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Case Study

Winning Customer Loyalty in an Automotive Company through Six Sigma: a Case Study

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Six Sigma is a disciplined approach to improving product, process and service quality. Since its inception at Motorola in the mid 1980s Six Sigma has evolved significantly and continues to expand to improve process performance, enhance business profitability and increase customer satisfaction. This paper presents an extensive literature review based on the experiences of both academics and practitioners on Six Sigma, followed by the application of the Define, Measure, Analyse, Improve, Control (DMAIC) problem-solving methodology to identify the parameters causing casting defects and to control these parameters. The results of the study are based on the application of tools and techniques in the DMAIC methodology, i.e. Pareto Analysis, Measurement System Analysis, Regression Analysis and Design of Experiment. The results of the study show that the application of the Six Sigma methodology reduced casting defects and increased the process capability of the process from 0.49 to 1.28. The application of DMAIC has resulted in a significant financial impact (over U.S. $110 000 per annum) on the bottom-line of the company. Copyright © 2006 John Wiley & Sons, Ltd.

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INTRODUCTION

In this ever-changing world of new customer needs, new markets, innovation and social change there is a constant drive to improve existing processes to serve existing customers and a desire to develop new processes to serve new customer needs[1]. Six Sigma has proved to be a powerful business strategy for meeting the aforementioned goals. Six Sigma is a highly structured process improvement framework that uses both statistical and non-statistical tools and techniques to eliminate process variation and thereby improve process performance and capability[2]. Linderman *et al*.[3] defined Six Sigma in the following way:

> '*Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates*'.

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The definition emphasizes the significance of the customer's definition of the defect rate and its importance while making a process improvement or when manufacturing a product. General Electric (GE) CEO Jack Welch describes Six Sigma as 'the most challenging and potentially rewarding initiative we have ever undertaken'[4]. The voyage of Six Sigma started in a manufacturing company and it has now sailed across financial services, healthcare and the public sector[5–9]. It is worth noting that Six Sigma still has air left in its sails and continues to build momentum with no sign of letting up[10].

The Six Sigma approach starts with a business strategy and ends with top-down implementation, having an impact on profits if it is successfully deployed[11,12]. It takes us away from 'intuition based decisions—what we think is wrong, to fact based decision—what we know is wrong'[13]. A number of papers and books have been published demonstrating the fundamentals of Six Sigma, such as what is Six Sigma[4,14,15], why do we need Six Sigma[16,17], what makes Six Sigma different from other quality initiatives[5,18], Six Sigma deployment[19,20], critical success factors of Six Sigma implementation[2], Six Sigma project selection[21,22], the organizational infrastructure required for implementing Six Sigma[5,20] and the role of academia and university in promoting the best-in-class practice of Six Sigma[23–25].

The aim of Six Sigma is to keep the distance between the process average and the nearest tolerance limit to at least six standard deviations and thus reduce variability in products and processes in order to prevent defects[26]. Six Sigma aims at achieving 3.4 defects per million opportunities (DPMO) with an assumption that the process mean shifts by as much as 1.5 standard deviations off the target[5,27]. A defect opportunity is a process failure that is critical to the customer[3]. Six Sigma methodology reduces processes to two common denominators, defects per unit (DPU) and sigma, and thus establishing a common language of variation among diverse organizations, i.e. applying the Define, Measure, Analyse, Improve and Control (DMAIC) framework for improving different processes in an organization[28,29].

Six Sigma has been exploited by many world class organizations such as GE, Motorola, Honeywell, Bombardier, ABB and Sony to name but a few, and has resulted in millions of dollars of bottom-line savings[1,30]. However, everybody has not been so enthusiastic—there have been failures too[4]. The reason for failure in most cases was attributed to the lip service provided by top management and their interest towards the initiative waning over time.

The attributes of Six Sigma makes the quality proponent ponder on its efficacy over other quality improvement initiatives or programs, some of which are cited below[31].

- *Framework.* The existence of a framework (DMAIC) where techniques such as Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), Design of Experiments (DoE) and Statistical Process Control (SPC) are integrated into a logical flow.
- *Approach.* A top-down approach starting from the CEO and involving a cross-functional team from the Quality, Sales, Marketing, Production and Human Resource departments.
- *Application.* While the original goal of Six Sigma was to focus on manufacturing operations, today the marketing, purchasing, billing, invoicing, banking and healthcare functions are also employing Six Sigma strategies with the aim of continuously reducing defects or errors and working towards perfection, and thereby achieving business excellence.
- *Focus.* Six Sigma applications are customer-centric, listening to the voice of customers (VOCs) and measuring it in terms of critical to quality characteristics (CTQs), i.e. mapping the VOC into product/service characteristics.
- *Organization.* In organizational terms, Six Sigma focuses on project-by-project features of its implementation. Six Sigma focuses on project management skills, project selection criteria and project reviews involving the cross-functional team.
- *Result.* The outcomes of Six Sigma projects are measured in financial terms that are a tangible measure of achievement that most people in the organization understand—not just project members.
- *Personnel.* Six Sigma emphasizes training, education and certification processes that result in black belts, green belts and yellow belts before embarking on any project.

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LITERATURE REVIEW

Six Sigma and process capability

Six Sigma is a measure of process performance and a process operating at Six Sigma quality has a defect rate of 3.4 DPMO[32]. The process capability indices C_p and C_{pk} are used as the vehicles to characterize the produced process quality. Six Sigma is achieved when the product specifications are at $\pm 6\sigma$ (where σ is the standard deviation of the process) and when the process width is half the specification band. The process potential (C_p) for a Six Sigma process would be 2 (when the process is centered) and the actual process performance (C_{pk}) would be 1.5 (when there is 1.5σ shift in the process mean). During the process capability analysis using C_p and C_{pk}, the process must be stable and normally distributed, and the estimated mean and standard deviation should be based on sufficiently large sample sizes[33].

It is not necessary that every process should operate at Six Sigma level. The selection criteria for a process should be based upon its strategic importance and the cost of the improvement relative to the benefit. A lower Sigma quality level of performance may be acceptable for some processes. For example, a credit card company had a target that 95% of customers wishing to speak to a customer service representative must be connected within six rings. The company discovered through a customer survey that customers were willing to wait up to seven or eight rings provided they were informed by a recorded voice that a customer service representative would attend to their queries soon. The company also found that a further reduction of up to five or less rings would not increase customer satisfaction significantly. In such cases, we do not really need a Six Sigma process capability. On the other hand, in some processes, even Six Sigma may not be sufficient; for example, the level of airlines landing their aircraft safely needs to be higher than the Six Sigma quality level.

Project selection for Six Sigma implementation

The success or failure of Six Sigma deployment in a business process hinges on selecting projects that can be completed within a reasonable time span (four to six months) and will deliver a tangible (quantifiable) business benefit in financial terms or customer satisfaction[34]. The selection of suitable projects in a Six Sigma program is a major factor in the early success and long-term acceptance of Six Sigma within any organization[35]. According to Adams *et al.*[20], 'during black belt training before project identification is the classic—getting the cart before the horse'. The project selection process must listen to three important voices: the voice of the process, the VOC and the voice of strategic business goals[17]. According to Snee and Rodebaugh[22], there are four key phases to the development of a mature project selection process: to identify the black belt projects to be worked on in early stages of Six Sigma, to create a Project Hopper (i.e. a collection of projects), to check that the project is linked to the strategic improvement of the organization and to create an improvement system that manages all the improvement efforts of the organization.

Antony[35] stressed the importance of the following guidelines when selecting any Six Sigma project: a linkage to a strategic business plan and organizational goals; a sense of urgency (how important the project is); the project scope (achievable within four to six months); the project objectives must be clear, succinct, specific, achievable, realistic and measurable; the project selection criteria must be established; the project must have the approval and support of senior management; there must be a focus on CTQ; and project selection should be based on realistic and good metrics (DPMO, yield, process capability, etc.). The aforementioned guidelines are also emphasized in the existing literature of Six Sigma[17,21,36–38]. Snee[21] has drawn attention to barriers in project success and concluded that a common theme of these barriers is that they are all management related. Table I focuses on barriers to the success of a Six Sigma project.

Critical success factors of Six Sigma

Critical success factors (CSFs) are those factors which are critical to the success of any organization. This means that, if the objectives associated with the factors are not achieved, the organization will fail—perhaps catastrophically so[39]. In the context of Six Sigma project implementation, CSFs represent the essential ingredients without which a project stands little chance of success.

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Table I. Barriers to the success of a Six Sigma project

Barriers to Six Sigma team success
Team not supported by management: • no champion and black belt assigned; • champion not meeting with black belt; • few or poor management reviews
Project scope too large: • attainable in the three to six month time frame; • an unrealistic scope (such as boiling the ocean) is probably the most commonly encountered cause of project failure
Project objectives not important to organization
Fuzzy objectives and poor process performance metrics
Team not trained or involved: • no involvement of functional groups, such as personnel from Finance, Information Technology, Human Resources, Engineering, Research and Development, etc. in the team; • many projects have failed because this support was lacking due to personnel shortages
Black belt and team not given time to work on project: • for black belts full-time is best, but they should be able to spend at least 80% of their time on a project; • green belts should be able to spend at least 20% of their time
Team too large: • team working with black belt should be not more than four to six members; • as the size of the team increases, it becomes difficult to find mutually agreeable meeting times and to reach consensus

Many authors have proposed CSFs of Six Sigma in a range of scenarios: manufacturing firms, service firms, software and the public sector, which need to be considered while implementing the program in their respective organizations[35,38,40–44]. A literature review in Six Sigma facilitated in identifying the CSF study carried out by academics and consultants, the details of which are presented in Table II. The table presents the research findings of authors with respect to key ingredients for the successful implementation of Six Sigma. The identification of such factors will encourage their consideration when companies are developing an appropriate implementation plan[2].

The findings of the leading academics and practitioners emphasizes the following factors which are imperative for the successful deployment of Six Sigma: management involvement and commitment; education and training; linking Six Sigma to customers; linking Six Sigma to business strategy; and project prioritization and tracking. It is worth noting that the aforementioned critical factors apply generally to the successful implementation of any major business initiatives, not just the Six Sigma program. The identification of success factors will encourage their consideration when companies are developing an appropriate implementation plan. If any of the CSFs are missing during the development and implementation stages of a Six Sigma program, it would then be the difference between a successful implementation and a waste of resources, effort, time and money[45].

This paper presents a case study performed in an automotive industry to eliminate the casting defects in an engine manufacturing process using the Six Sigma problem-solving methodology. The organization was encountering defects in the casting of one type of engine manufactured by the company. The application of a Six Sigma methodology (DMAIC) reduced the number of defects in the engine manufacturing process and thereby improved customer satisfaction and business profitability. The significance of the respective elements of the DMAIC problem-solving methodology is explained as follows.

- *Define*. The Define phase is concerned with the definition of project goals and boundaries, and the identification of issues that need to be addressed to achieve the higher (better) sigma level.
- *Measure*. The goal of the Measure phase of the Six Sigma strategy is to gather information about the current situation, to obtain baseline data on current process performance and to identify problem areas.

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Table II. CSFs of Six Sigma

CSFs	Manufacturing (Coronado and Antony[40])	Service (Antony[35])	Software (Antony and Fergusson[41])	Henderson and Evans[42]	Process Quality Associates[43]	Goldstein[38]	Public sector (Voehl[44])
Management involvement and commitment	✓	✓	✓	✓	✓	✓	✓
Understanding Six Sigma methodology	✓	✓	✓			✓	
Linking Six Sigma to business strategy	✓	✓	✓		✓	✓	✓
Linking Six Sigma to the customer	✓	✓	✓		✓	✓	✓
Project prioritization and selection	✓	✓	✓		✓	✓	
Organizational infrastructure	✓	✓	✓	✓		✓	✓
Cultural change	✓	✓	✓				
Project management skills	✓	✓	✓				✓
Linking Six Sigma to suppliers	✓				✓	✓	
Training	✓	✓	✓	✓	✓	✓	
Linking Six Sigma to employees	✓	✓				✓	✓
Integrating Six Sigma with financial accountability		✓	✓				✓
Project tracking and review		✓				✓	
Company-wide Commitment		✓		✓			✓
Full-time versus part-time resources						✓	
Information and analysis systems				✓	✓		
Use of quality tools				✓	✓		
Human resource management system				✓	✓		
Competitive benchmarking					✓		

- *Analyse.* The goal of the Analyse phase is to study the data using graphical/statistical analysis tools to identify and isolate the root cause(s) of quality problems.
- *Improve.* The goal of the Improve phase is to implement solutions that address the problems (root causes) identified during the previous (Analyse) phase.
- *Control.* The goal of the Control phase is to put in place ongoing measures to monitor both the process output and the factors that influence output variation, thus ensuring that results achieved in the previous phase are sustained.

CASE STUDY

This case study deals with the reduction of casting defects in an automotive engine. The problem was tackled using a Six Sigma DMAIC problem-solving methodology. The basic equation of Six Sigma, $Y = f(x)$, defines the relationship between a dependent variable 'Y' or the outcome of a process and a set of independent variables

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or possible causes which affect the outcome. In the present case study, 'Y' is the high customer dissatisfaction due to an unacceptable number of casting defects in the engine. A Six Sigma problem-solving methodology (DMAIC) is recommended when the cause of the problem is unclear[5]. This project was of the highest priority to senior managers within the company as it was known that an effective solution to this problem would have a significant impact on the bottom-line. Moreover, it was clear to the team members as well as to the project champion that the elimination of this problem would have a colossal impact on customer satisfaction.

Define phase

This phase of the DMAIC methodology is aimed at defining the scope and goals of the improvement project in terms of customer requirements and developing a process that delivers these requirements. The project team members include a champion, a black belt, the process owner, a green belt and two supervisory team members. In this phase, there were many questions asked by the team members during the project charting session, i.e. what is wrong in the production of casting? where is the problem? how big is the problem? what is the impact of the problem? The Six Sigma team ensured that the following points had been considered prior to embarking on the Measure phase.

The goal statement of the project defined by the team members was the reduction of casting defects from 0.194 DPU to 0.029 DPU that would result in an immense reduction in the cost of poor quality (COPQ). The team conducted destructive testing on the castings produced on different dates to identify the root causes of the casting defect. After performing a number of brainstorming exercises and using a multi-voting method, the team members arrived at the conclusion that the cause of defect was the porous core used for the casting process. The solution to this problem was unknown to the team. The impact of the problem was very severe as it was a main cause of casting defects, leading to a high number of warranty failures and high customer dissatisfaction.

The team focused on the following processes for enhancing customer satisfaction and reducing COPQ in the foundry:

- sand preparation;
- core making process;
- wash preparation and coating.

These processes were selected based on the sound engineering knowledge, the expertise of team members with the process and also taking into account the steps used in the manufacture of the core.

Measurement phase

This phase starts with a process mapping that provides a picture of the steps needed to create the output or process 'Y'. It is a pictorial representation of the process, which helps to identify all value and non-value added steps, key process inputs ('Xs') and outputs ('Ys'). Figure 1 shows the process mapping of a casting process for an engine with three core processes: sand preparation, core preparation and wash preparation, and coating.

Having mapped the process, the team proceeded to analyse the potential causes of the defects. Although this task is carried out in detail during the analysis phase of the Six Sigma methodology, the team had to consider how the 'Xs' are controlled in the given process. The cross-functional team brainstormed the reasons for the porous core causing casting defects in the engine manufacturing process. Figure 2 illustrates the cause and effect analysis for the porosity problem. The output of the cause and effect diagram depends to a large extent on the quality and creativity of the brainstorming session. In this case study, the effect is the porous core.

The cause and effect analysis showed that the process variables affecting the porous core were SL, BP, ANS, GCB, BD and VCR (the full names of these variables cannot be revealed here as the result of a confidentiality agreement between the authors and the company). Based on the brainstorming session conducted with the cross-functional team members and taking the experience of the engineers on the shop floor into account, it was inferred that the contribution of the porous core in causing casting defects was over 80%. Having constructed the cause and effect diagram, the team then created a cause and effect matrix. Table III shows the cause and effect matrix showing the customers' needs and the relative importance of the process characteristics which are critical to customers.

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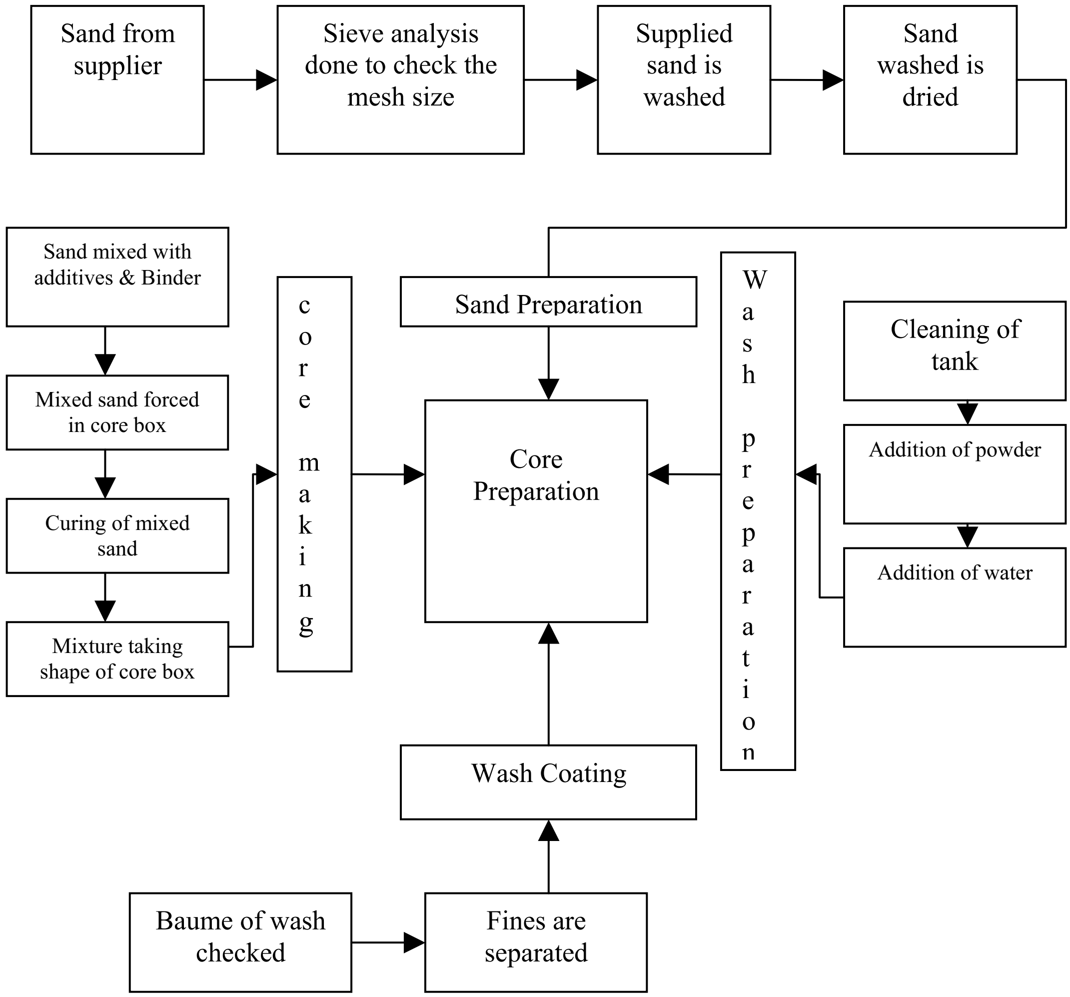

Figure 1. Process mapping for core preparation of casting

The next step was to define performance standards according to the customer requirements. The goals of the performance standards are to translate customer needs into measurable characteristics. Based on the specification limits, performance standards for each process parameter are established.

Having established the key process parameters and the CTQ (the depth of the porous core), it was essential to establish the accuracy of the measurement system and the quality of data. A data collection plan was established to focus on the project output and also to carry out the standard setting exercise. A Gage Repeatability and Reproducibility (R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether the measurement system is capable or not. The measurement system is considered acceptable when the measurement system variability is less than 10% of total process variability[46]. The Gage R&R study performed on the system identified a variation of 6.08%, which implies that the measurement system is acceptable. Table IV illustrates the results of the Gage R&R study carried out during the measurement phase of the project.

The baseline process capability (C_{pk}) was also established in this phase. The C_{pk} value based on the existing process conditions is estimated to be 0.49. This clearly indicates that process performance is poor and it clearly needs improvement.

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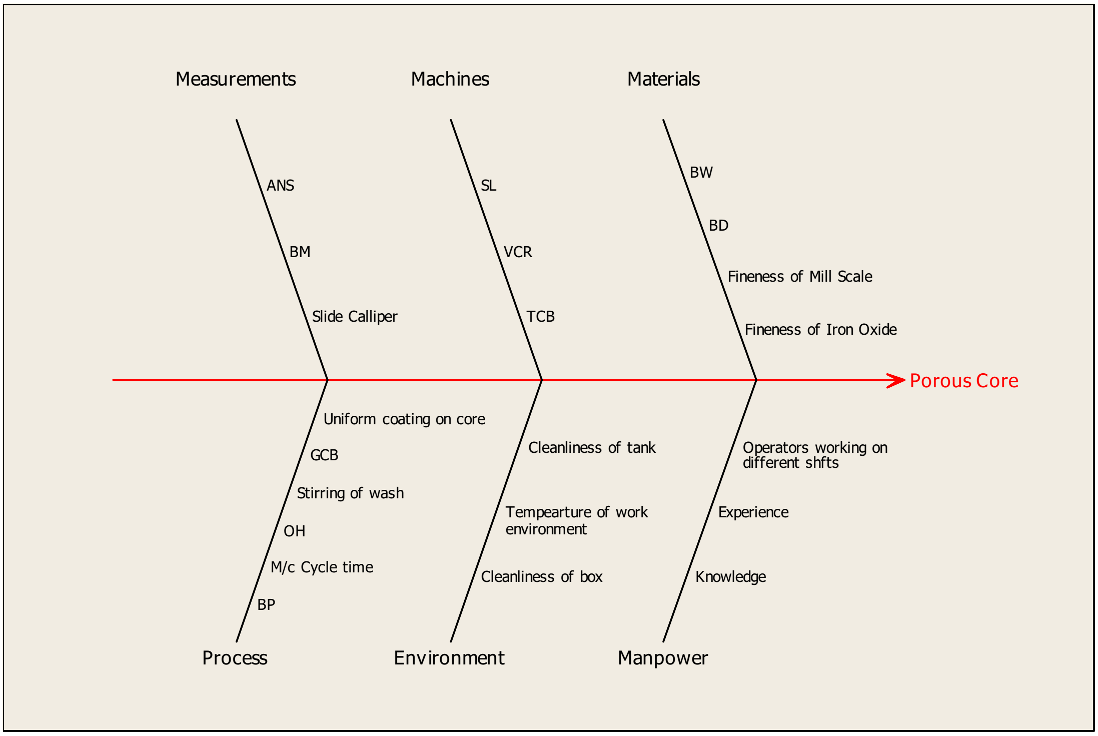

Figure 2. Cause and effect analysis of the porous core

Table III. Cause and effect matrix

	Process characteristics					
Customer needs	Depth of porous core	BW	PW	SW	SHW	Importance
Uniform coating	H	H	L	M	L	8
Proper thickness	H	H	L	L	M	9
Filling of porous core	H	M	L	L	L	9
Weighted requirements	130	112	26	42	44	

H, Strong Relationship = 5; M, Medium Relationship = 3; L, Weak Relationship = 1

Table IV. Results of Gage R&R study

	Variance	Percentage contribution of variance
Source		
Total Gage R&R	1.62×10^{-3}	6.08
	1.60×10^{-3}	6.02
Repeatability		
Reproducibility	1.67×10^{-5}	0.06
Part-to-part	2.50×10^{-2}	93.92
Total variation	2.67×10^{-2}	100.00

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Table V. Results of regression analysis for process parameters

Process parameters	P-value
SL	0.002*
ANS	0.414
BW	0.060
BP	0.155
BD	0.003*
FT	0.104
VCR	0.001*

* Indicates the significance of process parameters at the 5% significance level

Analysis phase

The first step in this phase is to gather data from the process in order to obtain a better picture of the depth of the porous core values under different process conditions. Data pertaining to factors affecting the response were collected over a period of 45 days from different shifts in the day. In routine foundry production, the casting is shipped to the customer if the mechanical test data satisfy the requirement of the standard and no defects occur in the casting.

Data related to factors affecting the response (the depth of the porous core) are analysed to determine not only the relationship between the process parameters and the response but also to determine the direction of process improvement. In the analysis phase, it was important to identify the possible sources of variation which lead to the casting problem. Moreover, it was also important to understand the causes for poor process capability. The aim of the project team is to enhance the process capability by reducing variation in the process. At this point, it is imperative to identify the parameters that are significant to the process so that they can be brought under statistical control. The improvement goal of the project is defined statistically through benchmarking with an automotive industry in the U.S.A.

A simple regression analysis is performed to determine the significance of the process parameters. It is concluded from the regression analysis that the variables having a 'P' value less than 0.05 are statistically significant for further study. Table V shows that SL, BD and VCR are the parameters that require further optimization and control. The optimization of these parameters will yield an optimum response (i.e. the depth of the porous core).

Improvement phase

In this phase, it was decided to perform a design experiment with the above three process parameters (SL, BD and VCR) identified from the analysis phase. DoE was conducted using the aforementioned process parameters identified from the previous phase. Each process parameter was studied at two levels in order to keep the size of the experiment at a minimum as well as to minimize time and cost constraints. A coded design matrix for the three significant variables (SL, BD and VCR) is depicted in Table VI. A 2^3 full factorial design was chosen so that both the main effects and the interaction effects among the parameters could be investigated. In order to have sufficient degrees of freedom for studying both the main effects and interaction effects, each trial condition was replicated twice[47]. Table VII illustrates the results of the experiment with the average depth of the porous core as the response of interest. The average depth of the porous core before the experiment was 1.25 mm.

As the objective of the experiment is to minimize the depth of the porous core, the first objective of the analysis was to determine the effect of process parameters and to understand the presence of any interactions, if present. Figures 3 and 4 illustrate the main effects plot and the interactions plot, respectively. In order to determine the statistical significance of both the main and interaction effects, it was decided to construct a normal probability plot of effects (see Figure 5). Figure 5 indicates that only the main effects are statistically significant at

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Table VI. Coded design matrix for the process variables to conduct DoE

SL	BD	VCR
1	1	1
1	2	1
1	1	2
1	2	2
2	1	1
2	2	1
2	1	2
2	2	2

Table VII. Results of the 2^3 full factorial experiment

			Depth of the porous core (mm)		Average depth of the porous core
SL	BD	VCR	Replication 1	Replication 2	
1	1	1	0.75	0.65	0.7
1	2	1	0.6	0.6	0.6
1	1	2	0.8	1.0	0.9
1	2	2	0.85	0.75	0.8
2	1	1	0.90	1.0	0.95
2	2	1	0.8	0.9	0.85
2	1	2	0.9	1.1	1.0
2	2	2	0.9	1.0	0.95

a 10% significance level. None of the interactions were statistically significant, although the interaction plot (Figure 4) suggests that there is a slight interaction between the VCR and SL. The main effects plot (refer to Figure 3) indicates that the optimum levels of process parameters for minimizing the depth of the porous core are BD—*high level*, VCR—*low level* and SL—*low level*.

Confirmation trials were carried out using the optimal settings and the average depth of the porous core was computed to be 0.80 mm. Moreover, the process variability was significantly reduced as well. The process capability (C_{pk}) has improved from 0.49 to 1.28. This clearly indicates a significant improvement to the process performance.

Control phase

The real challenge of Six Sigma methodology is not in making improvements to the process but in providing a sustained improvement to the optimization. This requires standardization and constant monitoring and control of the optimized process. An extensive training program for the personnel affected by the process changes was conducted within the company where the case study was performed. It is well known that real improvement will only come from the shop floor. Process sheets and control charts were made so that the operator can take preventive action before the critical process parameters and critical performance characteristics stray outside of the control limits. A complete database is prepared to maintain the improvement to the result. Proper monitoring of the process helped to detect and correct out-of-control signals before they resulted in customer dissatisfaction. Normal silica or chromite sand was mixed with shell sand with a recommended mesh number by the team to obtain a better result. Implementation of the aforementioned suggestions resulted in a further improvement of process capability and process yield.

Run charts for the depth of the porous core were constructed prior to and after improvements were made to the process, shown in Figures 6 and 7, respectively. The purpose of the run charts was to analyse variability

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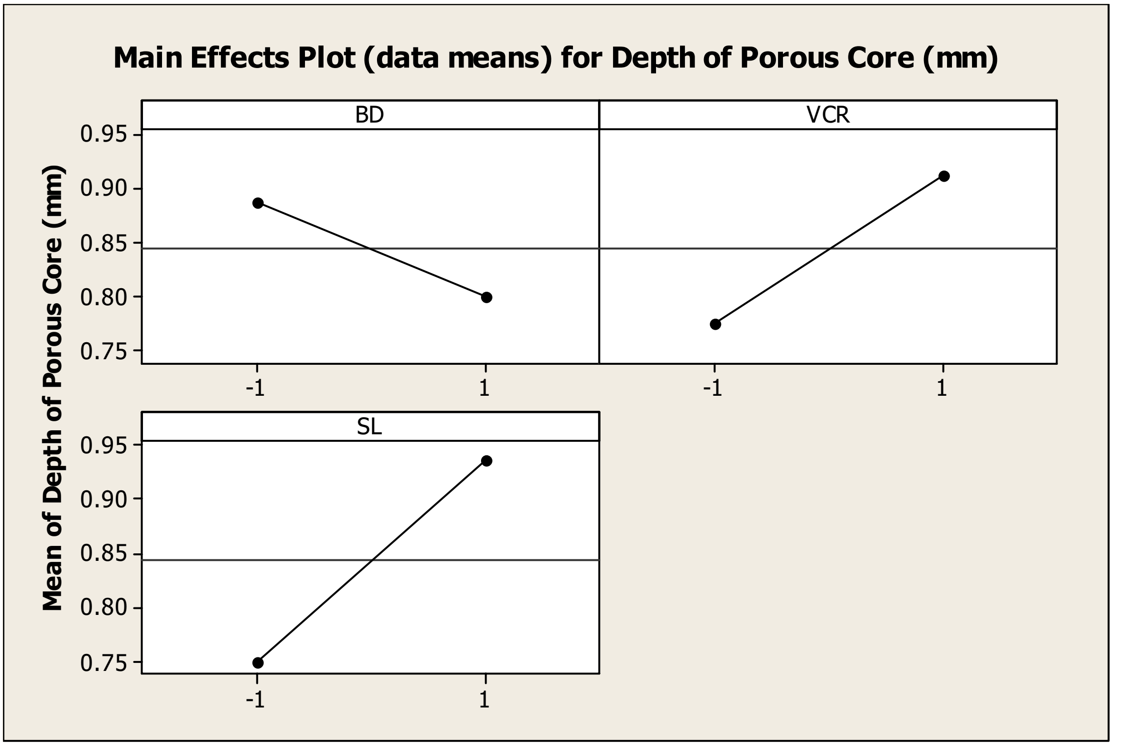

Figure 3. Main effects plot on the depth of the porous core

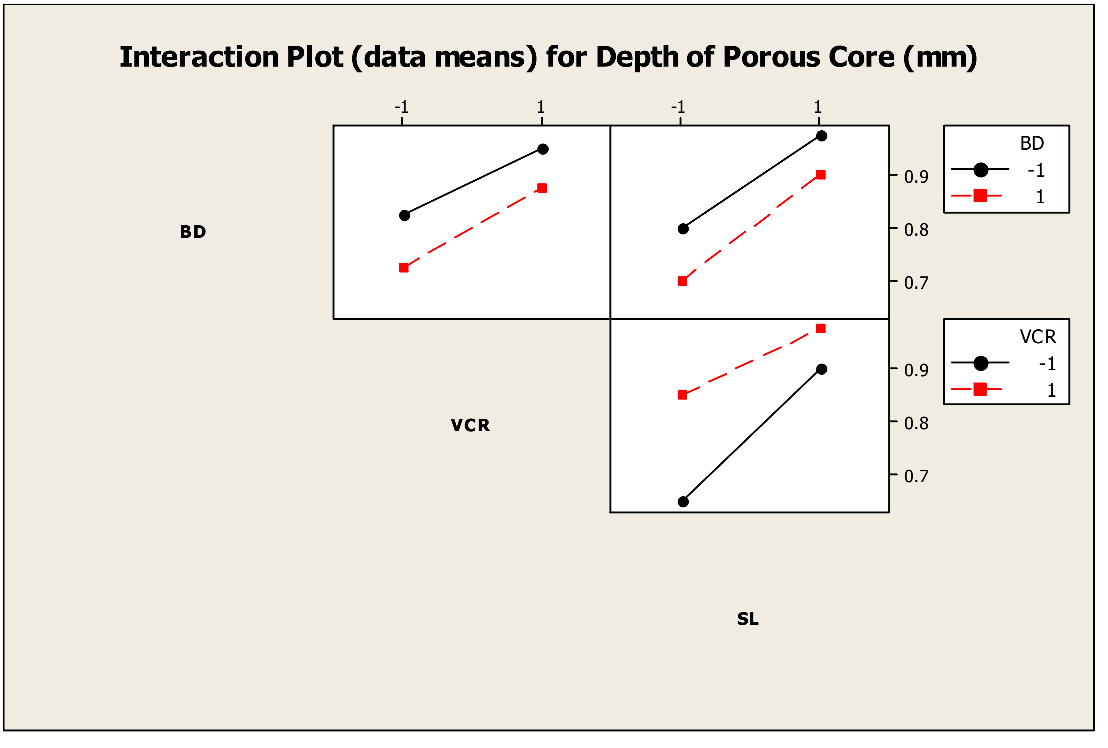

Figure 4. Interactions plot showing the interactions among the process parameters

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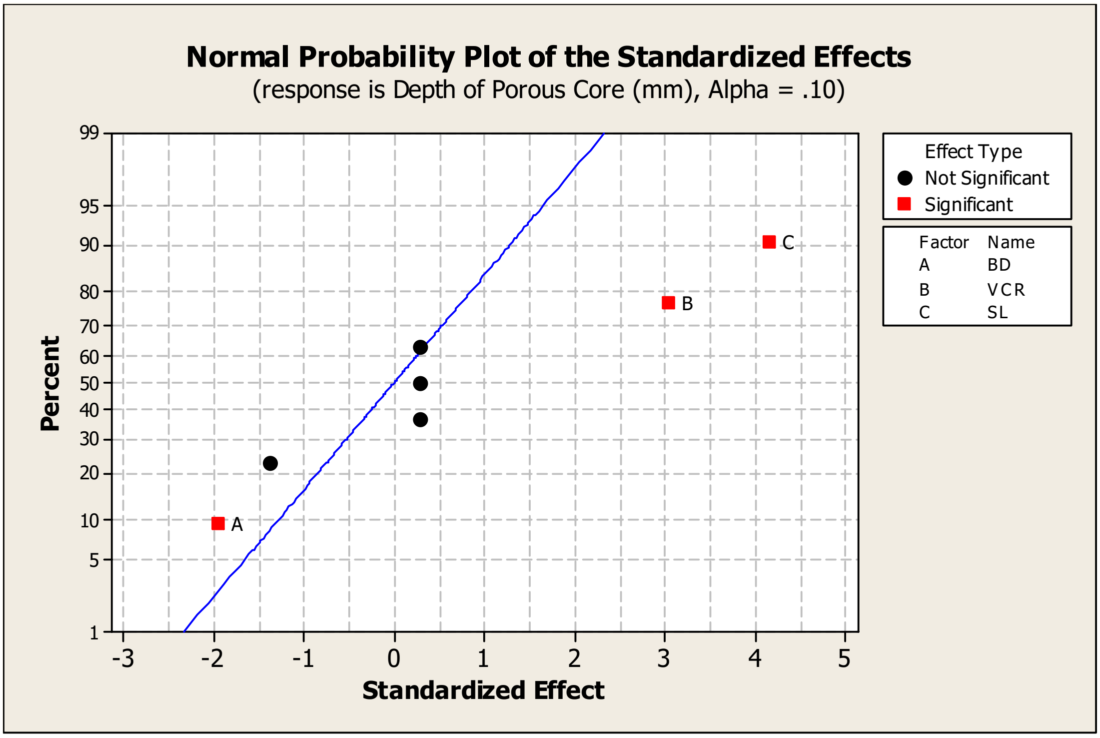

Figure 5. Normal probability of effects for the experiment

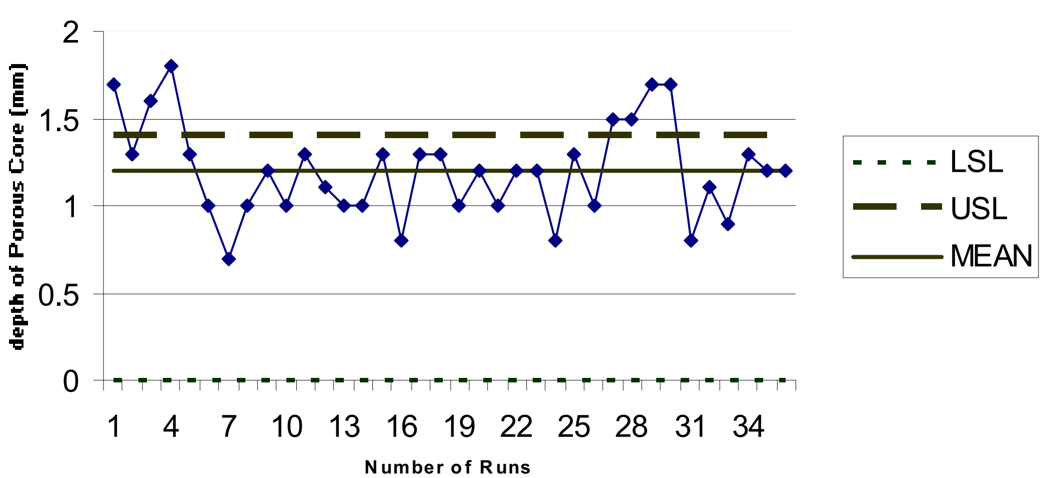

Figure 6. Run chart for depth of porous core before improvement

in the porous core around its mean value. Figure 7 (after the improvement phase) shows that all the points are within the specifications and the variability in the porous core has been reduced significantly.

The run chart shown in Figure 7 has only eight data points, as the authors' involvement in the project ended at this point. However, the company was contacted three months after project completion to check whether the company had experienced a sustained improvement. At that point in time there were more than 90 data points available to construct a new run chart and it was confirmed that the process was stable and within control.

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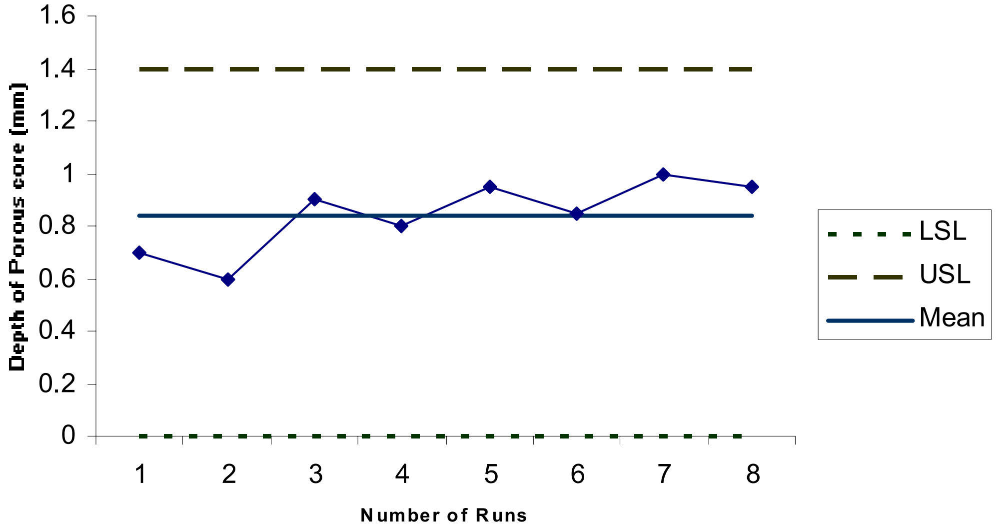

Figure 7. Run chart for depth of porous core after improvement

Improvement achieved from the Six Sigma project

After achieving the optimal condition and proving that a sustained improvement had been achieved, the team analysed the financial impact of the project. The cost incurred by the company in manufacturing the engine is divided into four categories: labour cost, raw material cost, operating expenses and other overheads. All these costs were incurred in manufacturing the product passing through various processing stages.

As the raw material is processed through various machines, some value is added at every stage of production. Therefore, a defect occurring at any stage of production is considered as a loss to the organization. However, the impact of defects on the organization increases the longer the defect goes undetected because at each stage some value is added to the product and each value adding activity has an associated cost. The impact of defects in the form of delay reschedule, rework, delivery delay and further inspection also increases the longer the defect goes undetected.

Savings generated from the Six Sigma project are divided into two parts: first, savings spawned from raw material and, second, savings from other sources that include labour cost, operating cost and other overheads. The bottom-line savings generated after Six Sigma implementation from this project was in excess of \$110 000, as acknowledged by the finance department of the organization. This would have also assisted the senior managers of the company in appreciating the efficacy of Six Sigma business strategy.

The following equations were used to calculate the DPU and the throughput yield:

$$\text{DPU} = \text{number of defects found/number of units processed} \tag{1}$$

$$\text{throughput yield} = e^{-\text{DPU}} \tag{2}$$

Table VIII presents the key results of the study showing the key metrics used in the study. These metrics clearly indicate the performance improvements achieved by the process after implementation of the Six Sigma methodology.

It was observed that the porosity in the core reduced drastically. The process capability of the system is increased from the previous value of 0.49 to 1.28, showing a tremendous improvement in the production system.

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

	Depth of the porous core	
Key metrics used	Before improvement	After improvement
Defect rate	0.194 DPU	0.029 DPU
Throughput yield	82%	97.14%
Capability indices	0.49	1.28
Process mean	1.202 mm	0.843 mm
Process standard deviation	0.277 mm	0.137

MANAGERIAL IMPLICATIONS

In this research work, the top-level management of the organization realized the importance of strategic initiatives needed for the successful deployment of Six Sigma. A brainstorming session was conducted to consider changes to the process, management practices and environment change required in securing an improved quality of work life and better business process, both of which are prerequisites for customer success and, ultimately, in achieving measurable and sustainable performance gains.

A successful introduction and implementation of Six Sigma requires the right mindset and attitude of people working within the organization. Management identified that the best way to tackle resistance to change is through increased and sustained communication, motivation and education. As worker motivation is very important in the successful implementation of Six Sigma, the management proposed methods of increasing employee motivation: incentive-based compensation, an employee ownership plan and the implementation of work-based teams. The reward may involve less renumerative awards and instead utilize highly visible awards such as plaques and coffee mugs.

The selection and prioritization of projects demonstrates that bottom-line impact is crucial for a Six Sigma program[2]. An unsuitable project selection leads to delayed results and also to a great deal of frustration. Following the work of Pande *et al.*[17], three generic categories of project selection criteria were considered by the management:

(1) business benefit criteria;
(2) feasibility criteria;
(3) organizational impact criteria.

Based on these three above categories, the next crucial step for management was the selection of the appropriate Six Sigma project so as to align the project with strategic goals of the business. The top management called a meeting of senior managers of different production units to discuss the customer complaints being sent to their respective units. The purpose of the meeting was to sort out the problems causing customer dissatisfaction. It was found that the majority of complaints coming from various parts of the country were related to casting defects in the engine manufacturing process, which was endangering customer loyalty towards the company. This problem was encountered by customers across the country.

In addition to top management, there was also a need to have an effective organizational infrastructure in place to support the Six Sigma introduction and development program within the organization. Thus, a cross-functional deployment team comprising people from middle-level management (executives from the Production Department, Quality Assurance Department, Sales and Marketing departments, etc.) and the workers involved on the shop floor were formed. As the organization's Six Sigma implementation was in its inception stage, experts were called in by the senior management, who included some of the authors of this paper. The Six Sigma initiative was led by the Divisional Manager of the Foundry shop, who is the project champion of this initiative. This was followed by formation of master black belt, black belts, green belts and other team members who represented different departments of the organization.

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After achieving the strategic goals and providing a sustained improvement for the organization, the management communicated the results and benefits generated to all its employees. Management felt that open communication and information sharing can promote a common culture and innovative behaviour in the organization. The importance of adequate and focused (e.g. role related) training for the successful implementation of Six Sigma cannot be overemphasized. The cost associated with training is viewed as an investment opportunity by the management. The organization followed a structured methodology for managing change. The management was committed to making Six Sigma a top priority within their business environment. The organization decided to provide coaching, counselling and training to the people involved in the project; giving rewards and sharing profits of the project with its employees to motivate them to bring about a cultural change within the organization; recognizing and reinforcing desired improvement alternatives and desired behaviours, which includes a periodic project review between management and the people responsible for improvement activities. Top executive leadership has established an expectation that all employees must be engaged in a successful Six Sigma project by the end of 2008.

CONCLUSION

Six Sigma is a disciplined, data-driven approach and methodology for eliminating defects in any process—from manufacture to transaction and from product to service. One of the primary themes of this modern management practice is to identify and prioritize high-impact projects and enable companies to establish goals that relate to bottom-line improvement, customer satisfaction and loyalty.

This paper presents a case study from a leading automotive company demonstrating how the effective introduction and implementation of a Six Sigma program in organizations can lead to a breakthrough in profitability, bringing with it a cultural change and gaining customer loyalty. The dramatic improvement achieved was the result of listening carefully to the VOC with the objective of evaluating and understanding their concerns. Creating and maintaining customer loyalty were the key challenges for the organization as the management was aware of the fact that it takes five to seven times as much time and money to replace a customer as to retain one.

Six Sigma is most effective when an organization already has a firm idea of what forms of products and services are in alignment with the organizations goals and customer expectations. It is suited to problems in which the output can be readily measured. This paper explored how the automotive industry can take steps to move towards the goal of achieving a Six Sigma quality level. The application of the DMAIC methodology has been extremely valuable in reducing casting defects. The defect rate per unit has been reduced from 0.194 DPU to 0.029 DPU. Moreover, the capability of the process has been significantly improved from 0.49 to 1.28. The estimated savings generated from this project were at least U.S. $110 000. The company was contacted one year after the project completion and it was reported that savings from this project have crossed over U.S. $250 000. The results of this project provided greater stimulus for the wider applications of Six Sigma methodology across the company in the future. The efficacy of DoE was realized by the management and the project team and this technique has become a part of their working culture. The company's management have been convinced of the benefits of adopting the Six Sigma problem-solving methodology and it has been linked directly to the strategic goals of the business.

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