESSIFOUND team members conduct the audit on the last Sunday of every month. When deviations are found, team members contact the CGM for corrections. Sample audit sheet is shown below in Figure no.5.37.

Name of the company:

Target Area: Manufacturing/ Quality control

Name and signature of Auditor:

Audit date:

Audit Technique	**Auditable item, Observation, Procedure etc.**	**Individual Auditor**	
		Yes	**No**
Observation	Have all associated been trained?		
Observation	Are wearing proper safety clothes /Accessories?		
Observation	Is sampling inspection or 100% inspection?		
Observation	Is a total number of defect minimised?		
Observation	Is quality check according to LESSIFOUND model?		
Observation	Is the total number of causes minimised?		
Observation	Is cause-effect diagram followed?		
Observation	Is lean six sigma level maintained or increase?		

Many out of compliance observation:

Total observation:

Corrective actions required:

Figure 5.37 Audit sheet

5.2.13. Step 13: Assess the level of acquiring core-competencies

In this step, CGM and LESSIFOUND team assess the level of improvement by 0.35 σ.With above improvement defect per million opportunities improved and moulding defect reduced which will improve the productivity of the plant with fewer correction required in final casting. Safety and training affect the result of finished casting. Top management realises the above fact and encourages the CGM to implement the same in their relative's foundries.

Before applying six sigma: So the six sigma level =4.75σ
After applying six sigma: Six Sigma level =5.10 σ
Improvement in sigma level=0.35 σ

5.3. Discussion

CGM found difficulty in step 3, 4, 9 and 12 to implement LESSIFOUND while staging 1 and two easy stages of LESSIFOUND. Managing Director Mr.Sanjaybhai is very cooperative and appreciate the work done by CGM and suggest a fewer foundry in which LESSIFOUND model can be implemented. Challenges involved in implementing LESSIFOUND in foundries measuring the defects and identification of sources of the defect. In general, staff supports CGM as their staff, and they give the true data and with positive attitude complete this steps also. They have not much information related to lean and six sigma technology before implementing LESSIFOUND model, but now they can sustain the sigma level.

CHAPTER-6

Implementation of lean six-sigma in sand casting process: An implementation study in a factory

6.1 Implementation study

The practical implementation aspects of LESSIFOUND model were studied in a foundry by name '*Mahalaxmi Foundry Industries'* (Hereafter referred to as *Mahalaxmi*). Mahalaxmi is situated in Bhavnagar district of Gujarat state of India. Mahalaxmi was started in the year 1959 by *Mr.Jagjivanbhai Arjanbhai Harsora*. He has been operating this unit as the Proprietor. In the year 1970, he started the second unit of Mahalaxmi in the same district. This second unit is managed by his son Mr.Arun Harsora. Thus today two units are functioning under Mahalaxmi. At the time of starting Mahalaxmi, there were only eight foundrymen. Today 30 foundry men are working in Mahalaxmi. At the time of starting, castings weighing 50 tons were manufactured in a year in Mahalaxmi. Today castings weighing 350 tons are manufactured in a year. The major cast-iron components manufactured in Mahalaxmi are drilling machine pillar and components like coupling, stand, rail and gates used in roller mills. Besides, cast-iron dies used in vessel manufacturing companies are manufactured in Mahalaxmi. These cast components are manufactured by employing a sand casting process with pit moulding and are supplied to the rolling mills and drilling machine manufacturing companies situated in the Gujarat state of India. While manufacturing these components, two casting defects namely blowholes, and is run are encountered. No concepts like TPM and Six-sigma have been implemented in Mahalaxmi. ISO 9001: Mahalaxmi has not also obtained 2008 certification. In this background, the steps of implementing LESSIFOUND model were studied in Mahalaxmi. The activities carried out in this direction are described in the following sub-sections.

The practicality of LESSIFOUND model was studied by making efforts to implement it in a foundry by name *'Mahalaxmi Foundry'* (This foundry will hereafter refer to as MF. MF is situated in Bhavnagar city of India. The front portion of the MF is shown in Figure 6.1.

Figure 6.1. The front portion of MF

The plant layout of MF is shown in Figure 6.2. As shown, it consists of seven departments. In one end, the administrative office is located. In the other end, the melting section and machine shop’s are located. In this section, the cupola furnace is located. The organizational structure of MF is shown in Figure 6.3.

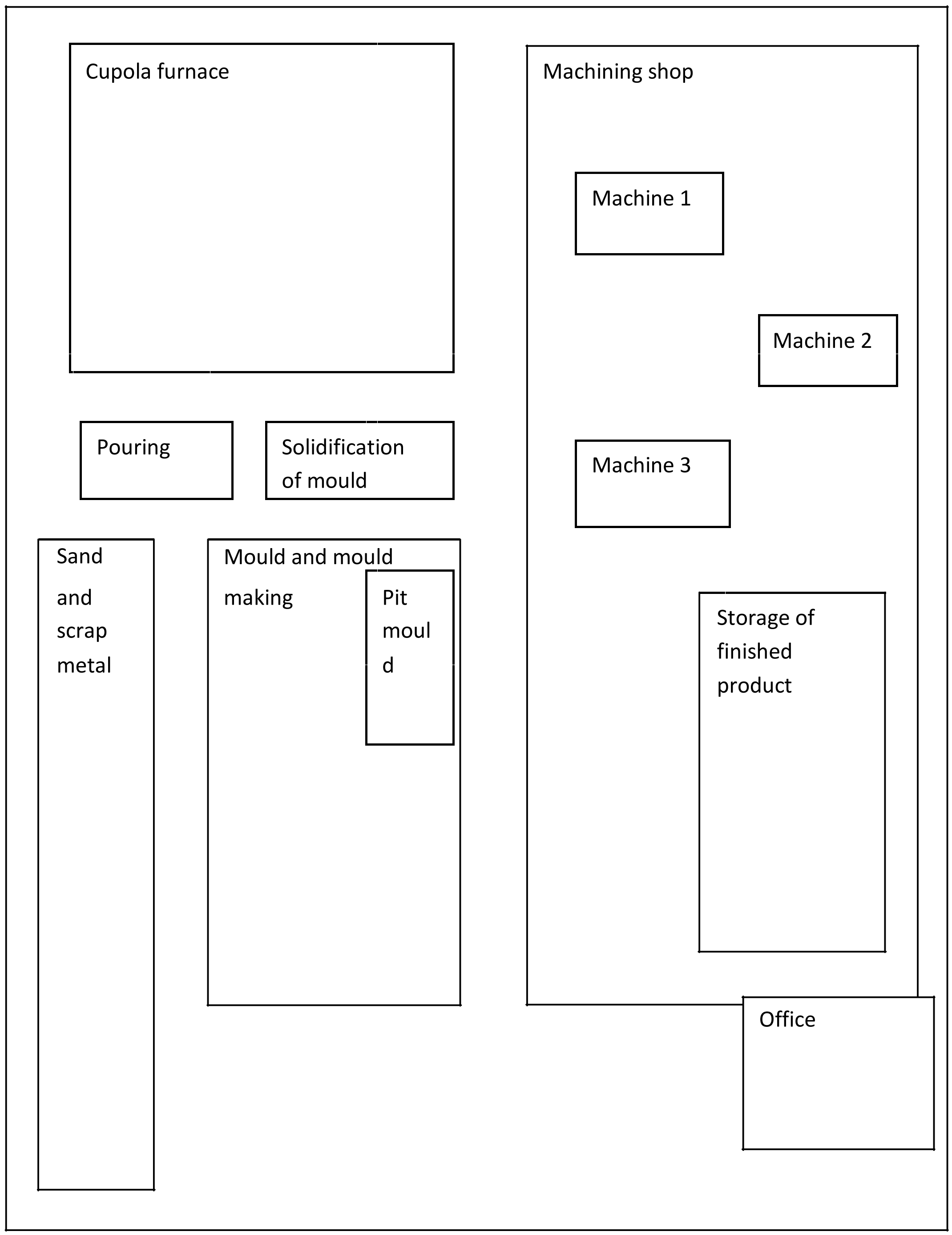


Figure 6.2. Plant layout of MF

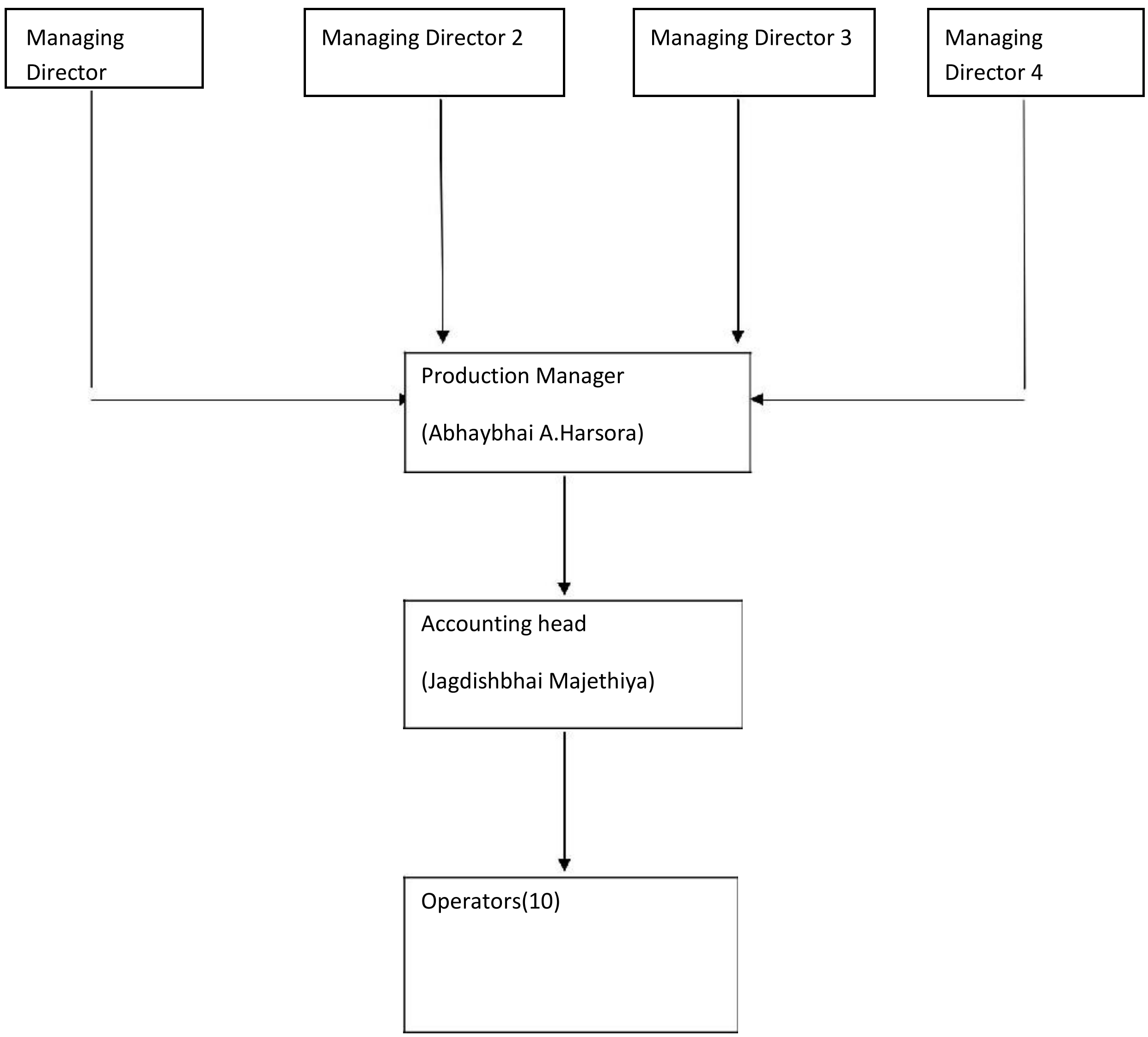


Figure 6.3. The organisational structure of MF

As shown, MF is owned by four managing directors are brothers and one of his son Abhaybhai A.Harsora as Production manager.They have very few people as administrative and account work. Majority of work is managed by M.D. themselves. Under the guidance of Mr.Arun Harsora administration work is managed while remaining foundry work and quality issues managed by other three managing directors. In MF, sand casting is followed to produce the castings of parts which are used in drilling machine and vessel manufacturing. Further, the castings of transmission parts like gears and couplings are produced in MF. The overall view of the foundry shop with cupola furnace in the foundry section of MF in which sand casting is carried shown in Figure 6.4.

Figure 6.4. Overall view of foundry shop of MF

In MF, cupola furnace is installed to produce castings of a pillar of drilling machine. The photograph of this induction furnace is shown in Figure 4.5. Generally, they started cupola furnace once in a week or according to customer's order requirement. The castings produced in MF are of Cast Iron. The conventional practices are followed to produce castings and inspect the same in MF. There have been no modern concepts like TPM and Six-sigma implemented in MF. The quality control practices have been conventional, and ISO 9001 based quality management system has also not been implemented in MF. No castings of MF are exported directly to any country.

Figure 6.5. Cupola furnaces used in MF

During the recent years, problems in improving quality and increasing production to match with competitive situations prevail in the foundry arena. In this background, MF is currently considering the implementation of ERP (Enterprise Resource Planning) and purchasing a spectrometer and hardness tester. A considerable number of customers have been machining the parts supplied by MF and exporting them to other countries. In this background, the efforts were made to implement LESSIFOUND in MF. To begin with, the first author of this paper was recognized as the ‘Consultant General Manager’ (CGM), to coordinate the implementation of LESSIFOUND steps in MF. In the beginning, the CGM met the Managing

Director of MF and exposed to him the LESSIFOUND model. The photograph shot down during one of these sessions is shown in Figure 6. 6. The details of activities carried out under these steps are described in the following sub-sections.

Figure.6.6 The CGM meeting with to the Managing Director of MF

6.2. Implementation of LESSIFOUND Model

CGM developed a 13 step model summarized as below :

STEP 1: Gather information and knowledge about foundry practices.

STEP 2: Decide the scope of a model concerning processes like Sand casting, Die casting, Investment casting and other foundry practices.

STEP 3: Map the candidate process in the company.

STEP 4: Determine the feasibility of applying model 53 tools and techniques in the foundry. (shown in the Literature review paper)

STEP 5: Decide the area and team for applying the model.

STEP 6: Impart training and education on model tools and techniques.

STEP 7: Define the problem.

STEP 8: Measure the performance in the problem areas.

STEP 9: Analyze the problem.

STEP 10: Improve the performance.

STEP 11: Implement the system.

STEP 12: Control the implementation of the system.

STEP 13: Assess the level of acquiring core-competencies.

CGM implemented 13 step model in MF as discussed below:

6.2.1 Step 1: Gathering of foundry knowledge

MF produces Cast Iron pillar for drilling machine as the primary product. They purchase raw material from Alang shipyard, 50 kilometers away from Bhavnagar. Alang is a big ship breaking yard in India, almost all kind of ships coming here for recycling /braking so raw material easily available at cheaper rate. They melt these scrap in cupola furnace and then produces Cast Iron pillar for the drilling machine. Approximate weight of these products 30 to 50 kg. Average production of ingot mould approx. 90 to150 pieces in a batch and number of batches depend upon customer order size. The time required for one mould is about 30 minutes per mould and 6 workers required for mould making. In MF 12 hours shift in a day and Friday was a week off. Approximately 2 to 3 days required for mould making in a batch of 90 units. Equipment used in Mould making with permanent mould box and 1 unit of sand Muller while mould repairing through trowel, shovel and rammer and moisture removed by gaggers. Mould prepare in to cope and drag two half and then clamp through dowel pins. Approximately time required for sand filling and ramming is about 8 minutes for cope filling and 6 minutes for drag filling. Core backing is not required in MF. Monthly they produce three batches of Cast Iron pillar used in the drilling machine, as well another casting also produced. In a month three times they make a Cupola charge in the evening at about 5.00 p.m. and continue till 11.00 p.m. Finished casting are paint and ready for shipment.

6.2.2 Deciding the scope of LESSIFOUND application

The CGM understands that as many as 50 types of state-of-the-art research practices are adopted in the world's leading foundries. In MF, only sand casting using Pit moulding is only being adopted. Hence the scope of application of LESSIFOUND in MF was its application in Pit moulding based sand casting process. After thus deciding the scope of the application of LESSIFOUND, the CGM studied the steps followed to carry out Pit moulding based sand casting process followed in MF. The information gathered by the CGM is depicted in the form of a block diagram in Figure 6.7. Then assembly of permanent moulds is made. A photograph shot when the pit moulds were made in MF is shown in Figure 6.8 and 6.9.

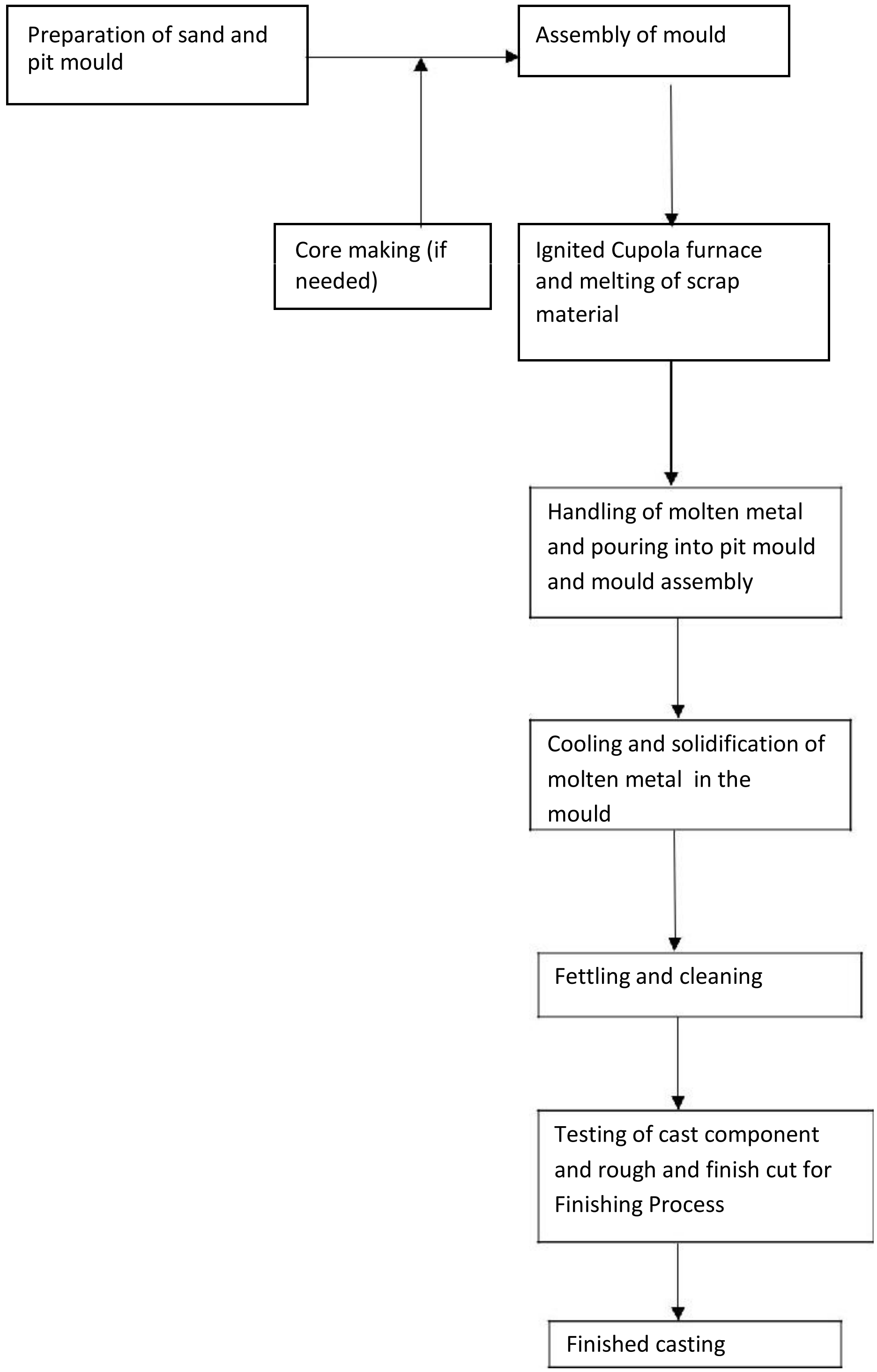


Figure 6.7 Steps of Sand casting process adopted in MF

Figure 6.8.Mould Making in MF

Figure 6.9.Pit Moulding in MF

Figure 6.10. Pouring into Mould and Riser filling

The photograph shot during the pouring of molten metal into permanent mould assembly in MF is shown in Figure 6.10. CGM communicate with workers during the breaking of mould and removal of casting pillar as shown in the photograph presented in Figure 6.11. Figure 6.12 shows the partial view of the permanent mould after removal of casting component.

Figure 6.11. Communication with workers

Figure 6.12.Moulding flask after partial breaking

The photograph shot when the stock of rough casting product near cupola was carried out in MF is shown in Figure 6.13. The burrs and protrusions found in the castings are removed using grinding operation in MF. A photograph shot while carrying out such turning operation in MF is shown in Figure 6.14.

Figure 6.13. The stock of rough casting

Figure 6.14. Rough turning operation carried in MF to remove burrs and protrusions in the castings

Then the castings are subjected to inspection and testing. A photograph shot while carrying out the inspection and testing of finished cast components in MF is shown in Figure 6.14. The defect-free castings are sent for final smooth turning finished cut as shown in figure 6.15. After finished cut lubrication oil rusted on the surface as shown in figure 6.16 The castings are now ready for shipment. In Figure 6.17, a photograph showing a sample of finished cast components kept ready for shipment in MF is presented. As the components cost in MF is heavy, the material handling using overhead cranes is carried out frequently. The photograph showing such material handling in MF is shown in Figure 6.15. The CGM discussed with GM about the sand casting process. According to the GM, no wastages are encountered while moulding assembly. Since the cast components are heavy, the rejection of a component made using sand casting process results in a loss of Indian National Rupees (INR) 20,000 in MF, however. It can also be repaired.

Figure 6.15. Storage of final casting pillar of drilling machine with an overhead crane in MF

Figure 6.16. Storage of lubricated casting pillar in MF

Figure 6.17. Finished casting components kept ready for shipment inMF.

6.2.3.Step 3: Mapping the candidate process

The CGM take several visits in MF and noting the things carefully and identified the wastes and rejection during a various process of sand casting like mould making, cupola surface melting, pouring and solidification, labour and machining and cleaning and testing. After gathering this information, the CGM draws the map shown in Figure 6.18 to map the processes in the foundry. As shown, in this map the CGM notes the occurrence of wastes and rejection of defectives under each process.

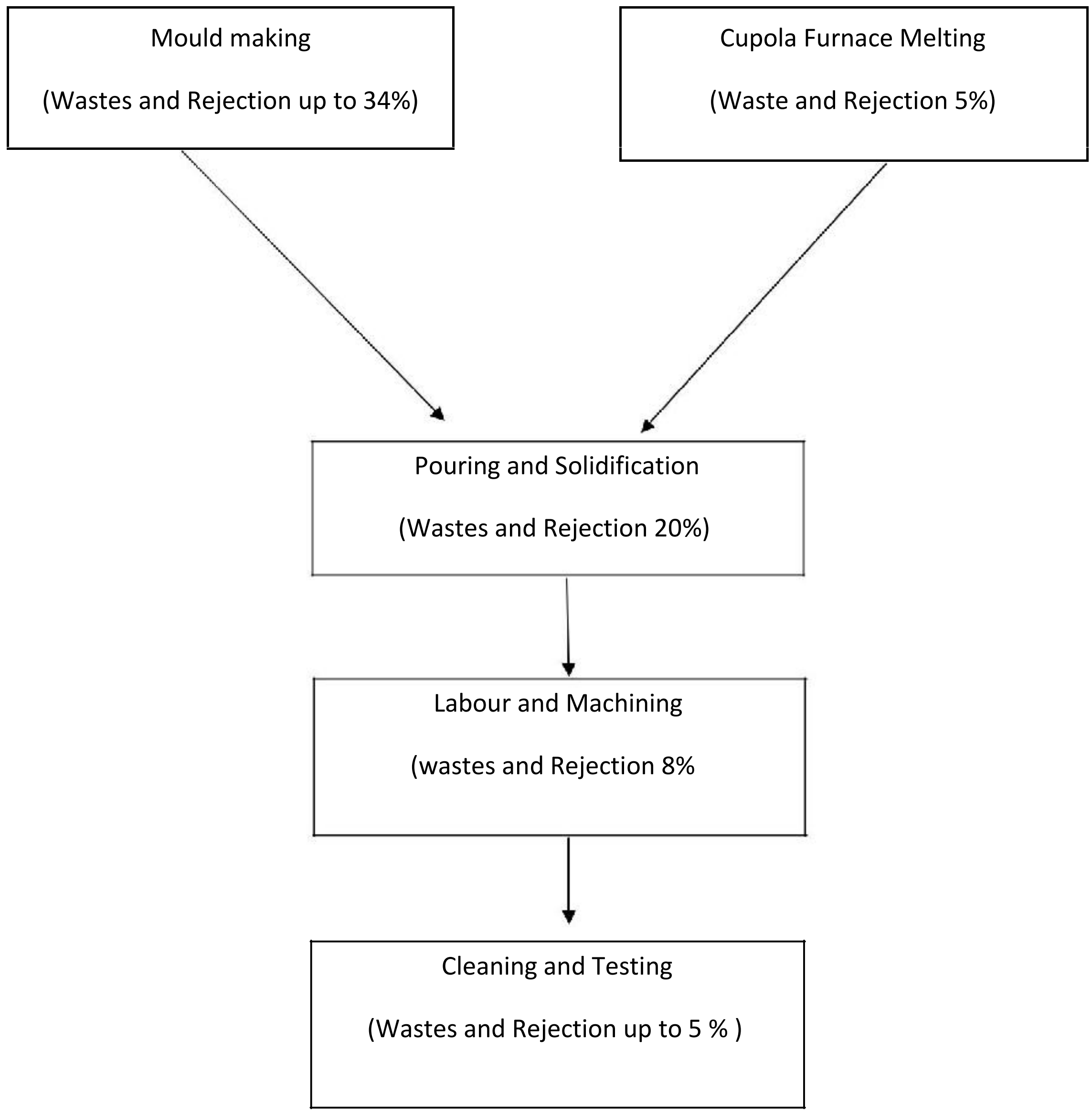


Figure 6.18. Mapping the processes in MF

6.2.4. Step 4: Determining the feasibility of applying LESSIFOUND tools and techniques

CGM identifies the wastes and rejection in MF at various stages of manufacturing a pillar of the drilling machine. With the above data of wastes CGM meets the managing director Mr.Arunbhai Harsora and Mr.Abhaybhai Harsora With this map and showing the feasibility of LESSIFOUND model in MF. After this conversation management allows CGM to implement the LESSIFOUND model in MF. Now CGM consults the top management about adopting the tools and techniques to overcome occurrence of wastes and defectives under each process like waste management under all the process, D-M-A-I-C approach, and a graphical tool like Pie chart for defect identification. The management agrees to allow the application of the above tools and techniques.

6.2.5. Step 5: Deciding the team and area of applying LESSIFOUND

Under this step, the CGM has the limited scope of team formation as the number of supervisors are very few, so CGM, Managing Director and production manager Mr Abhaybhai Harsora forms their team for LESSIFOUND model in MF. The CGM interviews these team members. Majority of wastes and error occurs in MF due to unskilled labours. So The CGM informs the top management about the formation of this LESSIFOUND team. The management approves the formation of this LESSIFOUND team and carrying out the subsequent steps.

- **Project number:1**
- **Project Title: Quality Improvement in labour skill and pouring method**
- **Team Leader: Darshana Kishorbhai Dave**
- **Team Members: Mr.Arunbhai J. Harsora Mr Abhay Harsora (Production and Q.C Head)**
- **Project Duration:4 Months**

6.2.6.Step 6: *Imparting training and education*

The CGM studies the chosen LESSIFOUND tools and techniques by referring to the case studies reported by the researchers and practitioners. After gathering this knowledge, the CGM designs training modules on these chosen LESSIFOUND tools and techniques. By making use of these training modules, the CGM trains the team members to apply the chosen LESSIFOUND tools and techniques in practice.

6.2.7. Step 7: Defining the problem

Under this step, the CGM and team of LESSIFOUND team members identified the problem. The LESSIFOUND team members inform that the occurrence of the high level of wastes and rejection rate is due to the labour problem. As MF located in prime location and they need workers on daily wedges per piece .i.e. for mould and mould assembly six workers required for 3 to 4 days. So workers prepared mould assembly hurriedly to get more rupees, so mould defect occurs during pouring. Now during pouring cycle, such mould failure at any point, so one worker is required to fill that gap from liquid metal removes outside. Workers are changing in every batch so the quality of finished pillar also vary. However, CGM observed during pouring metal removes from riser then also worker fills the mould assembly continuous, and metal flows on the high surface of moulding flask. Thus unskilled labour and inappropriate pouring method cause wastes.MF is a small scale industry, and nature of product manufacturing is similar, so LESSIFOUND team assign this problem for solution. Thus this problem was defined, and the project charter was developed by the CGM and LESSIFOUND team members. This project charter is shown in Figure 6.19.

- *Date of starting the project:* July 1, 2014
- *Date of completing the project:* September 3, 2014
- *Project deliverables:* Waste elimination and zero defect in labour skill and pouring.

LESSIFOUND Project

Project number: 1

Project title: Quality improvement in Labor skill and pouring method

Team leader: DARSHANA DAVE

- *Team members*: **Mr. (M.D.4), Arunbhai J. Harsora Mr Abhay Harsora (Production and Q.C Head)**
- *Problem definition*: Assigning inappropriate method leads to the occurrence of higher wastes and rejection in solidification.

Project duration: 3 months

Figure 6.19. Project charter

Implementation of Six Sigma (D-M-A-I-C) Methodology

Phase 1 (Define): During manufacture of the casting of a drilling machine maximum Possibility of rejection from last 35 year. This is a defect that we identify and try to resolve with LSS.(D-M-A-I-C).

Figure 6.20. Design

Identify the Problem in MF: Defect-free sand casting product should be produced with no rejection.

6.2.8. Step 8: Measuring the performance

While executing this stage, the team of LESSIFOUND identifies waste from their plant. Subsequently, the number of castings rejected due to the existence of the above-stated problem in the foundry is determined by the LESSIFOUND team members. Using this data, the CGM and LESSIFOUND team members find that the sigma level of producing the castings in the foundry as 3.55. The calculation details are shown below:

After making these measurements, the CGM and LESSIFOUND team members fix the target by overcoming the defined problem.

- Area: Foundry
- Customer requirement: Defect-free casting product

- DPMO (defect per million opportunities): during /after sand casting process carried out
- Total number of heat treatment component from 15th November 2014 to 5th March 2015: 990
- Number of Defects found during /after casting body of 140 Identification of defects Sources: 7

$$DPMO = \frac{\text{total no.of defects detected}}{\text{No.of units produced* opportunities of defect per unit}}$$

$$= \frac{140*1000000}{990*7}$$

$$=20202.02$$

Six Sigma level =3.55 σ

6.2.9.Step 9: Analyse the problem

The CGM and LESSIFOUND team members carry out the Cause-Effect diagram to determine the cause of occurrence of the defined problem. The CGM and LESSIFOUND team members find that the absence of information about the material to be cast, the absence of a safety chart and inadequate training of workers are the causes that cause the defined problem. Detailed analysis of causes and number of frequency of occurring the defects are mainly seven as shown below. Material composition, Labor Problem, Cupola problem, Improper fettling operation and solidification, others and improper machining causes the defined problem.

During site visit, we identify the following six types of defects and frequency of defects.

Table 6.1. Causes and the frequency of occurrence (Before LSS)

Sr.No.	Causes	Frequency
1	Material composition	14
2	Labour problem	76
3	Cupola problem	7
4	Improper fettling operation	14
5	Improper solidification	11
6	Others	7
7	Improper machining	11
	Total	140

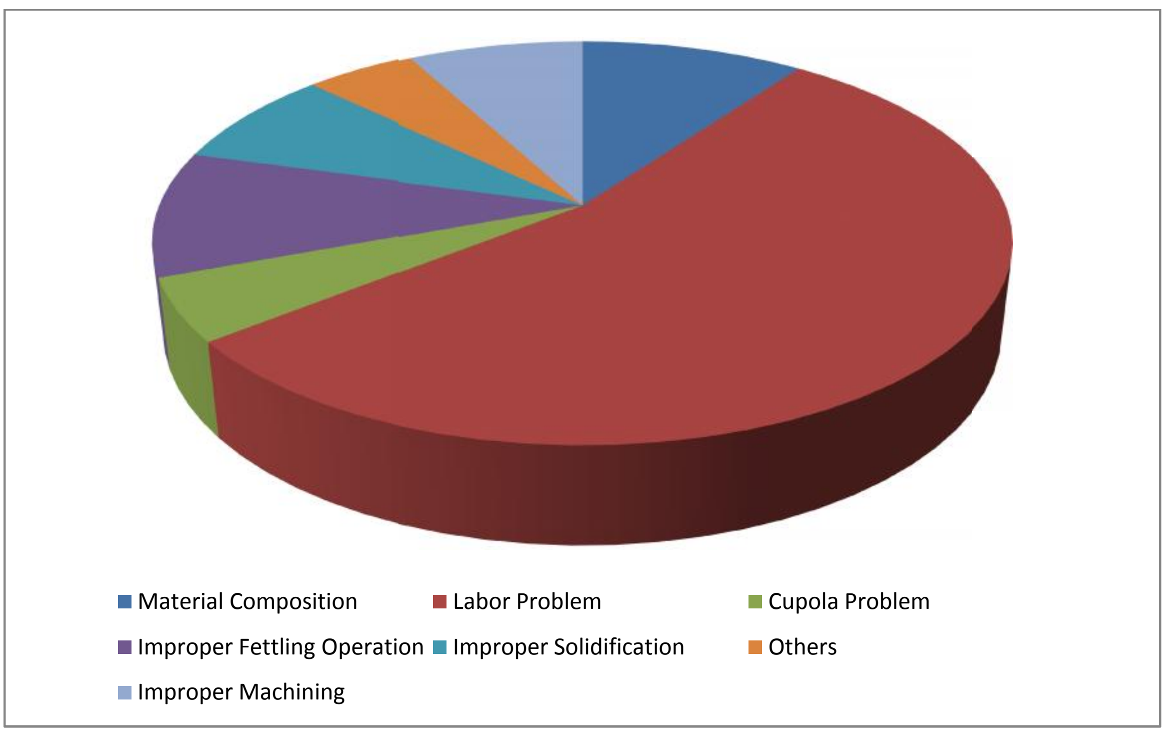


Figure 6.21.Proportion of Defect(Before LSS)

After several visits, we identify the causes and sources of a defect and plot the Cause-Effect diagram as below in figure 6.22. Wrong material composition, low skilled labour majorly affect the improper pouring, odd timing of solidification, Environmental changes,improper machining by a number of rough cut more than required, power breakdown etc. affect the wastages of production and reworked required by machining or melting back to the Cupola according to rejection percentage.

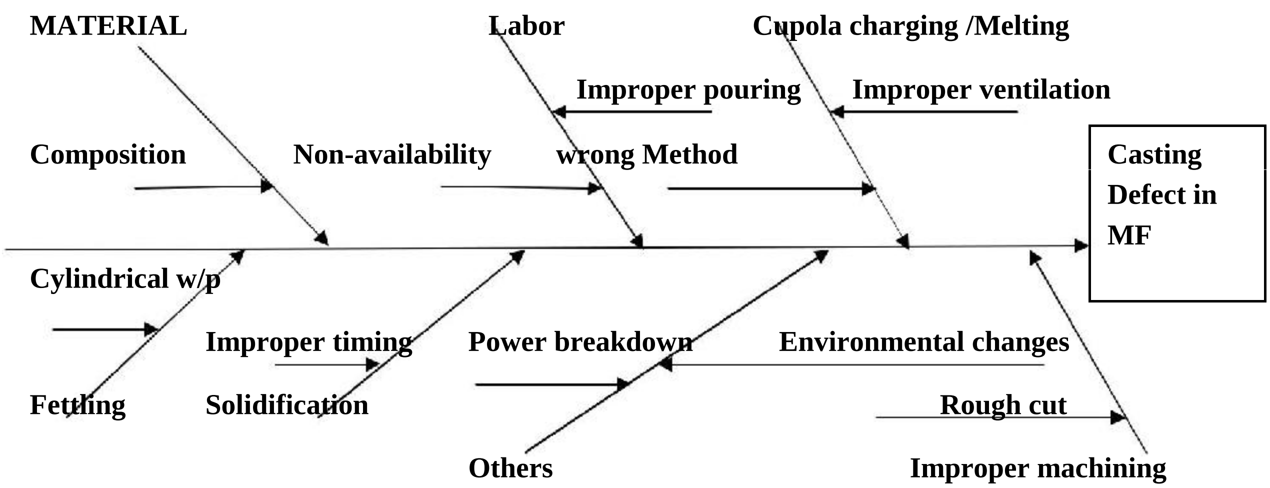


Figure 6.22. Cause-Effect Diagram for Identification of Sources of Defect in Pillar of drilling Machine

6.2.10. Step 10: Improve by providing solutions

The CGM and LESSIFOUND team members discuss providing solutions against the causes identified in the previous stage. After thorough discussion, the CGM and LESSIFOUND team members suggest maintaining at least 2 to 3 workers monthly. Provide training and assure them to keep them in the same plant for a longer period .so they work accordingly and positive attitude towards work. Second, the CGM and LESSIFOUND team members suggested preparing safety chart to indicate the method of pouring into mould and safety standards. Third, the CGM and LESSIFOUND team members suggested a chart containing standard time and duration for each process.Overall improvement in defects identification and reduction in defects from 140 to 87.Material defects can be reduced by 62 %, Improper machining and solidification defects also reduced by 50%.

Table 6.2. Causes and the frequency of occurrence (After LSS)

Sr.No.	Causes	Frequency
1	Material composition	9
2	Labour problem	53
3	Cupola problem	3
4	Improper fettling operation	8
5	Improper solidification	5
6	Others	3
7	Improper machining	6
	Total	87

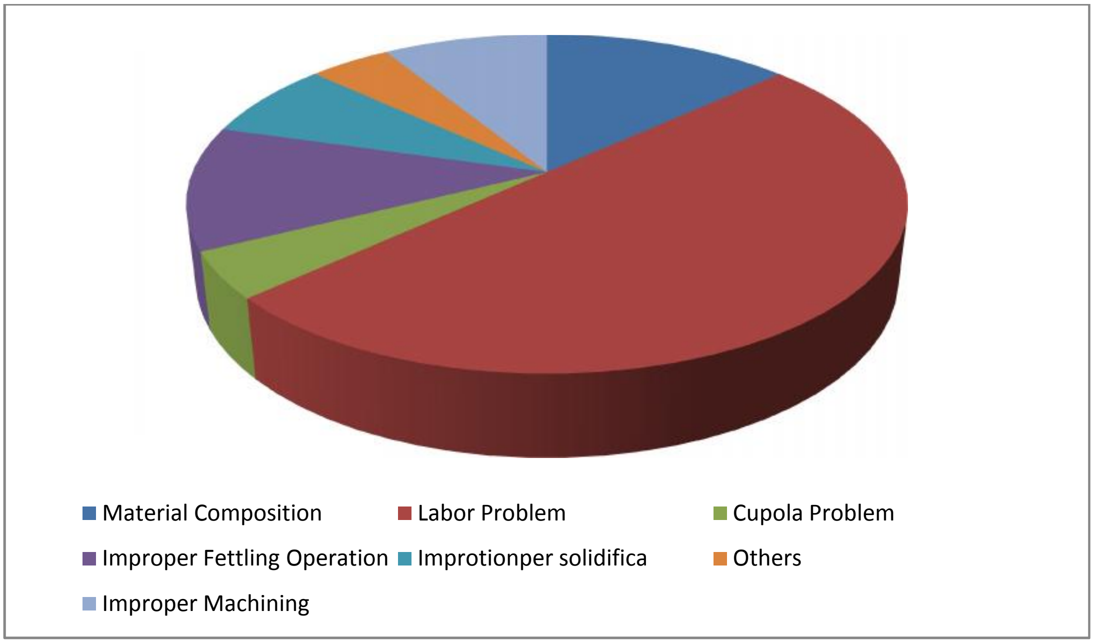


Figure 6.23.Proportion of Defect(After LSS)

- Total number of heat treatment component from 15th March 2015 to 5th September 2015: 1485
- Number of Defects found during /after casting body : 87

- Identification of defects Sources: 7

$$DPMO = \frac{\text{Total no.of defects detected}}{\text{No.of units produced* opportunities of defect per unit}}$$

$$= \frac{87*1000000}{1485*7}$$

$$=8369$$

Six Sigma level =3.89σ

We train the workers about sand ramming and others real sources of the defect, and we reduce the defects from 140 to 87.

6.2.11.Step 11: Implementing the solutions

The CGM and LESSIFOUND team members prepared a daily sheet to check the continuance of the system installed in the previous step. The CGM and LESSIFOUND team members implement LESSIFOUND model in MF and conduct the audit on the last Sunday of every month. In Step 10 we improve the sigma level from 3.55σ to 3.89σ, so we keep the standard symbols and charts on the company to maintain the same level in future also.

6.2.12.Step 12: Controlling the implementation of the system

Name of the company:

Target Area: Manufacturing/ Quality control

Name and signature of Auditor:

Audit date:

Audit Technique	Auditable item, Observation, Procedure etc.	Individual Auditor	
		Yes	No
Observation	Have all associated been trained?		
Observation	Are wearing proper safety clothes /Accessories?		
Observation	Is sampling inspection or 100% inspection?		
Observation	Is a total number of defect minimised?		
Observation	Is quality check according to LESSIFOUND model?		
Observation	Is the total number of causes minimised?		
Observation	Is cause-effect diagram followed?		
Observation	Is lean six sigma level maintained or increase?		

A number of out of compliance observation:

Total observation:

Corrective actions required:

Auditor's comment:

Figure 6.24. Audit sheet

The CGM and LESSIFOUND team members prepared an audit sheet to check the continuance of the system installed in the previous step. The CGM and LESSIFOUND team members conduct an audit on the last Sunday of every month. When deviations are found, the CGM and LESSIFOUND team members take swift actions to restore the status queue. Sample audit sheet is shown above in figure 6.31.

6.2.13. Step 13: Assess the level of acquiring core-competencies

The CGM appraises the top management about the implementation of solutions. The top management receives reports from CGM about the occurrence of wastes and rejection of castings. From these reports, the top management understands that there has been nearly no wastages and rejections due to the installation of the system of LESSIFOUND. The customer who receives the first consignment also informs that the quality of castings is superior in comparison to those are supplied by other foundries. These observations indicate that the application of LESSIFOUND enables the foundry to acquire core-competencies.

- Before applying six sigma: So the six sigma level =3.55σ
- After applying six sigma: Six Sigma level =3.89σ
- Improvement in sigma level=0.34σ

6.3. Discussion

CGM found difficulty in step 8, 9, 10 and 11 to implement LESSIFOUND while other stages are easy stages of LESSIFOUND. Fewer Challenges involved in implementing LESSIFOUND in foundries. Majority of foundry data available and they can give the necessary data because they want to eliminate wastes from the shop floor and improve the quality level. Though this is small scale industry then also it is possible to implement all the steps of LESSIFOUND model.

CHAPTER-7

Results and discussion

7.1. Introduction

In this chapter of doctoral work concluded with the comparison of developed LESSIFOUND model with other researchers developed model shown below in Table 7.1.

Table 7.1. Comparison of Various LSS Model with Developed 13 step LESSIFOUND Model

Researches Printed LSS Model	Lean Tools								Six Sigma Tools
	5S	Value stream mapping (VSM)	Total Productive Maintenance (TPM)	Kaizen	Suppliers, Inputs, Process, Outputs and Customers (SIPOC)	Investigation of seven wastes.	5-Whys.	Value flow map.	D-M-A-I-C
Thomas et al. (2009)	Yes	Yes	Yes	×	×	×	×	×	Yes
Laureani and Antony(2010)	×	×	×	Yes	×	×	×	×	Yes
Salah etal. (2010)	×	Yes	×	Yes	×	×	×	×	Yes
Laureani et al. (2010)	×	×	×	×	Yes	Yes	×	×	Yes
Snee(2010)	×	Yes	×	Yes	×	×	×	×	Yes
Barnes and Walker(2010)	×	×	×	×	×	×	Yes	×	Yes
Atmaca and Girenes (2011)	×	×	×	×	×	×	×	Yes	Yes

Chiarini(2012)	×	Yes	×	×	×	×	Yes	×	Yes
Gupta etal. (2012)	Yes	Yes	×	Yes	×	×	×	×	Yes
Chen and Lyu(2009)	Yes	×	Yes	×	Yes	×	×	×	Yes
Developed Lessifound Model	Yes	Yes	×	Yes	×	Yes	×	Yes	Yes

After comparison, it revels developed LESSIFOUND model better than all the available models .out of 9 primary tools like **5S, VSM, TPM, Kaizen, SIPOC, Investigations of seven wastes, 5-Whys. Value flow map and D-M-A-I-C** doctoral work of thesis utilise 6 tools in the research**.** TPM, SIPOC and five whys not used in this work as there are less machining time and lower variety of vendor identification. All other models utilize 3 to 4 tools in their implementation work only. So developed LESSIFOUND model is better than the previous model.

7.2 Comparison of 13 step LESIFOUND model implementation in three foundries of Gujarat

Based on above result I conclude that developed LESSIFOUND model can be applied in all the foundry practices, field survey stage in step 1 is more in case of the specialized foundry. Improvement in sigma level may vary according to types of wastes identified, and solution of sigma level may vary according to the involvement of foundry men, senior management and top-level management.

Table 7.2 Summary of 13 Step LESSIFOUND Model into foundry SME'S: Gujarat

Step No.	**Company 1 German Technocast, Plot No.192/193/194 Vatva,GIDC,Ahmedabad**	**Company 2 Sanjay Castings Ind.(PVT.)Ltd Survey No.217/218/219 Sihor Bhavnagar**	**Company 3 Mahalaxmi Foundry Plot No.301,G.I.D.C.-2 ,Sihor, Bhavnagar**
1. Gather information and knowledge about foundry	Yes	Yes	Yes

practices.			
2. Decide the scope of the model concerning processes like Sand casting, Die to cast, Investment casting and other foundry practices.	CO2 casting process with Induction furnace	Sand Casting with Cupola furnace	Sand Casting with Cupola furnace
3.Map the candidateProcess in the company.	overall rejection 15 to 20%	overall rejection 5 to 8%	overall rejection 5 to 10%
4.Determine the feasibility of applying model 53 tools and techniques in the foundry. (shown in the Literature review paper)	Yes	Yes	Yes
5. Decide the area and team for applying the model	Mr.Nayan Patel(M.D.), Mr. Hiren Patel(Admin Head), Mr.Suresh Vyas(Q.C. Head), Mr Kaushal Patil(Production head)	Mr Sanjaybhai Rathod(M.D.), Mr Hardikbhai Vyas(Production and Q.C Head), Mr Mukeshbhai Gohil (Maintenance Head), Mr Milanbhai Mehta (Admin's head)	Mr. (M.D.1) Manharbhai J. Harsora, Mr. (M.D.2) Batukrai J. Harsora, Mr. (M.D.3), Rameshbhai J. Harsora, Mr. (M.D.4), Arunbhai J. Harsora Mr Abhay Harsora (Production and Q.C Head).

6.Impart training and education on model tools and techniques.	Yes	Yes	Yes
7.Define the problem.	Identify the Defects in Casting production	Identify the Defects in Casting production	Identify the Defects in Casting production
8. Measure the performance in the problem areas.	3.76σ(230unit production, 19 defects, seven opportunities)	4.75σ(7600unit production,22 defects, five opportunities)	3.84σ(470 unit production ,27 defects,6 opportunities)
9.Analyse the problem	Yes	Yes	Yes
10.Improve the performance.	4.06σ(330unit production ,12 defects,7 opportunities)	5.10σ(8800unit production ,07 defects,5 opportunities)	4.14σ(560unit production ,14 defects,6 opportunities)
11.Implement the system.	Yes	Yes	Yes
12.Control the implementation of the system.	Yes	Yes	Yes
13.Assess the level of acquiring core-competencies.	0.3σ	0.35σ	0.3σ

CHAPTER-8

Conclusion

8.1. Introduction

In the starting of doctoral work, the author focuses on review the research activities conducted to examine the theoretical and practical aspects of LSS and identify the research activities conducted in different industrial sectors to practically implement LSS. This review activity concluded that foundry is one of such factor where the author identifies a scope of implementing Lean Six Sigma successfully. Further author prepared a questioner (Appendix A) and made a pilot study in the various foundry of Gujarat to identify a scope of implementing LSS and result of this questioner shown in chapter 7. There was a strong need of LSS in the foundry, so author prepared a roadmap for LSS implementation as LESSIFOUND model as discussed in thesis chapter 3.Thesis chapter 4,5 and 6 shows investigations for gaining knowledge on the implications of practically implementing the designed LESSIFOUND model in three foundries of Gujarat. Chapter 7 shows results and discussion on LSS implementation .Based on above result author conclude that developed LESSIFOUND model can be applied in all the foundry practices, field survey stage in step 1 is more in case of the specialized foundry. Improvement in sigma level may vary according to types of wastes identified, and solution of sigma level may vary according to the involvement of foundry men, senior management and top level management .core competencies can be improved by 0.3 sigma. Causes and sources of casting defect can be identified, safety program created in all three foundries and audit sheet also provided to maintain this sigma level in future also. LESSIFOUND model is a general model so it can be applied for various casting practices like sand casting, CO2 casting etc. so the author selected various casting practices . The result shows LESSIFOUND can be applied in various casting practices industry. By implementation of LSS in a foundry, defects can be reduced, productivity and safety can be improved and monthly thousands of rupees saved. Moreover, the involvement of every worker towards quality can be improved so rework and rejection can be reduced. All three managing director and company owner are happy with this LSS implementation in their plant and appreciate author by providing an appreciation letter for her successful implanting LSS and wish for her bright future and colorful doctoral degree.

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2. Dave,D ., Panchal H.(2018) ‘waste optimization through the implementation of lean six Sigma principles in a sand casting foundry of Gujarat’ , International Journal of Engineering & Science Research, Vol-8, Issue-7,pp 61-67(UGC approved journal)
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International Conference

1. Dave, D., R. Murugesh , Devdasan, S. (2016) ‘Acquirement of Core Competencies Through The Implementation Of LSS In Foundries---A Theoretical Proposition And Discussion’, International Conference on Advanced Material Technologies (ICAMT)-2016,*27th and 28th December 2016.Dadi Institute of Engineering and Technology (DIET), Visakhapatnam, Andhra Pradesh, India. Elsevier Materials Today: Proceedings*
2. Dave, D., R. Murugesh , Devdasan, S. (2016) , ‘Implementation Of Lean Six-Sigma In Sand Casting Process: An Implementation Study In A Foundry’, International Conference on Advanced Material Technologies (ICAMT)-2016,*27th and 28th December 2016.Dadi Institute of Engineering and Technology (DIET), Visakhapatnam, Andhra Pradesh, India. Elsevier Materials Today: Proceedings*

APPENDIX-A

"INVESTIGATIONS ON DRIVING INNOVATION IN SMALL SIZE FOUNDRIES THROUGH THE IMPLEMENTATION OF LEAN SIX-SIGMA PRINCIPLES".

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Government Engineering College,

Patan

Gujarat

Questionnaire for Foundries

SECTION-A

Q1.ContactDetails of Respondent

Name of Company and address :-

Name of Respondent:-

Mobile No:-

E-mail address:-

Q2.Position of Respondent in Organization/Company (Give Tick mark)

Please indicate your position in your organization

□ GeneralManager □QualitycontrolManager□ FunctionalManager

□ Area/BusinessSector Manager□ Foreman /Superintendent□ Senior Engineer

□ Junior Engineer□ Technician□ Six Sigma Specialist

□ others (pleasespecify):__

Q3.Experience of Respondent (Give Tick mark)

Please indicate your experience by indicating the number of years of involvement in the activities.

□ <1Year□ 1to2Years□ 3to5Years□ 6to10Years□ >10Years

Q4.Lean (Give Tick mark)

Please indicate if you know this methodology

□ Yes □ No

Q5.Responsibility of Respondent.(Give Tick mark)

Please indicate whether your responsibility is Full-time or Part-time

□ Full-time Involvement □P a r t -time Involvement

Q6.**Type of Foundry (Give Tick mark)**

□Cast Iron foundry□ Steel Foundry□ Non Ferrous Foundry□ Conventional Send casting□ Shell Molding□ Investment Casting□ Die Casting□ Centrifugal Casting□ Injection Molding □Others

Q7.Employees in organization/company (Give Tick mark)

Number of full-time employees in your organization

 1to20 21to50 51to100 101to200 201to500 501to1000 1001to2000

 2001to 5000 5001to10000 >10000

Q8.Sector (Give Tick mark)

Within which sector does your organization operate?

 Public Private Not-for-Profit/Community Others (please specify):

Q9 **Type of company**

□ Small Scale □ Medium Scale □ Large scale

Q**10Doesyourorganizationhavea Quality Control Department**

 Yes No

Q11 Total no of Employees in Quality Control Department_________

Q12Quality Systems adopted (Give Tick mark to)

Do you have any of the following Quality Systems in place?

 ISO9001 ISO9002 ISO9003 ISO9004 ISO14000

 MBNQA(Malcolm Baldrige National Quality Awards)

 EFQM(European Foundation for Quality Management)

 Others(please specify):

Q13Business Improvement Initiatives (Give Tick mark)

Business improvement initiative implemented in your organization.

 Business Process Reengineering (BPR) Quality Assurance cycle

 Quality Control Total Quality Management (TQM)

 Total Predictive Maintenance (TPM) none others (please specify):

____

Q14Major defect founding in casting.

 Blow holes pin holes Cracks porosity others ______________

Q15 Approximate Annual Rate of Rejection Percentage ________________

Q 16 **Improvement in rejection rate after any Quality System/Tools applied_____________**

Q17 (A) Six Sigma (Give Tick mark)

Has Six Sigma been implemented in your organization?

□ Yes□ No□Partially

(B) If No, then what are reasons for not implementing SixSigma?

□ Costly procedure □ Too much Complicated (involves too much statistics)

□ Need to hire consultants□ Lack of awareness & Knowledge

Q18 Area /Process where Six Sigma methodology has been applied

□ Yield Improvement□ Quality Improvement□ Productivity Improvement137

□ Cost Reduction□ Customer Complain □ Methods Engineering □ Melting

□ Pattern Making□ Felting□ Heat Treatment □ others _________________

Q19. Length of Time (Give Tick mark)

How long as your organization been using the Six Sigma Initiative?

□ <1Year□ 1to5Years□ 5to10Years□ >10Years□ Not Applicable

Q20. Sigma Level Achieved (Give Tick mark)

Average sigma capability level of your core business processes

□ <1Sigma□ 1to2Sigma□ 2to3Sigma□ 3to4Sigma□ 4to5Sigma

□ >5Sigma□ Not Sure/Applicable

Q21.No of Six Sigma Projects Completed in company (Give Tick mark)

How many Six Sigma projects have your organization completed

□ <5□ 05to10□ 11 to 20□ 21to30□ 31to40□ 40to50□ >50

□ Not applicable

Q22. You want to apply Lean Six Sigma Methodology in near future?

□ Yes□ No□ Not Sure

Thank You for Participation

Please send the Filled questioner to following address in Given Envelop

Darshana Kishorbhai Dave
73/Laxminagar;
Sidsar Road;
Before sports complex;
Bhavnagar-364002
Mobile No-9724333160
E-Mail Address:- dave_dars@yahoo.co.in

SECTION-B

This section try to identify the various factors which are required while implementing Six Sigma in your organization. Please check the appropriate number according to the **Given1-5 point scale.**

1-NotImportant; **2-**Somewhat important; **3-**Neutral; **4-**Important;**5-**VeryImportant

Q1 Main objectiveof Lean six sigma project.

Main objectives	1	**2**	**3**	**4**	**5**
To improve Quality					
To enhance operational excellence					
To improve customer satisfaction					
To become world-class organization					
To improve bottom-line					
To solve chronic problem					
To remain competitive in the global market					
To create better image of product/service					
To Reduce cost					
To increase productivity					

Q-2Benifits of Lean six Sigma project.

Main Benefits	1	**2**	**3**	**4**	**5**
Supplying products and providing services in accordance with the customer needs .					
Removal of non-value adding steps.					
Reduction of cost of poor quality.					
Cycle time reduction.					

Development and improvement of operational capabilities.					
Increasing of value-adding activities					
Achievement of global optimization.					
Adoption of data driven methodologies					
Minimization of variation in quality characteristics and achieving zero-defect manufacturing.					
Cost savings .					
Achievement of competitive advantage					
Process improvement					
Reduction of wastes.					
Financial benefit.					

Q-3 What are main difficulties (Barriers) for implementation of Lean Six Sigma?

Main Difficulties and Barriers	1	**2**	**3**	**4**	**5**
identification of bottlenecks .					
lack of awareness and interest on the part of both management and employees					
lack of strategical orientation					
Employee cultureis not compatible					
lack of roadmap indicating the steps for implementing LSS					
Poor training/coaching					
Unmanaged expectations					
Lack of leadership					

difficulty of collecting the appropriate data					
Low employee retention					
Lack of suitable data					
Poor project select					
Part-time involvement in Six Sigma projects					
Too complex use and implementation					
Others_________________________________					

Q-4 What are the importance level of various tool & Techniques used?

Main Tool & Techniques used	1	**2**	**3**	**4**	**5**
Process mapping and VSM					
Cause and effect analysis and cause and effect diagram (CED).					
Visual management					
Pareto analysis					
Project charter					
Supplier-input-process-output-customer (SIPOC)					
Rapid improvement workshop (RIW).(Kaizen or similar)					
Cost of poor quality (COPQ)					
Plan-do-check-act/PDCA [synonymous with plan-do-study-act (PDSA)]					
Kanban					
5S					
TPM					
Design of experiments(DOE)					

Box plots					
Control charts.					
Failure mode and effects and analysis (FMEA).					
Brainstorming					
Standardisation [synonymous with standard operating procedure (SOP)]					
Mistake proofing (Poka-Yoke)					
Single minute exchange of die (SMED)					
Layout planning					
Measurement analysis (synonymous with measurement system analysis)					
Process capability					
XY matrix					
Root cause analysis (RCA)					
Why-why analysis (synonymous with 5-whys).					
Tree diagram					
Cause and effect diagram with the addition of cards (CDEAC).					
Kepper-Tregoe (K-T) approach					
Partition diagram					
Classification and regression tree (CART)					
Test of hypothesis					
GEMBA or workplace investigation method					
Takt time analysis					
Histograms					
Scatter diagram					

Workplace Management					
Just-in-time					
Production flow balancing					
Kaizen					
Change management tools					
Regression analysis					
Hypothesis testing.					
Quality function deployment(QFD)					
Statistical process control					
Project Management					
Analysis of means and variance					
KANO analysis					
Time trap analysis					
Repeatability chart					

Q-**5 Importance of Critical Success Factors (CSF)**

Main Critical Success Factors	1	**2**	**3**	**4**	**5**
Management commitment and participation					
Organizational infrastructure					
Cultural change					
Training					
Linking Six Sigma to customers					
Linking Six Sigma to business strategy					
Linking Six Sigma to employees					

Linking six sigma to suppliers					
Understanding of Six Sigma methodology					

Q-6 Specific Area Where Lean Six sigma has been applied in your organization

(Tick mark in box).

Production Quality Entire operation Project Delivery Design

Other ________________

Q-7 Would you like to avail findings of the study?

If yes please give me E-**mail for communication. _________________________**

Q-8 Would you like to implement LSS model in to your organization?

Yes No

<u>Thank You for Participation</u>

Darshana Kishorbhai Dave

73/Laxminagar;

Sidsar Road;

Before sports complex;

Bhavnagar-364002

Mobile No-9724333160

E-Mail Address:- dave_dars@yahoo.co.in

<u>Please send the Filled questioner to following address in Given Envelop</u>

==================================

Comments/Suggestions:

Approved/ Not Approved

Seal and Signature of Expert/Verified Person: