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Implementing the Lean Sigma framework in an Indian SME: a case study

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Lean and Six Sigma are two widely acknowledged business process improvement strategies available to organisations today for achieving dramatic results in cost, quality and time by focusing on process performance. Lately, Lean and Six Sigma practitioners are integrating the two strategies into a more powerful and effective hybrid, addressing many of the weaknesses and retaining most of the strengths of each strategy. Lean Sigma combines the variability reduction tools and techniques from Six Sigma with the waste and non-value added elimination tools and techniques from Lean Manufacturing, to generate savings to the bottom-line of an organisation. This paper proposes a Lean Sigma framework to reduce the defect occurring in the final product (automobile accessories) manufactured by a die-casting process. The proposed framework integrates Lean tools (current state map, 5S System, and Total Productive Maintenance (TPM)) within Six Sigma DMAIC methodology to enhance the bottom-line results and win customer loyalty. Implementation of the proposed framework shows dramatic improvement in the key metrics (defect per unit (DPU), process capability index, mean and standard deviation of casting density, yield, and overall equipment effectiveness (OEE)) and a substantial financial savings is generated by the organisation.

Keywords: Six Sigma; Lean; Case study; Framework; SME

1. Introduction

The last two decades has witnessed an increased pressure from customers and competitors for greater value from their purchase whether based on quality, faster delivery, or lower cost (or combination of both) in both manufacturing and service sector (Basu 2001, George 2002). This has encouraged many industries to adopt either Six Sigma (as their process improvement and problem solving approach) or Lean Manufacturing (for improving speed to respond to customer needs and overall cost) as part of management strategy to increase

the market share and maximise profit. All the large companies such as Toyota, Danaher Corporation, General Electric, Motorola, Honeywell, and many others, have achieved dramatic results by implementing either Lean or Six Sigma methodologies in their organisation (Womack and Jones 1996, Harry 1998, Basu 2001, Murman *et al.* 2002, Sharma 2003, Arnheiter and Maleyeff 2005).

Shah and Ward (2003) accentuated the importance of plant size, plant age, and union status on the likelihood of implementing 22 manufacturing practices that are key facets of the Lean production system. The core thrust of Lean production is that it works synergistically to create a streamlined, high quality system that produces

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finished products at the pace of customer demand with little or no waste. Lean strategy brings a set of proven tools and techniques to reduce lead times, inventories, set up times, equipment downtime, scrap, rework and other wastes of the hidden factory.

The statistically based problem solving methodology of Six Sigma delivers data to drive solutions, delivering dramatic bottom-line results. Linderman *et al.* (2003) accentuated the importance of social and psychological considerations in understanding Six Sigma phenomena and how effective use of goals helps alter the behaviour of organised members and their perceptions about how much change is possible. Authors further emphasised on the understanding of the technical aspect as well as behavioural insight for successful deployment of Six Sigma. Sodhi and Sodhi (2005) illustrated how a global manufacturer of industrial equipment applied Six Sigma to its price setting process for one product line. In this study, Six Sigma has transformed the tenor of the relationship between the pricing and sales staffs from adversity to relative harmony for making joint decisions that are aligned with strategic objectives of the business.

Each methodology proposes a set of attributes that are prerequisites for effective implementation of the respective program: top management commitment, cultural change in organisations, good communication down the hierarchy, new approaches to production and to servicing customers and a higher degree of training and education of employees (Salzman *et al.* 2002, Antony *et al.* 2003).

Companies across the spectrum have found the most effective way to eliminate the flaws that lead to rework and scrap, and create one unified idea of continuous improvement, is the integration of Lean Manufacturing and Six Sigma (Smith 2003). The integration of the two systems can achieve much better results than either system can achieve alone. While, Lean strategies play an important role in eliminating waste and non-value-added activities across the organisation, Six Sigma, through the use of statistical tools and techniques, takes an organisation to an improved level of process performance and capability. The two methodologies emphasise the unfathomable involvement of top executives and communication with the bottom line to develop robust products and processes in their organisation.

Most companies using the integrated approach apply basic Lean tools and techniques at the beginning of their program, such as current state map, basic house keeping using 5S practice, standardised work, etc. After implementing the above tools and techniques some wastes are eliminated from the system. Now, the tools and techniques of Six Sigma are used to offer powerful solutions to chronic problems. The comprehensive set of tools, techniques and principles that can be employed in

the integrated approach of Lean and Six Sigma business strategies is delineated in figure 1. Figure 1 is based on the previous works of experts in Lean and Six Sigma (Womack and Jones 1996, James-Moore and Gibbons 1997, Hoerl 1998, Rother 1998, Breyfogle III 1999, Harry and Schroeder 1999, Emiliani 2000, Hines and Taylore 2000, Pyzdek 2000, Antony *et al.* 2003, Snee and Hoerl 2003). The use of the comprehensive set of tools mentioned above can help to reduce all kinds of waste (rework, over production, waiting, material, human skills, transportation and unnecessary movement) from the organisation (Ohno 1988, Womack *et al.* 1990, Shingo 1992, Hines *et al.* 1998, Liker 1998).

This paper presents a case study undertaken by implementing a Lean Sigma framework into an Indian small- to medium-sized enterprise (SME) in order to reduce the defects which occur in the final product manufactured by the company and thus satisfy their customers. The company was regularly receiving complaints from its customers on crack propagation in the automobile accessories manufactured by the company. This was the major cause of customer dissatisfaction and was putting customer loyalty at risk. To retain its customers, the management realised the importance of removing operational inefficiencies and wastes from the organisation. The goal of the organisation was to reduce the defects in the product, work-in-process inventory, scrap and rework cost.

The rest of the paper is arranged as follows: Section 2 provides an insight into the die-casting process, the problem encountered by the company and the rationale behind selecting Lean Sigma methodology to tackle the problem. The reasons for using Lean Sigma as a continuous improvement methodology for this case study is cited in section 3. Section 4 elucidates the steps involved in implementing the proposed framework to identify the root cause of the problem and propose corrective action to minimise the impact of the problem on customer satisfaction. The effectiveness of proposed Lean Sigma framework is discussed in section 5. Section 6 throws light on some of the difficulties encountered while implementing the proposed framework. The paper is concluded in section 7.

2. Company background

The die-casting unit under study was established in 1978 with 150 employees, which comes under the category of SME as per the classification given by Indian Trade Industry. The organisation is engaged in designing and manufacturing various types of precision machined components using pressure and gravity die-casting processes. The main customers of the company are

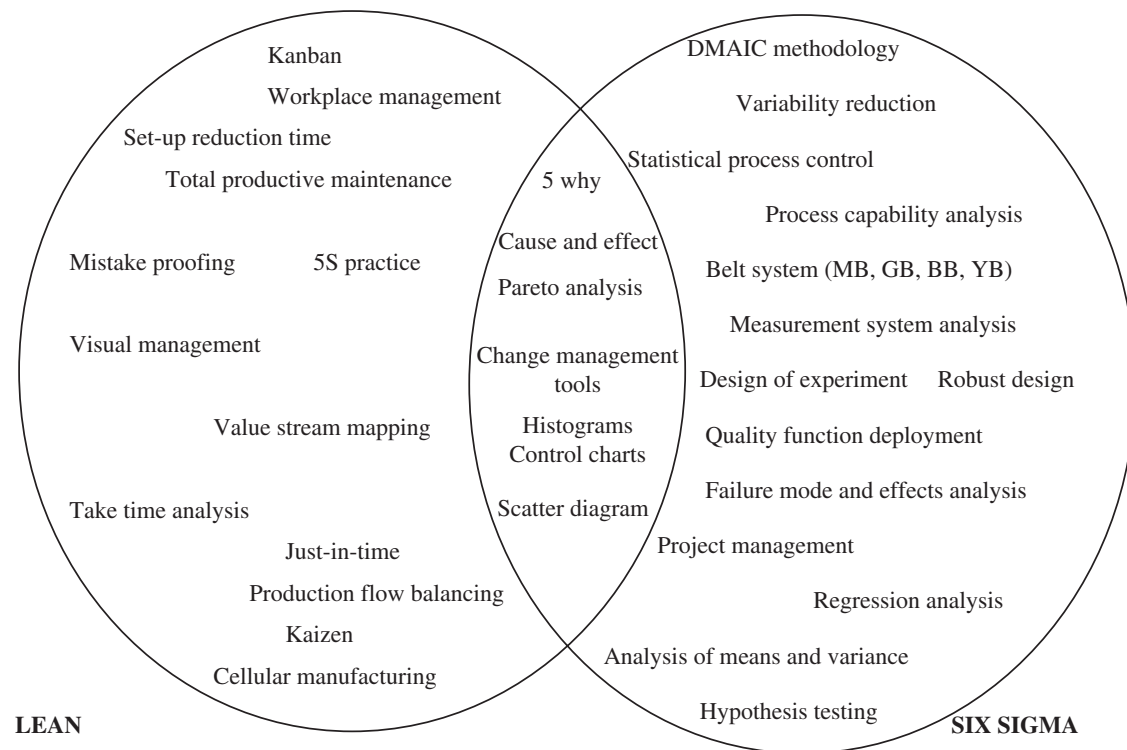


Figure 1. The tools and techniques of Lean and Six Sigma.

ordinance factories, the automobile industry, and textile machine manufacturers. The company manufactures around 250 000 units of die casting products per year to cater for the needs of its customers. The employees work in three shifts per day, each shift of 8 hours, and six days a week to meet the market demand.

The die-casting process starts with placing Al-alloy ($\text{AlSi}_9\text{Cu}_{13}$) ingots in the furnace and heating them for a sufficient duration. When the metal melts and achieves a suitable temperature in the casting furnace, it is inserted into the dies by plunger pressure. As the metal solidifies the cast product is taken out with the help of an ejector pin and placed in a trolley. The cast product then goes to the trimming and fettling shop where extra projections are removed. The trimmed product is moved to the drilling section (MC1) where the different holes and grooves are made as per the dimensions in the drawing. In the next step, semi-finished products go to the de-burring unit (MC2) where the external and internal holes are cleaned and burrs are removed. It is then moved to the chamfering and threading unit (MC3) where fine cutting at different angles along the surface and the making of external and internal threads are performed. Cleaning and polishing operations are performed subsequently in the next stage. Finally, the finished product is stored in the dispatch department

from where it is sent to the customer according to an agreed schedule. Customer orders are taken care of on the basis of first come first serve (FCFS). Quick turnaround orders (QTA) are taken care of by rescheduling the batch processing as decided by the production manager.

3. Rationale for implementing Lean Sigma

The application of different quality programmes to reduce the operational inefficiencies and wastes requires top management involvement and commitment in order to provide appropriate resources and training. The top level management in the SME were proponents of Lean and used to practice TPM, Kaisen, and 5S systems in the organisation. Management showed confidence at the beginning of the initiative and supported the quality and production managers with the variety of resources and training required for successful deployment of Lean principles. As a result, there was less work-in-process inventory with reduced scrap and rework cost.

Management interest in the quality initiatives undertaken started waning as the demand from its customers increased. The wish to maximise return on investment and the fear of not meeting the customer demand

compelled the management to concentrate more on production than on quality of the product. This resulted in an increase in work-in-process inventory, scrap and rework cost, and more defects (external and internal casting defects like foliation, cracks, cold shut, pinhole porosity, etc.) in the final product. There were many hidden wastes embedded in the manufacturing process that were ignored by the company because their manufacturing capacity was higher than their production requirements. Problems were tackled by increasing the work-in-process inventory leading to higher inventory carrying cost. In the last six years, demand for their product became high due to globalisation and the boom in the automobile sector. In order to meet the customers' demand, production of automobile accessories was given top priority, irrespective of the quality of product. The management was able to meet the customer demands by putting the quality of product at risk. This resulted in a number of customer complaints from different parts of the country.

This intimidating situation led management to ponder over redeploying the quality initiatives taken at the beginning. As most of the customer complaints were related to crack propagation in the final die-casting product (resulting in improper functioning of the automobile engine), management formed a team to identify the root cause of problems. Moreover, there was a constant increase in in-process inventory, machine downtime, idle time at different workstations, and there was also concern about the health and safety issues of the employees as the average number of accidents on the shop floor were increasing each year.

The management, after a thorough brainstorming session with the senior managers of different departments, generated a list of 15 possible projects that could enhance customer satisfaction. Multi-voting was then used among its cross-functional team to narrow down the projects list to a smaller list of the top priorities or to a final selection. Multi-voting allows the item that is favoured by all, but not the top choice of any, to rise to the top (Tague 2004). In order to ensure greater decision-accuracy, the voting was done by weighting the relative importance of each choice. Further, the outcomes from the multi-voting was debated by team members to avoid errors from incorrect information or understanding about each project. One of the questions raised during brainstorming was related to the selection of a continuous improvement method from a range of existing quality improvement programmes. The team decided to implement the Lean Sigma methodology to eliminate defects, reduce variation and reduce inventory and overall complexity from the system. While Lean streamlines processes and eliminates waste (idle time, machine downtime, in-process-inventory), reduces

overall complexity, and helps to uncover the value-added activities of a process, Six Sigma can solve complex cross functional problems where the root causes of a problem (in this case, crack propagation) are unknown and help to reduce undesirable variations in processes. The integration of two approaches eliminates the limitations of individual approach. The team members decided to adopt Six Sigma over TQM because of the following reasons:

- TQM focuses on long-term results and expected pay-off is not well defined. Six Sigma creates a sense of urgency by emphasising rapid project completion within 6 months.
- Improvement results from TQM initiatives are small and do not bring rapid changes. The die-casting company under investigation is an SME and cannot afford to visualise tangible benefits after a period of 1 year.
- TQM provides a vast set of tools and techniques with no clear framework for using them effectively, whereas Six Sigma uses DMAIC methodology for problem solving which successfully integrates a set of tools and techniques in a disciplined fashion.
- TQM is motivated by quality idealism, whereas Six Sigma is driven by tangible benefits for all major stakeholders (customers, shareholders, and employees).

It was decided that Lean would be used to create a foundation that allows the tools of Six Sigma to yield greater benefits, faster. Similar work was carried out by Cua *et al.* (2001), who investigated the practice of TQM and Lean simultaneously and the results revealed that that manufacturing performance is associated with the level of implementation of both socially- and technically-oriented practices of the aforementioned programs. After a number of discussion sessions a framework was developed between the team members and the facilitators, the latter being the authors of this article. The details of the framework are discussed in the next section.

4. Framework for Lean Sigma implementation: a case study

A model or framework is proposed by authors to implement Lean Sigma in the organisation and is delineated in figure 2. The framework is developed by authors after a number of meetings with top and middle level management. The facilitators meticulously studied the whole die-casting process, met up with the employees working on the shop floor and enquired about the key parameters associated with each process,

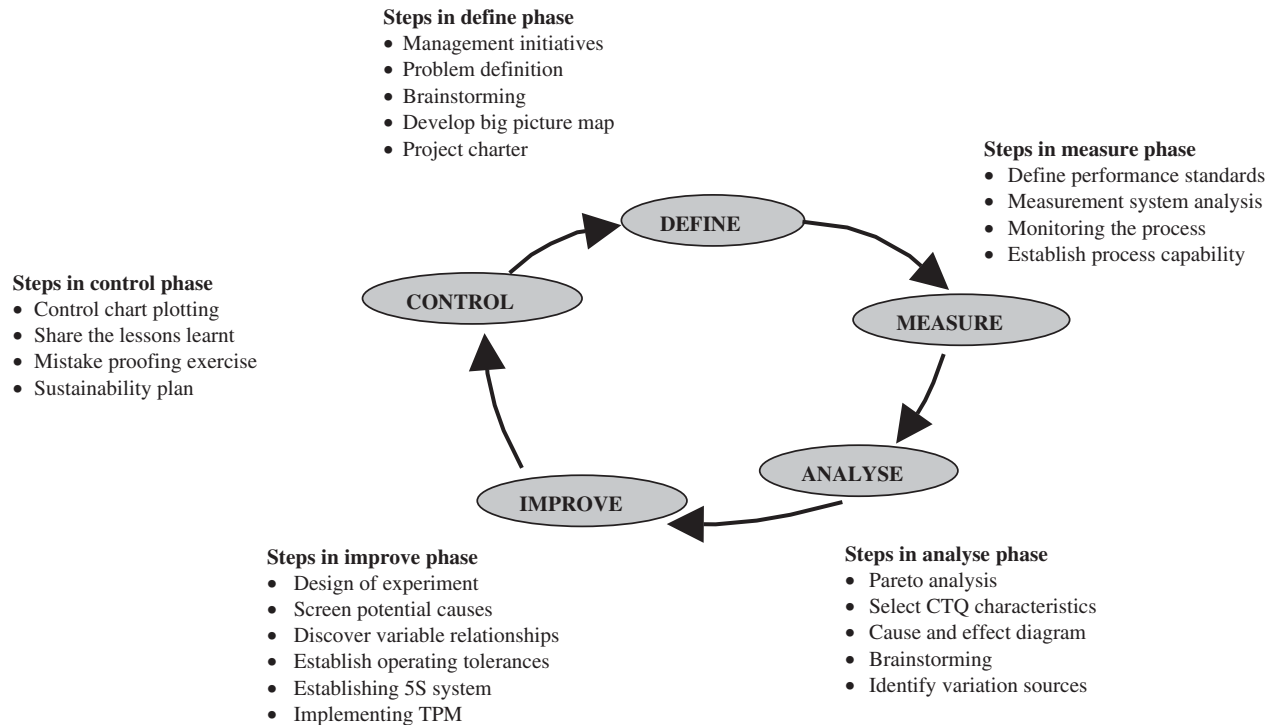


Figure 2. Proposed framework for Lean Sigma implementation in the organisation.

scrupulously studied the documents of the production and quality departments to check on the defective products manufactured each day. This helped develop the Lean Sigma framework for implementation on the shop floor. In the proposed framework, Lean tools are used within the Six Sigma (DMAIC) problem-solving methodology to reduce the defects occurring in the final product.

4.1. Define

4.1.1. Management initiatives. An emergency meeting was called by top level management with operators, engineers and senior managers of different departments to discuss the restructuring required in the current practices for enhancing the market share and customer satisfaction. In order to instigate enthusiasm and motivation among employees for bringing about the required changes, senior management decided to communicate not only the successes but also the problems encountered while implementing Lean Sigma framework. This helped in identifying the mistakes committed in other projects and learning from such mistakes. A cross-functional team was formed consisting of the operators, engineers from production, quality, and marketing department, and senior managers. This team

spent many hours on the shop floor observing, in order to collect data and understand the different processes associated with the die-casting unit.

4.1.2. Problem definition. A number of brainstorming sessions of team members were conducted to identify critical to quality (CTQ) characteristics based on the voice of customer (VOC) input. In the meeting the problem of the die-casting unit, the size of the problem, the impact of the problem, etc., were discussed among the team members and it was apparent that most of the customer complaints related to crack propagation in the automobile accessories manufactured by the company. The goal of the team members was to identify the root cause of problem and reduce the defects occur in the product.

4.1.3. Current state map. In order to have an insight into the current state of the die-casting unit, a current state map is developed which gives a closer look at the process so that opportunities for improvement can be identified. The movement of materials through different processes/facilities during manufacturing is shown in the current state map (figure 3).

As shown in the current state map, the manufacturing process starts with die casting and extends all the way through to shipping. Below each process, process cycle

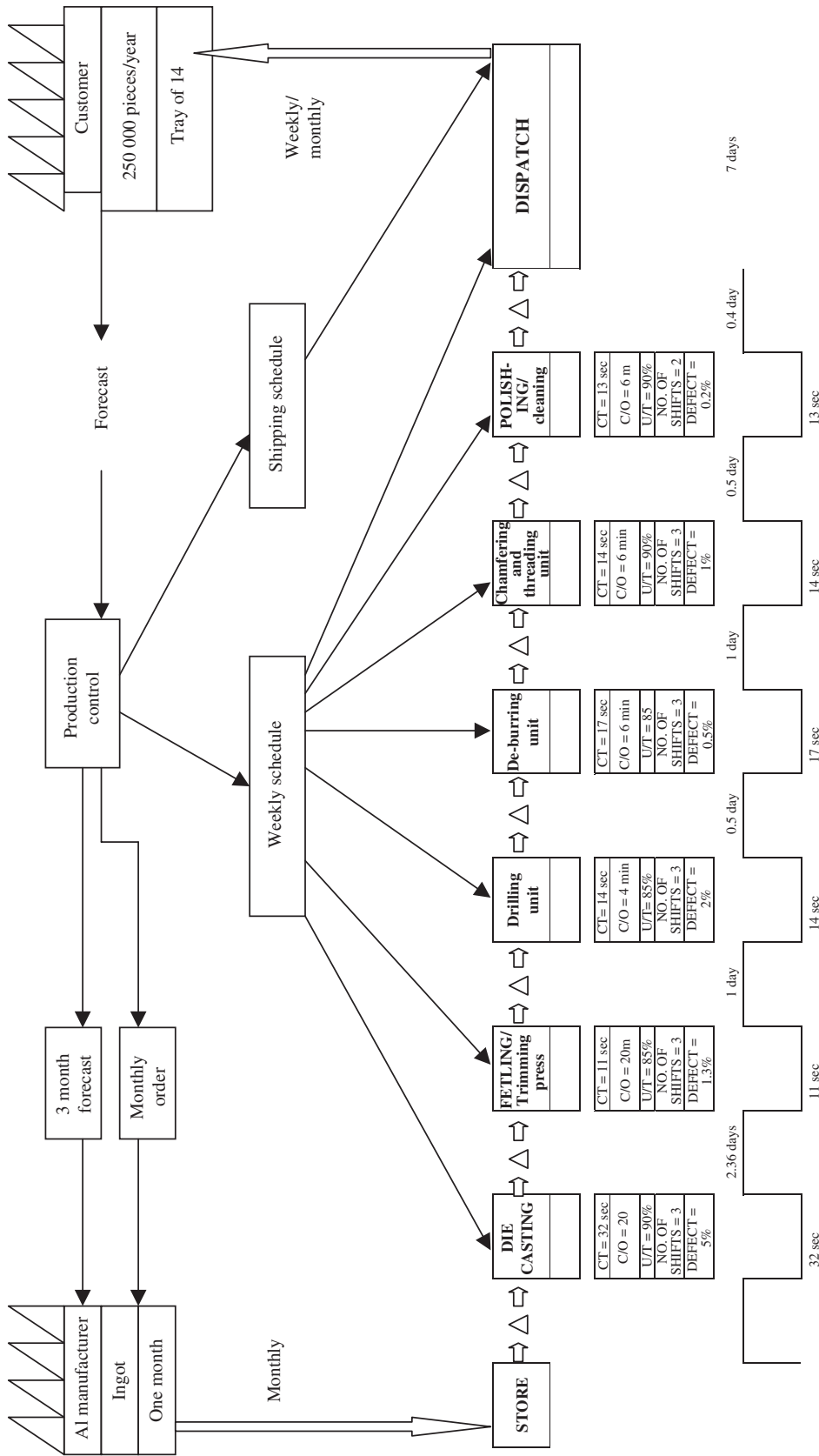


Figure 3. Current state map. Lead time = 5.76 days, Value added time = 101 sec.

time (CT), machine uptime (U/T), the number of shifts, the changeover time (C/O), and the percentage defect are listed. It should be noted that data are collected based on interactions with the workers at different work stations. During the development of these state maps it was found that the defect rate was high and was unacceptable.

4.2. Measure phase

The team was divided into small groups to monitor the defects occurring in each process involved in the manufacturing of die-casting product. The team had been collecting data of defective products for the last 2 years and had identified the critical processes where maximum defects were occurring, but no action was taken. In order to validate the historic data, the team members decided to collect the data of defective product for the following 6 days of production from their respective work stations. The collected data was analysed and it was found to match with the historic data, showing that the maximum numbers of defects were coming from the die-casting machine, de-burring operation (MC2), and chamfering and threading operation (MC3).

The next step was to determine a performance standard based on customer requirements. A data collection plan was established to focus on the project output and also to carry out the standard setting exercise for the same. A Gauge repeatability and reproducibility (R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether it was accurate or not. A study was performed to check the accuracy of gauges used for the measurement of characteristics as well as the reproducibility of the worker in performing operations on the machine. The Gauge R&R study performed on the system showed a variation of 8.01%, which implied that the measurement system was acceptable. Using high performance and accurate equipment, we were able to secure the correct measurements of the die-casting parameter values and react in time for the necessary corrective actions for the experimental procedure. What the customers want is a sound casting with measurable characteristics, such as the density of the casting. Therefore the ultimate goal of the team was to increase casting density.

The company was operating at a baseline capability of 0.12 with defects per unit (DPU) being 0.18. The desired specification limit of casting density was 2.73–2.78 g/cc and the casting produced before the implementation of Lean Sigma had an average density of 2.45 g/cc.

4.3. Analyse phase

The objective of the team members was to determine the root causes of defects and identify the significant process parameters causing the defect. Out of six casting defects, air inclusion, shrink holes, and gas holes porosity are internal defects whereas cold shut, foliations, and soldering are surface defects. The internal defects are formed during the casting process as the metal solidifies. The micro holes created inside the casting are due to air or gas entrapment and result in crack propagation due to differential pressure and force created inside the casting. This crack propagation impedes the proper functioning of the final product and thus is very significant to overall performance of the machinery where die-casting parts are fitted. The Pareto chart shown in figure 4 illustrates the percentage contribution of internal and external defects in the process. It can be concluded from table 1 and figure 4 that internal defects are the result of poor casting density and amounts to 67% of total defects in the process. Other defects occur in the de-burring, chamfering and threading operations due to tooling and clamping problems.

All the defects mentioned above decrease the soundness of the casting, i.e. decrease the density of the casting. After conducting several brainstorming sessions, the team members concluded that the density of the casting is the most important critical quality characteristic in the die-casting process as it was related to many internal defects (air entrapment, gas holes porosity, shrink holes, etc.). The objective of the die-casting process was to achieve 'better casting density' while minimising the effect of uncontrollable parameters. To have a clear picture of the process parameters

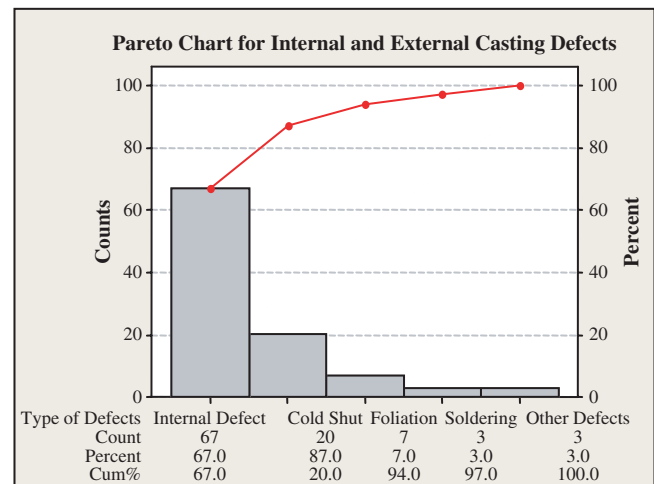


Figure 4. Pareto chart for the internal and external casting defects.

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Table 2. Process parameters with their ranges and values at three levels.

Parameter destination	Process parameters	Range	Level 1	Level 2	Level 3
A	Metal temperature (°C)	610–730	610	670	730
B	Piston velocity 1st stage (m/s)	0.02–0.34	0.02	0.18	0.34
C	Piston velocity 2nd stage (m/s)	1.2–3.8	1.2	2.5	3.8
D	Filling time (ms)	40–130	40	85	130
E	Hydraulic pressure (bar)	120–280	120	200	280

Table 3. Results of L_{27} OA.

Trial no.	A	B	C	D	E	A × B	A × C	B × C	R1	R2	R3	Average	S/N
1	1	1	1	1	1	1	1	1	2.336	2.338	2.441	2.372	7.500
2	1	1	2	2	2	1	2	2	2.339	2.442	2.447	2.409	7.637
3	1	1	3	3	3	1	3	3	2.442	2.505	2.448	2.465	7.839
4	1	2	1	2	2	2	1	2	2.427	2.444	2.416	2.429	7.713
5	1	2	2	3	3	2	2	3	2.545	2.577	2.595	2.572	8.210
6	1	2	3	1	1	2	3	1	2.435	2.336	2.374	2.382	7.538
7	1	3	1	3	3	3	1	3	2.716	2.728	2.701	2.715	8.680
8	1	3	2	1	1	3	2	1	2.346	2.429	2.392	2.389	7.566
9	1	3	3	2	2	3	3	2	2.439	2.442	2.445	2.442	7.759
10	2	1	1	2	3	2	2	1	2.445	2.501	2.487	2.478	7.884
11	2	1	2	3	1	2	3	2	2.439	2.441	2.398	2.426	7.701
12	2	1	3	1	2	2	1	3	2.418	2.381	2.443	2.414	7.658
13	2	2	1	3	1	3	2	2	2.542	2.513	2.504	2.520	8.031
14	2	2	2	1	2	3	3	3	2.459	2.463	2.445	2.456	7.808
15	2	2	3	2	3	3	1	1	2.543	2.585	2.591	2.573	8.212
16	2	3	1	1	2	1	2	3	2.441	2.493	2.502	2.479	7.887
17	2	3	2	2	3	1	3	1	2.594	2.588	2.591	2.591	8.274
18	2	3	3	3	1	1	1	2	2.539	2.542	2.545	2.542	8.108
19	3	1	1	3	2	3	3	1	2.474	2.495	2.489	2.486	7.914
20	3	1	2	1	3	3	1	2	2.603	2.595	2.588	2.595	8.288
21	3	1	3	2	1	3	2	3	2.438	2.473	2.452	2.454	7.803
22	3	2	1	1	3	1	3	2	2.704	2.685	2.692	2.694	8.611
23	3	2	2	2	1	1	1	3	2.640	2.682	2.654	2.659	8.497
24	3	2	3	3	2	1	2	1	2.703	2.698	2.691	2.697	8.623
25	3	3	1	2	1	2	3	3	2.671	2.679	2.685	2.678	8.562
26	3	3	2	3	2	2	1	1	2.726	2.717	2.720	2.721	8.699
27	3	3	3	1	3	2	2	2	2.745	2.747	2.752	2.748	8.785

(OA) design to meet the experimental requirement is a 27-trial experiment (L_{27} OA) and the experimental layout is depicted in table 3. The company was initially operating with the following settings: A_1 , B_1 , C_1 , D_2 , E_3 .

The casting density is a ‘larger the better’ type of quality characteristic. Thus, the S/N ratio used is given by:

$$S/N \text{ ratio} = -10 \log \left[\frac{1}{n} \sum_{i=1}^n \left(\frac{1}{y_i^2} \right) \right] \quad (1)$$

where y_i is the casting density for a trial condition. Each trial condition was repeated three times (i.e. $n=3$). The S/N ratios are computed for each of the 27

trial conditions. The average values of the S/N ratios for each parameter at different levels for all the trials are listed in table 4 and plotted in figure 6. The influence of interactions on the casting density was negligible based on the analysis and was thus omitted from the table and figure.

From figure 6, it is clear that casting density is at maximum when the process parameters A, B, D and E are kept at level 3 and parameter C at level 1. Once the optimum settings of process parameters were identified, the team members decided to implement 5S system and total productive maintenance (TPM) to establish a clean environment within the shop floor and also to reduce the idle time of machine and employees on the shop floor.

Table 4. The average values of S/N ratios for each process parameter at different levels.

Factor	A	B	C	D	E
Level 1	7.827	7.803	8.087	7.960	7.923
Level 2	7.951	8.138	8.076	8.038	7.966
Level 3	8.420	8.258	8.036	8.201	8.309

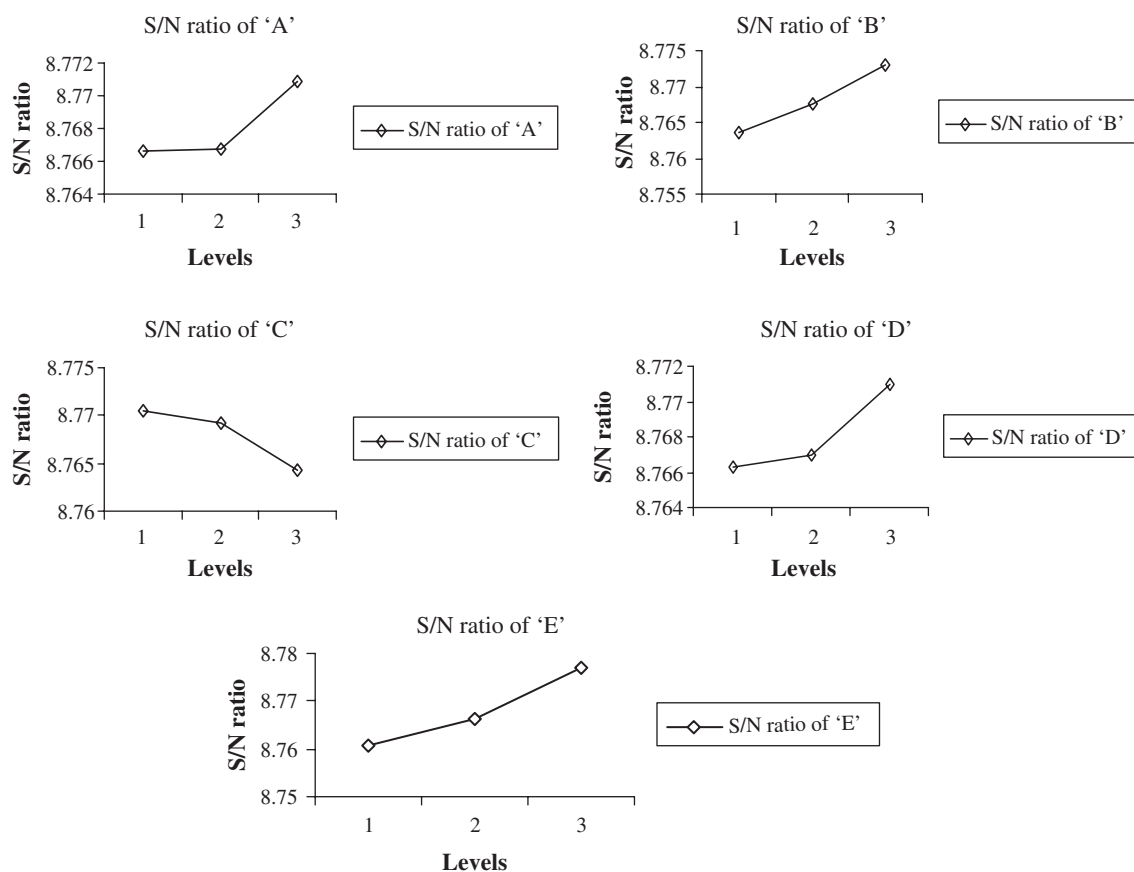


Figure 6. Average value of S/N ratio for the five parameters at three levels.

4.4.2. Confirmatory test. In order to validate the results obtained from the improve phase, a confirmatory experiment was performed using the optimal setting of process parameters A, B, D and E at level 3 and C at level 1. The average value of casting density was computed as 2.75 g/cc. This resulted in an increase of casting density by over 12%. In order to check that the results were valid and sound, it was decided to observe the value of casting density for the next three days of production.

4.4.3. 5S system. 5S was developed by Toyota to eliminate the hidden factory waste by describing a set

of actions to maintain an organised work place (Monden 1998). The following are the Japanese words that describe those actions—Seiri (sort), Seiton (set in order), Seiso (shine), Seiketsu (standardise), Shitsuka (sustain) (Mastroianni and Abdelhamid 2003). Top level management decided to implement the 5S system in order to establish a standard approach to housekeeping within the organisation and help reduce the non-value-added time for employees (Dale 1994, Womack and Jones 1996). Moreover, there was also concern about the health and safety issues of the employees as the average number of accidents on the shop floor were increasing per year. The 5S training pillars were

implemented on the shop floor which helped the organisation in the following ways:

- A day to day floor cleaning programme was initiated and it was ensured that the employees had sufficient lighting on the shop floor to work in the afternoon and night shifts.
- In order to minimise the idle time at each process, operators were provided with a rack to place the items correctly in the respective block provided in the rack.
- The trimming unit was moved nearer to the die-casting machine so that time was saved in transportation from die-casting machine to trimming press.
- The cleaning of dust particles, grease, and oil from the machines to ensure the health and safety of employees.

The implementation of the 5S System helped to organise the work environment, standardise the work flow and assign clear ownership of processes to employees. It also helped in increasing the productivity by reducing idle time of some processes.

4.4.4. Total productive maintenance (TPM). A TPM programme was introduced to the organisation in the late 1990s and was a complete fiasco due to lip service provided by management without showing any interest in actual implementation of programme. TPM was only used for documentation purposes and for attracting customers. Tough competition within the market place forced the management to rethink on proper implementation of the TPM programme within the Lean Sigma framework to markedly increase production and, at the same time, increase employee morale and job satisfaction. There was a constant increase in in-process-inventory, machine downtime and idle time at work stations which was easily be tackled by proper implementation of TPM programme (Dale 1994, Womack and Jones 1996).

The steps taken by management to facilitate effective implementation of TPM are listed below.

- Periodic maintenance of machines, i.e. cleaning, lubrication, inspection, and corrective action on all machines on the shop floor.
- Collection and analysis of data on downtime of machine and remedial action to increase the overall equipment effectiveness (OEE) and thus the overall plant efficiency (OPE).
- Creating an equipment improvement team and TPM area co-ordinators to monitor the proper implementation of the programme.

- Involving employees at all levels of organisation to achieve zero defects, zero breakdown, and zero accidents in all functional areas of the organisation.
- Accentuating the training programme for effective implementation of programme.

4.5. Control phase

4.5.1. Sustainability. The main purpose of the Six Sigma methodology is not only improving the process performance but also having the improved results sustained in the long run. Hence, the standardisation of the optimal process parameters setting is required. From time to time, control charts are plotted, as shown in figure 7, to check that the product is meeting the desired specification. The die-casting process has been improved by optimising the critical process parameters A, B, C, D and E to around 730°C, 0.34 m/sec, 1.2 m/sec, 130 ms, and 280 bar respectively. For measuring accurate values of above process parameters, different sensors (pressure sensors, temperature sensors, and position and velocity sensors) are used. The implementation of the aforementioned suggestions resulted in enhanced profitability of the organisation.

4.5.2. Mistake proofing exercise. A mistake is a deviation from an intended target. Human error, malfunctioning of machines, or improper environmental conditions are examples of mistakes that can lead to a defect. A mistake may consist of performing a prohibited action, not performing a required action, or performing a required action incorrectly (Dale 1994). A mistake proofing exercise was performed to reduce the number of defects occurring in the process.

Management decided to accentuate the following points in order to prevent the occurrence of other defects at different stages of production:

- Checking the defects at the preliminary design phase so that defects are not passed to the production stage.
- Failure mode and effect analysis (FMEA), in-house scrap and rework data, inspection data, and analysis of customer complaints were used to pinpoint potential problems that could be resolved by mistake proofing.
- Cross-functional teams were formed to discuss the manufacturing and design problems that are likely to cause mistakes/defects/failures.
- Sharing of information related to company performance with its employees.
- Training people on the shop-floor regarding details of production and quality issues as well as other

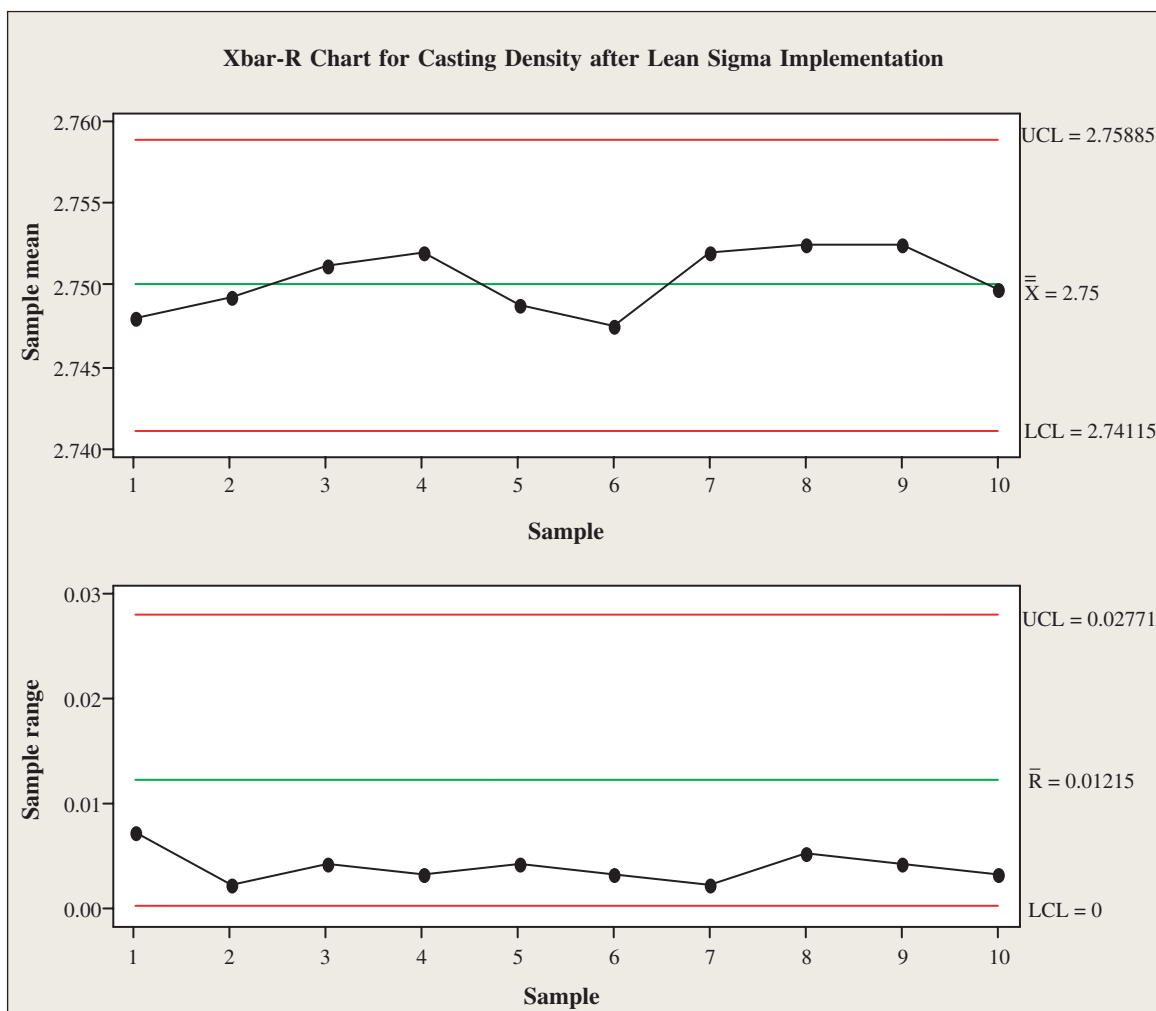


Figure 7. Control chart for casting density after implementing Lean Sigma strategy.

activities such as problem solving and team building.

- Use of control charts and graphs at each processing stage to keep the employees aware of the real time performance at the respective stages of production.
- To motivate and recognise employees contribution in establishing best practices within the organisation.
- To reward and recognise the employees involved in the project.

5. Effectiveness of the proposed Lean Sigma framework

The team evaluated the financial benefits generated by sustaining the Lean Sigma project. The cost incurred by the company in manufacturing die-cast products was divided into four categories: labour cost, raw material cost, operating expenses, and other overhead costs.

All these costs were incurred in the manufacture of the product and it passing through various processing stages. A break up of all these costs in manufacturing a single unit that passes through six sections is listed in table 5.

Some value is added at every stage of production as the raw material is processed through various machines. Therefore, the occurrence of a defect at any stage of production must be considered a loss to the organisation. The implementation of the Lean Sigma framework resulted in a colossal reduction in defects occurring at each stage of production. Table 6 gives the details of savings generated by the organisation when the defect is detected at a particular stage.

It is shown in table 6 that the number of defects as a percentage coming in each stage has decreased considerably. The savings generated due to reduction in defects was estimated around \$46 500 per year.

Table 5. Total cost incurred in manufacturing a unit product.

	Labour cost \$/unit	Raw material cost \$/unit	Operating cost \$/unit	Overhead cost \$/unit	
Die casting	0.72	0.53	0.97	0.32	
Trimming	0.80	–	0.87	0.19	
Drilling	0.70	–	0.82	0.24	
De-burring	0.52	–	0.77	0.18	
Chamfering	0.58	–	0.8	0.21	
Cleaning and polishing	0.66	–	0.86	0.38	
Total cost	3.98	0.53	5.09	1.52	\$11.12/unit

The implementation of Lean Sigma framework also helped in:

- reducing the machine downtime;
- establishing a standard housekeeping procedure;
- increasing the confidence level among employees;
- instigating a sense of ownership among employees for their work;
- enhancing OPE and OEE;
- rectifying the customer complaints;
- reducing inventory;
- reducing machine set up time;
- reducing the number of accidents at workplace.

The savings generated by the organisation by achieving improvements in aforementioned areas are as follows:

- The decrease in machine downtime from 1% to 6% helped in increasing the OPE and OEE. This resulted in estimated savings of over \$40 000 per year.
- Work in process inventory reduced by over 25% and resulted in estimated savings of over \$33 000 per year.
- Standard housekeeping procedures helped to reduce the number of accidents at work place significantly. This reduced the amount of compensation the management needed to pay to injured employees (around \$20 000 on average per year).

Thus, there was an improvement of around \$140 000 per year in monetary terms for the company after implementation of the Lean Sigma strategy. Table 7 presents the significant improvements in the key performance metrics after implementation of Lean Sigma methodology. The key metrics used for comparing the results after implementing the Lean Sigma framework included: Defect per unit (DPU), process capability index (C_p), mean and standard deviation of casting density, first time yield (FTY), and OEE.

The following equations are used to calculate the defect per unit (DPU), FTY, and OEE:

$$\text{DPU} = \frac{\text{Number of defects found}}{\text{Number of units processed}} \quad (2)$$

$$\text{FTY} = e^{-\text{DPU}} \quad (3)$$

$$\text{OEE} = A * E * Q \quad (4)$$

where A stands for availability of machine; E connotes performance rate; and Q symbolises the quality rate (percentage of good parts produced out of total production) or yield of die-casting product.

It can be inferred from the table that there was significant improvement in the key performance metrics achieved by the company. This motivated the management for horizontal deployment of the Lean Sigma approach in other areas of the organisation such as transactional processes, service-related processes, etc., and to share the benefits generated with its employees.

6. Difficulties encountered in implementing the Lean Sigma framework

For any continuous improvement programme, it is important to discuss the difficulties encountered while implementing the programme. It provides valuable lessons learned from previous projects that should be taken care of while starting the new project. In this case, convincing top management was the most arduous task as management was not ready to compromise on production to improve the quality of the final product manufactured. The top management people felt that investing in quality means increasing the cost of production, which they cannot afford to do when faced with stiff challenges from its competitors. The management teams were convinced by citing examples of some Indian companies that have reduced their production cost significantly and enhanced their

Table 6. Break up of cost saving at each stage of production.

	Labour \$/unit	Operating cost \$/unit	Overhead \$/unit	Total cost \$/unit	Per cent defect before Lean Sigma	Per cent defect after Lean Sigma	Annual impact before Lean Sigma (\$)	Annual impact after Lean Sigma (\$)	Savings after Lean Sigma implementation (\$)
Die casting	0.72	0.97	0.32	2.01	5	0.023	25125	115.575	25009.43
Trimming	0.80	0.87	0.19	1.86	1.3	0.01	6045	46.5	5998.5
Drilling	0.70	0.82	0.24	1.76	2	0.017	8800	74.8	8725.2
De-burring	0.52	0.77	0.18	1.47	0.5	0.003	1837.5	11.025	1826.475
Chamfering	0.58	0.8	0.21	1.59	1	0.0016	3975	6.36	3968.64
Cleaning and polishing	0.66	0.86	0.38	1.9	0.2	0.008	950	38	912
Total							46732.5	292.26	46440.24

Table 7. Comparison before and after improvement based on key metrics.

Key metrics used	Before improvement	After improvement
Defect rate	0.18 DPU	0.0068 DPU
FTY	83.5%	99.32%
Process capability	0.12	1.41
Process mean	2.45	2.75
Process standard deviation	0.069	0.0059
OEE	0.48	0.83

bottom-line results using the application of Lean and Six Sigma principles.

It is quite natural to encounter resistance from employees if you try to introduce and implement some new business strategies in any organisation. The employees of the organisation under observation thought that implementation of the new strategies could endanger their job opportunities and poor performance result in them losing their jobs. This attitude was corrected by top management, convincing the employees that their jobs would not be in danger and that they would be rewarded for better performance. This gradually boosted confidence in the employees and eventually they were ready to embrace the proposed framework in their processes.

Moreover, resistance from management was also noticed when the team had decided to implement the 5S system in the organisation in order to ensure proper housekeeping and to reduce accidents in the factory by ensuring a safer environment. The management thought that ergonomics would have no impact on the performance of the employee and, ultimately, production. The management teams were convinced by showing them the savings that can be generated if accidents are avoided 'right first time' (RFT) and how proper housekeeping can reduce the idle time of the operator and machine. These were some of the difficulties encountered by the Lean Sigma team while implementing the proposed framework.

7. Conclusion

The following conclusions are drawn from this case study:

1. The implementation of Lean Sigma framework provided an impetus for establishing best practice within the company. Moreover, it also provided the company with a performance benchmark on

which they could base future performance enhancement programmes.

2. The optimal settings of the process parameters have improved the casting density of the die-casting process by over 12%.
3. A significant improvement was observed in the key performance metrics (e.g. DPU, process capability, first time yield, etc.) after implementation of the Lean Sigma strategy.
4. The implementation of the Lean Sigma strategy has resulted in savings of around \$140 000 per year.
5. Successful implementation of the proposed integrated framework of Lean and Six Sigma provided an impetus for bringing a cultural change in the company with systematic implementation of the integrated approach throughout the organisation.

The proposed framework for Lean Sigma implementation needs to be validated in different scenarios for establishing its validity. This can be considered as one of the limitations of the proposed framework. Moreover, in general there is no standard framework for Lean Sigma implementation. In addition to this, there is no clear understanding on the usage of tools and techniques within the Lean Sigma framework. This is perhaps an area of future research for the authors. It has also been observed by the authors that there is no clear guidance within the framework as to which strategy (Lean or Six Sigma or Lean Sigma) should be selected at the early stages of a project. Further research is also required in identifying the critical success factors (CSFs) of Lean Sigma. The authors are extending and improving the proposed framework by implementing the framework in different manufacturing industries in India. More new tools and techniques will also be added to the existing framework as part of further research into the area of study.

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